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Automation and Robotics for Construction

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Mathematical modeling of microalgae-mineralization-human structure within the environment regeneration system for the biosphere compatible city

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Abstract

Modern fast growing megacities and urban agglomerations exert extremely high environmental load. One of the biggest problems of megalopolises is the human organic waste disposal. Under current technology, waste utilization requires enormous extent of sewer networks and large areas of treatment plants, which deform the natural landscapes and expensive to operate. Organization of local recycling of organic waste is crucially important at creation of new urban objects satisfying the principle of biosphere compatibility. In addition, it should be noted, that with the rising of building tallness in modern cities the use of centralized water systems leads to excessive overruns of electricity by pumping equipment, therefore the local effluent regeneration systems is the optimal solution for skyscrapers. Making a start from successful design experience of closed ecological life support systems, which were initially created for long-duration space flights, our research implements the idea to realize closed circle for flows of substances and energy for utilization of human waste and improving air quality within residential building. We focus on small volume treatment facilities designed for 20-30 people. The main difference of our system is the high degree of closure of flows. Thus, the hardest part it is to balance all technological processes. To solve this problem we suggest using rather complicated and accurate modelling founded on non-stationary partial differential equations describing the laws of matter conservation as a basis of an automatic control system. In this article, we present a mathematical model to simulate and control processes of transport phenomena in the system microalgae-mineralization-human. The model includes flow equations, the equations of reaction-advection-diffusion on a stratified set (linked 1D and 2D domains).

Keywords: Biosphere compatibility of cities; closed ecological life support systems; mathematical modelling; photobioreactor; treatment plants

1. Introduction

One of the biggest problems of megalopolises is the human organic waste disposal. According to the UN, the world volume of wastewater is about 1500 km³ per year, 80% of which either has insufficient treatment or is discharged without treatment at all. In addition to the environmental aspect, the problem has significant economic consequences, since the electricity expended for water treatment in developed countries is between 2 and 3% of the whole electricity that is produced.

Organization of human-waste treatment is one of the most important parts of the urban development projects. The current trend is to create treatment systems which are centralized as much as possible. Ideally, there should be no individual or small systems. It is believed that in this case the ecological situation can be fully controlled. However, such organization of process has side effects. Firstly, it is the possibility of occurrence of enormous environmental damage in case an incident at the central treatment plant. Secondly, the need for construction and maintenance of sewer lines of large length; some probability of defects of sewerage integrity and untreated sewage leakage. Thirdly, treatment facilities occupy large areas deforming the natural landscapes. Additionally, as mentioned, current treatment technologies are highly energy-intensive. Let us give some of the figures, which are typical for the average European city with population of about 500,000 people. Within the actual wastewater

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treatment technology, facilities for such a city are located on the square about 7 - 8 hectares, consume about 25 MW of electricity, and require maintaining 1,700 km of sewerage network.

We offer a new and daring concept of local treatment facilities (small objects with the ability to scale the volume that can be located in the immediate of buildings, and directly inside the building), the principle of which is based on a closed cycle biological transformation of matter. The main requirement such facilities meet is compliance with the principle of the biosphere-compatibility. The term Biosphere Compatible Economic Activity or Biosphere-Compatibility means an activity that uses technology based on the principles and laws of functioning of biological systems, principles of self-ecological communities, and closed circuit units of matter and energy.

We make a start from the experience of creation of the closed-loop biological life support systems (LSSs) that initially was being developed for long-term space flights. No other field of science has influenced imagination and vision more than the research and outcomes related to space exploration, either it is in terms of science fact, or science fiction. Analysis of the opportunities and prospects of using various space technologies for designing the systems on the Earth that may be described as being sustainable has been given by (Bock & Linner, 2010). In the 60s-80s of the last century, by a series of successful experiments with such kind of systems, the possibility to build an artificial closed ecosystem fully utilizing human waste was proved (Sychev, Levinskikh, & Shepelev, 2003), (Sychev, 2000). We develop the idea to apply this approach to the wastewater treatment systems for terrestrial conurbations.

2. The Project Concept

Obviously, the implementation of the idea of closed wastewater utilization systems similar to biological life support systems for space stations is associated with difficulties in terrestrial conditions. Firstly, traditionally, biological life-support systems are considered extremely energy-intensive. Secondly, balancing of the processes for small-volume facilities under conditions of randomly fluctuating wastewater volumes is a rather difficult task.

In the study to overcome these difficulties, we use the following key innovative approaches

- Implementation of closing system through oxidation processes, for example, combustion of residual biomass or using microbial fuel cells, what is possible to perform on Earth to create energy-efficient system;
- Balance control substances is performed by an automated control system, at the basis of which lies a direct mathematical modeling of biochemical processes in wastewater treatment plants, using the latest advances in the theory of constrained optimization in the form of partial differential equations.

During the 60s - 80s, at Institute of Biomedical Problems and Institute of Biophysics of Russian Academy of Sciences, there were several experiments with ecological LLSs based on the following links of the ecological chain: microalgae - mineralization - human and microalgae - mineralization - higher plants - human (Sychev, Levinskikh, & Shepelev, 2003), (Sychev, 2000). As the project being implemented currently, should be mentioned the MELiSSA -project (Micro-ecological life-support system) of the European Space Agency. In this project, scientists plan to include one more heterotrophic link – animals, namely fishes (Nelson, Pechurkin, Allen, Somova, & Gitelson, 2010).

In all types of closed ecological LLSs, algae is a basic element (link) of LLS, which allows regenerating the air, and water completely and provides (Sychev, Levinskikh, & Shepelev, 2003), (Sychev, 2000):

- Partial nitrogen cycle by way of the full use of human urine nitrogen by unicellular algae;
- Cleaning the atmosphere of a hermetic volume from various water-soluble gaseous contaminants through their full absorption and utilization in a photo-reactor by algae and attendant microorganisms (photo-reactor is an universal resettable hydro-biological filter);
- Optimization of air ion and aerosol composition of the atmosphere;
- Stabilizing of content of water-insoluble impurities (methane, carbon monoxide, etc.) by way their adsorption on the algae cell and microorganism surface and the subsequent removal of the grown biomass from the system;
- Ousting microflora, including pathogenic to humans, from micro biocenosis by a competitive relationship.

For our task, the structure Microalgae-Human-Mineralization option has been chosen as central and controllable core of system. In this case, it is possible to consider our treatment plant as a set of artificial aquatic ecosystems. Components of aquatic ecosystems is not different functionally from the components of terrestrial ecosystems. However there are some features. Organisms in the water biochemically are closely related to their environment and depend on the concentration of soluble substances. Due to the water density, which is the considerably greater than of air, many aquatic organisms are free-floating. The water consists of spatial-distributed suspended substances, microalgae, and microbes. The water also creates the possibility of biochemical links between communities of hydrobionts through the allocation of many organisms oxygen, carbon dioxide and various metabolic products into the water. These substances, toxic, or, on the contrary, stimulating other organisms, form the network by which organisms are connected implicitly, without direct contact. This feature of aquatic ecosystems allows describing their processes quite efficiently via the laws of matter conservation in the form of Reaction-Advection-Diffusion equations. As a result, we have an effective tool to create a reliable system for monitoring and control.

The functional diagram of the model Microalgae-Human-Mineralization is shown in Figure 1. The diagram has a simplified form but reflects the main streams of matter.

Stability and reliability of the structure Microalgae-Human-Mineralization is implemented by controlled flow circulating between a bioreactor-mineralizer and photoreactor cultivating algae. This combination of systems implement the natural self-purification processes, but which are intensified many times over. The structure can be integrated into a residential building in the form of the following combinations of elements presented in Figure 2.

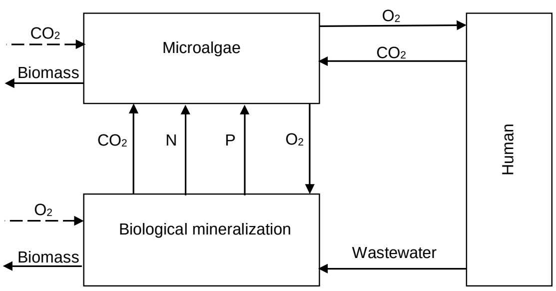


Figure 1. Functional diagram of the model Microalgae-Human-Mineralization

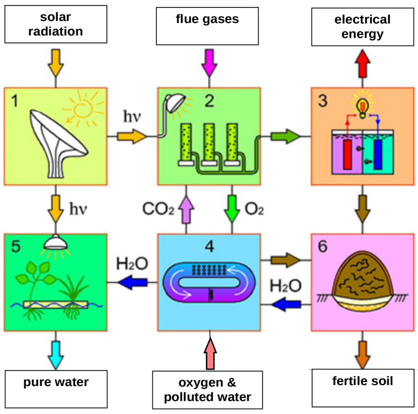


Figure 2. Schematic diagram of the photobiological treatment plant: 1 - lightguide, 2 - photo-reactor, 3 - microbial fuel cell, 4 - circulating oxidation channel (bioreactor - mineralizer), 5 - post-treatment hydroponic facilities, 6 - composter

Organic substances are oxidized in the mineralizer 3, mainly due to oxygen, which is formed in the photobioreactor. Thus, the key unit, the point of control of purification process' efficiency is the flow distribution system, which could regulate flow rate of oxygenated liquid returning into the system i.e. coming from the device 2, photoreactor cultivating algae, to the device 4, bioreactor-mineralizer.

There is also possibility of having two extra controls in a system. The first is blowing the additional airflow into the bioreactor-mineralizer in some dynamic regime. For example, it is necessary to supply oxygen to bacteria in the dark, when there is no enough oxygen produced by algae. The second is flue gases injecting into the photoreactor for supplementary bacteria nutrition. Injection of air and flue gases can be carried out through saturators, devices for dissolution. Separation of sludge biomass occurs in a desilter: one part goes back into the reactor, and the excess is removed from the system. Residual biomass can be used as raw materials for the production of electricity through some oxidation process to close system. There can be different approaches (methane-tanks, biodiesel, combustion, composting, microbial fuel cells). Everyone has its own pros and cons. The main thing that the oxidation generates energy and CO2, which are used into the system then again.

3. Simulation and Control of Microalgae-Mineralization-Human Structure

Dynamics of elementary volume biochemical reactor can be written in vector form using the laws of conservation of mass and momentum as an artificial ecosystem (Astrakhantsev, Rukhovets, & Menshutkin, 2003), (Astrakhantsev & Rukhovets, 1994), (Bulgakow, Buzalo, Zhmenya, & Zaharchenko, 2012), (Buzalo, Zhmenya, & Ermachenko, 2014)

$$\frac{\partial C}{\partial t} + U \cdot grad(\mathrm{C}) - div(D\ grad(\mathrm{C})) - W = 0\,; \tag{1}$$

$$W = N\mu\,; \tag{2}$$

$$\frac{\partial U}{\partial t} + U \cdot div(U) - div(\nu\ grad(U) + \frac{1}{\rho} grad(P) = G\,; \tag{3}$$

$$div(U) = 0\,; \tag{4}$$

where $C = (\mathrm{C}_1, \mathrm{C}_2, ..., C_{m+n}) = (S_1, S_2, ..., S_m, X_1, X_2, ..., X_n)$ is the vector of concentrations of substances which includes elements describing concentrations of biogens S_i (BOD, COD, ammonia nitrogen, nitrates, phosphates, oxygen, carbon dioxide, cell quotas) and concentrations of different kinds of microorganisms X_i (different kinds of microalgae); *N* is the matrix of stoichiometric coefficients, $[m+n \times l]$, where l is the number of processes leading to changing of concentration; μ is the vector of the rates of biochemical reactions; *W* is the reaction term; *D* is the vector of diffusion coefficients; *U* is the flow velocity vector; *P* is pressure; *G* is the vector field of mass forces; ν is viscosity, ρ is density.

Determining the reaction function has always been a complicated and debatable issue. There are several classical approaches to the description of the reaction member. Namely: Monod functions (Monod, 1949), which are suitable for chemostat-like systems where growth rate of microorganisms is limited by the substrate concentration; more complex functions taking into account the concentration of intracellular resources (Droop, 1974), (Jorgensen, 1976). Nowadays, for dynamic modeling of biological treatment facilities (mineralisers), different software is used (GPS-X, WEST, STOAT, etc.), which usually is built on standard models with activated sludge ASM (Active Sludge Model) (Henze, Harremoes, la Cour Jansen, & Arvin, 1995), (Henze, Gujer, Mino, & van Loosdrecht, 2000). However, it should be noted, that at the moment, there are no universal approaches and the methods described above can apply only to a certain, narrow class of problems. We believe that it is appropriate to use a linear combination of radial basis functions for reaction term setting. According to the principle of "limiting factors" (Liebig, 1840), and the law of "cumulative effects of factors" (Mitscherlich, 1909), (Mitscherlich, 1925). for every living organism, there is an environmental niche outside of which its inhibition or death occurs. In other words, the biocenosis state is determined by the sum of radial basis functions of wellbeing in the phase space of environmental factors

$$\mu_i = \sum_j \left[\mu_{ij}^{\max} \cdot X_j \cdot \prod_{S_k \in \Omega_{X_{ij}}} \exp\left(-\frac{\left(S_k \text{-} S_{i\,jk}^0\right)^2}{\sigma_{i\,jk}^2} \right) \right],\ i = 1, 2, ..., l\,; \tag{5}$$

where, within the i^{th} biochemical process, $\mu_{ij}^{\max}$ is the maximum growth rate of the microorganism X_j; $\Omega_{X_{ij}}$ is the set of substances affecting change in the concentration of microorganism X_j; $S_{i\,jk}^0$ is the optimum value of the concentration S_k which provides the maximum growth rate of the microorganism X_j; $\sigma_{i\,jk}$ is the radius of tolerance of X_j to S_k.

The form (5) has a fairly clear physical meaning and also it allows embedding a subprocess of data assimilation in the algorithm solving the problem (1 - 4) for correction of *W* by the use of radial basis neural networks. What is possible to do on a base of an additional software as well as with using a specialized hardware-chip. It is also important to note that the proposed mathematical model takes into account the inhibition of enzymatic processes, and therefore, is applicable for describing the trigger process (Ermachenko, 2012).

In the final version of the model, the flow equations in some elements of system can be reduced to Saint-Venant equations. The mathematical model is formulated as a boundary value problem defined on a stratified set containing 1D and 2D. The problem is supplemented by the initial, boundary and gluing conditions that we do not give because of their bulkiness. Since a technological solution for architecture of elements 2 and 4 depicted in Figure 2 has a variety of options the computational domain may take a different structure. One of the variants is shown in Figure 3. The Figure 4 shows some examples of calculations of velocity and substance concentrations in the reactor-mineralizer.

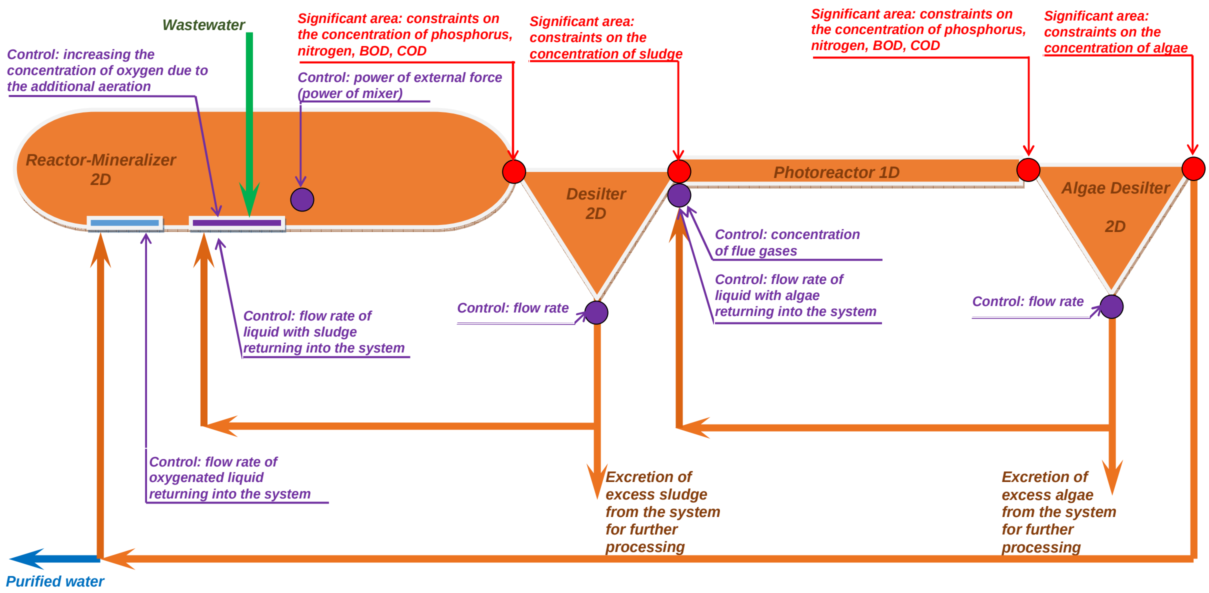
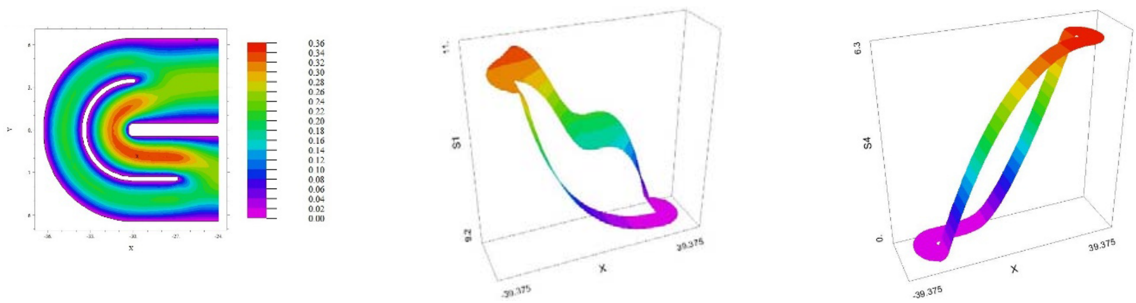


Figure 3. Computational domain



a) Velocity modulus on the rotary section b) BOD concentration c) The oxygen concentration

Figure 4. Calculations of velocity and substance concentrations in the reactor-mineralizer (circulating oxidation ditch)

The objective function for the control problem is minimizing of energy costs for air additional injected into the system through the saturator, and operation of the pumps and mixing devices. All of these control parameters are ‘source terms’, right-hand sides of either equations or boundary or gluing conditions. Denote their power as vector f. The time axis is divided into sections and controls are assumed as piecewise-constant. Then the optimization problem for each interval will have the following form

$$\min_{f \in F_{ab}} J = \langle P, f \rangle ; \tag{6}$$

where P is vector which components are corresponding of elements of vector f and equal to one in sources areas, and zero – otherwise; $\langle \ , \ \rangle$ is the scalar product of a selected function space; F_{ab} is the set of admissible controls. The constraints are, firstly, equations (1 - 4) with initial, boundary and gluing conditions, secondly, is constraints on water quality in significant areas (at the liquid's exit point from each of the devices). Thus state variable constraints are

$$\left\langle p_{k_i}, C_i \right\rangle \le \Theta_{k_i}, \; i = 1, 2, ..., m+n \; ; \quad (7)$$

where p_{k_i} are functions equal to one in k_i th significant area, and zero – otherwise; Θ_{k_i} are given values.

To solve control problem (1 - 7) we use method of adjoint equations with linearization of the initial problem. As a result, our problem is reduced to a series of linear programming problems, which allows us to significantly reduce the problem and perform almost real time control despite the complexity of underlying model. We have described some features of this method of adjoint equations [7, 8].

6. Conclusion

The paper develops the idea of closed biological wastewater utilization systems. This work represents, to the authors' best knowledge, the first application of theory of optimal control of mutter and momentum conservations laws formulated as partial differential equations to problem of regulation of work of closed-loop treatment facilities. Further, a controlled closed-loop purification systems can be integrated in a building through the self-sustaining, interchangeable and standardized platforms, so-called mainboard-inspired one, situated beneath a modular home and controlling all water installments and energy components needed for a household, that being developed by (Bock & Linner, 2010). In conclusion, as the future direction of development of these complex of technologies, we would like to note such methods providing a mathematical model by data as the use of microfluidic sensors for chemical analysis and genome sequencing technologies that are actively developed in recent times.

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Development of a BIM-based automated construction system

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Abstract

Automation technology has advanced in industry, such as aerospace, ship building, automobile, etc. However, automation technology in construction has grown slowly. This paper describes current additive manufacturing (AM) processes in construction. Base on the similar principle, the paper explores a new BIM-based automated construction system (BIMAC) including detail of execution setup, data issues and filling layer algorithm, and shows printed results, which are the highly customized building components. The further research about construction scale AM is presented. While still in its infancy, this research has the potential to improve the traditional construction methods, and solve problems like high accident, low quality, loss of skilled workers, and so on.

Keywords: Additive manufacturing, concrete printing, automated construction process, Building Information Modeling, filling layer algorithm.

1. Introduction

In recent years, advances in sensing technology, Numerical Control (NC) technology and the automatic driving system have led to improve the function and accuracy of automation system. Today, the automation systems have replaced humans in many complex, boring and dangerous industrial production activities. Industries, such as aerospace, ship building automobile, etc., has advanced Computer Aided Design (CAD) system modeling method and automatic assembly method (Buswell, Soar & Gibb, 2005). However, the construction automation development lags behind other industries for decades. According to reports, construction industry is facing some serious problems as follows (Warszawski & Navon, 1998): a) high accident rate at construction sites; b) Low quality of work; c) project management at construction sites is difficult; d) low labor efficiency; e) skilled workers have been lost.

Since the end of last century, in the United State and Japan, automation technology, in varying degrees, has been applied in the construction industry to solve problems such as productivity, quality, safety, high cost and the shortage of skilled labor (Stein, 1993; Everett & Saito, 1996). However, because the robot system cannot detect and solve problems independently in real-time operation, leading to single task robots are limited to a small construction area. In addition, most of the automation system requires many prefabricated parts, which means additional inventory, transportation and machinery cost. It will be expensive for using traditional automation technology to establish a fully mature automation system which can solve the problems of the construction industry (Hwang & Khoshnevis, 2004; Hwang & Khoshnevis, 2005). Slow development of automation technology in construction for the following reasons (Khoshnevis & Bekey, 2003; Khoshnevis, 2004) :a) automation technology is not suitable for large scale construction products; b) automation technology is not suitable for conventional design approach; c) compared with other industries, the amount of the final output is rather less and the types are quite fewer; d) the limitation on materials selection; e) Expensive automation equipment makes the automation technology unattractive; f) the introduction of automation technology make an impact to the traditional project management.

Construction industry should seek new automatic construction process to replace traditional manufacturing and assembly process, because the currently available automation technology and engineering technology may not be enough to overcome these obstacles effectively and economically (Hwang & Khoshnevis, 2005). Today, there is a kind of automatic process called as AM which has the potential of application in the production of large structures. This process adopts the method of the whole building collaborative molding instead of the traditional architectural forms of girder, slab and column. In recent years, AM has been applied in automobile design, aerospace and medical industries, etc. (Hwang & Khoshnevis, 2004). However, most existing AM processes are only suitable for small and medium scale manufacturing parts, because they are unable to delivery

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many kinds of building materials and their material deposition efficiency is very low(Khoshnevis, Kwon & Bukkapatnam, 2004).

2. Additive manufacturing in construction

Lim, Buswell introduced current construction scale AM processes capable of manufacturing large components in 2012 (Lim, Buswell & Le, 2012): In the 1990s, Pegna developed an AM process using cement based materials (Pegna, 1997). And the processes that are currently proposed and have already achieved the function of architecture printing, mainly include the Contour Crafting (CC) process form University of Southern California (Khoshnevis, 2000), D-shape process form the British Monolite company and Concrete Printing process from Loughborough University (Lim, Le & Webster, 2009).

Prof. Khoshnevis, B has led a team for long-term study of the CC process, and has suggest that it can be applied to the automatic construction of building works (Khoshnevis, 2000). The CC process is a kind of AM using a trowel to achieve a precise and smooth surface of the printed output. With the CC process, it is possible to automatically build large scale architecture components, even the whole building. (Hwang & Khoshnevis, 2004; Zhang & Khoshnevis, 2010; Khoshnevis, Carlson & Leach, 2012; Zhang & Khoshnevis, 2013).

Monolite Company successfully developed a large-size inorganic material printing process called "D-shape". This process adopts a deposition process of sand and powder, which is selectively hardened using a binder. Once a part is complete it is then dug out of the loose excess powder bed that should be removed away eventually to finish the printing work. This process has been used to create 1.6 m high architectural pieces called “Radiolaria” (Dini, 2014).

Prof. Lim, Buswell put forward another large-scale Concrete Printing process, further promoting the development of automatic construction of building works. Concrete Printing process is based on the extrusion of cement mortar and the solidification of materials themselves, and this process has been developed to retain 3-dimensional freedom and has a smaller resolution of deposition, it cloud printing size >1m dimension (Lim, Le & Webster, 2009; Lim, Buswell & Le, 2012).

The basic principle of those AM technologies (

Figure 1) is “layered manufacturing and overlay layer by layer”. AM decomposes a three-dimensional model into lamellar files of a certain thickness in a certain direction of the model (usually Z direction), then amends the lamellar files and generates NC programs, and finally imports the NC programs to the Computer Numerical Control (CNC) system so that the CNC system controls the material regularly and accurately, stacking up to achieve automatic construction.

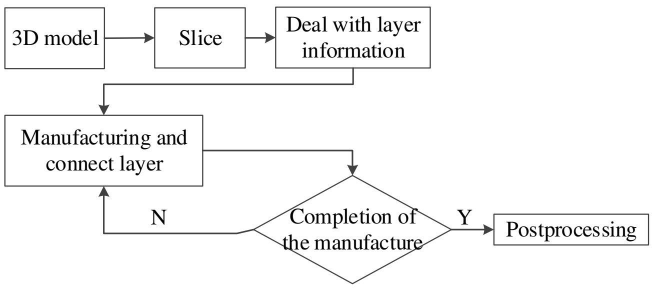


Figure 1. The basic principle of AM

3. Current state of BIMAC research

3.1. Composition of BIMAC

The BIMAC includes two core parts: NC program generating system and NC program execution setup. According to the filling layer algorithm, NC program generating system could converts the Building Information Modeling (BIM) model layer data sliced by manual operations to specific CNC codes. And those codes drive NC program execution setup to automate manufacture building components which are the same size as the BIM models (

Figure 2).

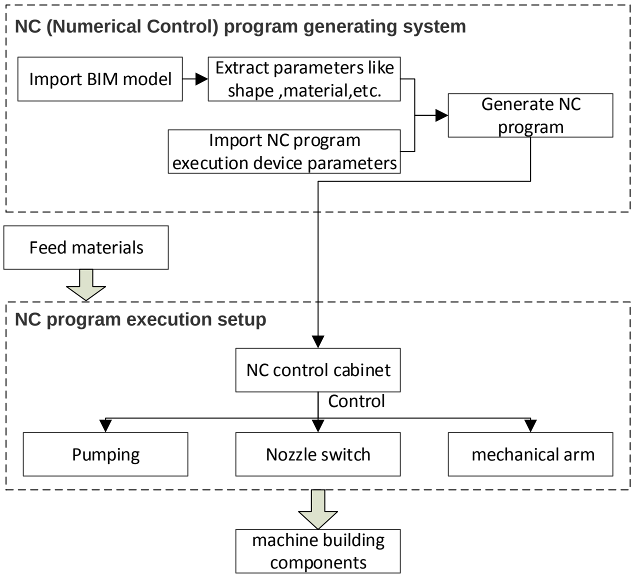


Figure 2. Composition diagram of BIMAC

3.2. Execution setup

The execution setup consists of a NC operation cabinet, a screw pump with a hopper, an electronic nozzle connected to the hopper by the hose and a mechanical arm of XYZ axes (Figure 3). The screw pump pumps up and conveys material (like cement mortar mixture) that has been modulated previously, and the vertical nozzle extrudes the cement mortar and deposits it on a flat worktable in controllable amounts. The nozzle on the mechanical arm is capable of linear motion along XYZ axes and curvilinear motion along XY axes. As the cement mortar exits the extrusion nozzle, the machine moves the nozzle assembly in XYZ axes at pre-specified speed, accumulating the cement mortar layer by layer and the switches of the screw pump and the nozzle, ultimately materialized a desired BIM building model. It could printing components which size <1.2m dimension.

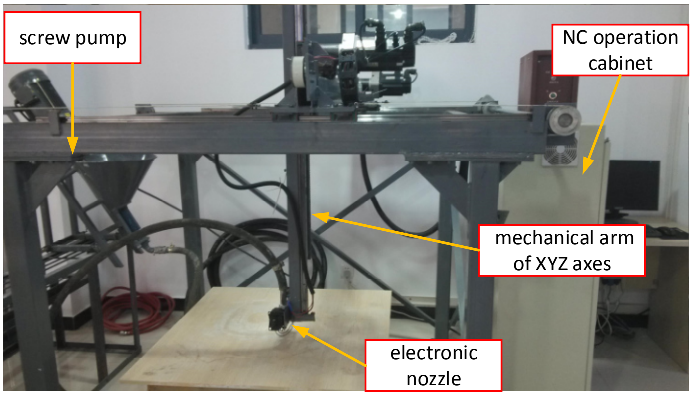


Figure 3. NC program execution setup of the BIMAC

The related parameters of some machines and devices of the NC execution system are listed as the following:

- The driving motor of machine tool is GSK 80SJT, 2.4Nm of torsion and 0.75kW of power. Movement of The machine arm is around 1m, ±0.2mm of absolute positioning accuracy, ±0.15mm of repeat positioning accuracy and 0.1mm/1m of parallelism and straightness, and 0~10m/min of moving velocity.
- The motor power of screw pump with speed control device of variable frequency is 1.5KW, and the flow of screw pump can be controlled within a range of 0.0~2.0L/min;
- The switch of the nozzle can be electrically controlled, and the diameter of the square or round shape nozzle is 9mm, 12mm and 15mm.

3.3. Data issues

To create an object, which is the same as the design model, need the specific machine operations derived by CNC code generated from design model. This process is described in the following steps (Buswell, Thorpe & Soar, 2008):

- Step1: The model data designed by CAD software is transformed into the STereo Lithography (STL) file, which is a list of the coordinates of a series of triangular facets whose edges all touch perfectly to form a representation of the surface of the model.
- Step2: To create the 2.5D layers from the 3D model. Each layer contain lists of lines or polylines.
- Step3: These layers with the machine specific parameters are then translated into the machine tool paths in CNC codes which are commonly called ‘G-codes’.
- Step4: The setup can be run on G-code to machine a building component.

The left picture in

Figure 4 depicts how the model information is processed to produce a physical object. The modeler must also be a manifold modeler (TC Chang, 2006), ensuring that the model can be unambiguously sliced Standard functions can be used to generate a STL file (Buswell, Thorpe & Soar, 2008).

However, the STL file can only describe the 3D geometry information of the object, and does not describe the information such as material, color, etc. It cannot support to machine a building component using different materials. So we change process like the right picture in

Figure 4. The 3D solid model in IFC format is designed by BIM software like Revit, and sliced by manual operations. The new process obtain each layer’s information of contour, material, color, and so on. In addition, the new process need control parameter data of the automatic construction mechanism, including layer thickness, Nozzle diameter, mechanical arm speed, and X Y Z coordinates of initial starting point.

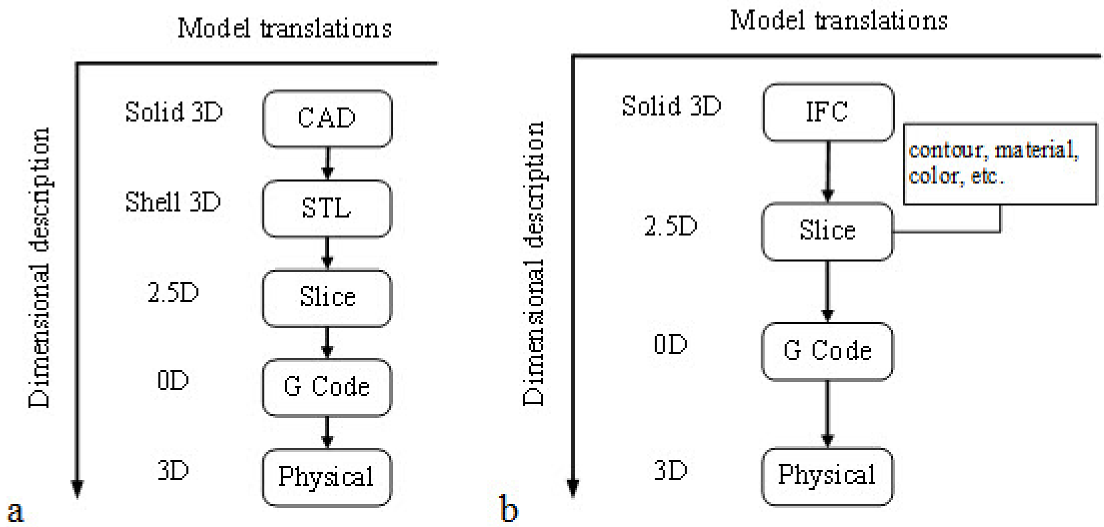


Figure 4. Steps in producing an artefact, (a) using traditional AM processes, (b) using a new AM process based on BIM

3.4. *Filling layer algorithm and result*

Focus on each layer sliced (Assuming layer thickness is H), this system alter scan-line algorithm to support the generation of CNC code which can control the move of mechanical arm, the switch of pump and nozzle. Rules for determining the scan-lines of two filling algorithms: In the odd layers, scan-lines are in parallel with the X axis; in the even layers, scan-lines are in parallel with the Y axis.

Filling layer algorithm A: It is mainly used for rectangle shapes: black lines are frame lines of shape, and red are scan-lines (Figure 5a).

- Rules 1: Print Layer N (N=1, 3, 5……). First, the nozzle should be moved to the starting point which is nearest to the origin of a coordinate axis on the scan-lines. Then the nozzle is opened and moved along the S-shaped scan-lines parallel to x-axis to the end point (X_{e1}, Y_{e1}, Z_{e1}). Lastly the nozzle should be closed.

- Rules 2: Print Layer N+1. After finishing Layer N, the nozzle is raised a certain height H, gets to the point (X_{e1}, Y_{e1}, Z_{e1}+h). Then the nozzle is opened and moved along the S-shaped scan-lines parallel to y-axis. Lastly the nozzle should be closed.
- Rules 3: According to the rules above, the nozzle prints every layers until the last layer is printed.

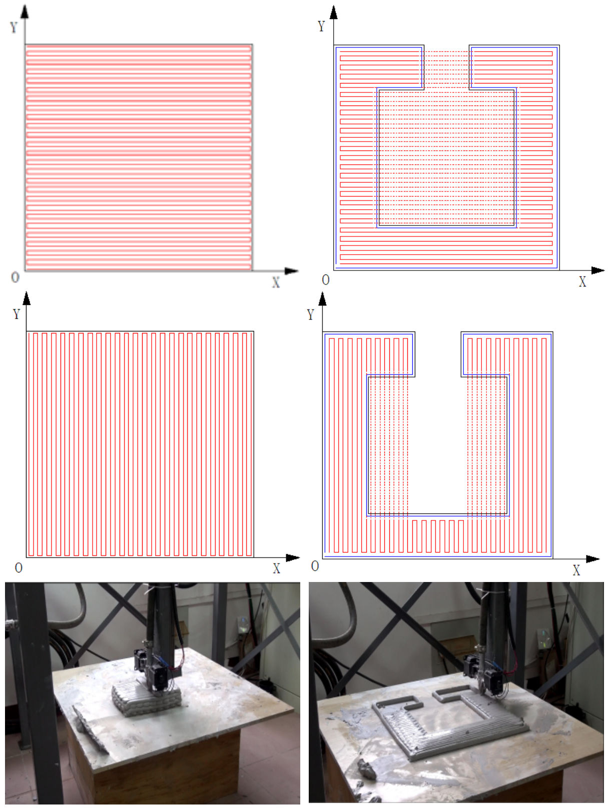
Filling algorithm B: It can be used for complex planar shapes: black lines are frame lines of shape; red are scan-lines, blue are contour lines, solid means the nozzle is opened, and dotted means the nozzle is closed (Figure 5b).

- Rules 1: Print Layer N (N=1, 3, 5……).

Contour printing: First, the nozzle should be moved to the starting point(X_{s2}， Y_{s2}， Z_{s2}) which is nearest to the origin of a coordinate axis on a set of contour lines. Then the nozzle is opened and moved along the set of contour line to the end point. And then the nozzle should be closed and moved to the nearest point of the un-printed set of contour lines, continue the steps above until all sets of contour lines is finished, then the nozzle is closed.

Internal filling: After finishing all the contour lines, the nozzle should be moved to the starting point which is nearest to the origin of a coordinate axis on the scan-lines. Then the nozzle should be opened and moved along the S-shaped scan-lines parallel to x-axis to the end point. Lastly the nozzle should be closed.

- Rules 2: Print Layer N+1. The starting point of contour printing is the point(X_{s2}， Y_{s2}， Z_{s2}+H), and scan-lines parallel to y-axis, other rules are the same as Rules 1.
- Rules 3: According to the rules above, the nozzle prints every layers until the last layer is printed.



a b

Figure 5. Printing path and result, (a) Filling layer algorithm A, (b) Filling layer algorithm B

4. Further research

4.1. New building materials or alternative materials

The biggest problem for automatic construction technology to face with is the material problem. To meet the requirements of automatic construction, new materials must have better rheology and can quickly condense in the air and also need to address the problem how to make perfect combination between the layers.

4.2. Accuracy issue

There are many factors affecting the accuracy of automatic construction, mainly including nozzle size, material shrinkage, hierarchical processing of model, location precision of 3D printers, etc. Wherein the size of the nozzle is one of the most important problems, or rather, the smaller the nozzle size, the higher the accuracy, yet the lower the construction speed at the same time. Therefore, it needs to take comprehensive consideration of the accuracy and speed of construction to set proper nozzle size. In addition, using trowels like the CC process to change the surface smoothness is also a good method to increasing construction speed (Hwang & Khoshnevis, 2004).

4.3. Algorithm development

Optimized filling layer algorithms are critical in that the time of machine running can significantly be reduced, and relate to the strength of the printed components. This paper provides some simple filling layer algorithms, which may cause time waste due to many invalid paths. So the optimization of the filling layer algorithms is very important. Furthermore, the development of hierarchical algorithm of BIM model is also important to reduce manual operations and improve the efficiency of auto-generate NC programs.

4.4. New giant 3D printer

It's rather obvious that if the active range of the printer nozzles is to be able to cover the entire width of the output size, the range is definitely larger circle. Thus, to achieve automatic construction of buildings, it is bound to create a giant 3D printer larger than printed buildings. Taking into account its practicability, it need to focus more on the developments of its light weight, high precision and removability as much as possible. The CC process made some good ideas that can guide the coming development (Khoshnevis, 2004).

4.5. Multi-nozzle and multi-material printing processes development

BIMAC provides a good foundation for multi-material collaborative printing and the next step is to design a 3D printer for different nozzles corresponding to different materials. For example, using cement materials for walls while using plastic materials for doors and windows frame, or when some nozzles print the upper components, other nozzles extrude supporting materials (such as sand) to support for the upper, and finally remove the support materials after finishing printing.

5. Conclusion

In the recent decade, automated construction processes capable of manufacturing large building components have been reported. Those processes, based on AM, integrate modern CAD/CAM technology, NC technology, precision servo drive technology and new material technology. This paper focus on a new automated construction system called BIMAC, which base on AM process introducing BIM technology. BIMAC described in this paper uses conventional construction materials such as cement and plaster, some printed results are shown, and some further research according to the limitations and problems are suggested. Preliminary results are promising and show that flexibility and potential of further development of BIMAC.

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Aerial laser inspection of buildings facades using quadrotor

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Abstract

Monitoring is the backbone of any project management task. In construction, where the service or product to be delivered is directly related to human beings, quality assurance reigns supreme in terms of priority and importance.
Construction project goes beyond handing over of the building. The upkeep of the building requires continuous monitoring to maintain the safety aspects as well as aesthetic elements of the building including facades and marble constructions. Laser scanning and photogrammetry can be used for inspection and detection of defects, which can be very valuable for preventive maintenance.
We offer to expand the role of the terrestrial laser scanning mechanism, to an aerial inspection and 3D building model generation using quadrotors based on simulations. This will automate the scanning process, increase range of the inspecting device and minimize the time of shifting and setting up the laser or the cameras, especially when operating in difficult site conditions, hence the aim of this paper.

Keywords: quadrotor; aerial building inspection, quality management.

1. Introduction

Three-dimensional technology has invaded the market of imaging. Nowadays, we count several applications where the three dimensional technology is utilized. For example, in medical field, endoscopic manufacturing companies has released a 3D exoscopes, that can give a 3D preview of an organ. In parallel, delayed 3D constructions are used in Cath-Labs and MRI technology. In the entertainment field, 3D films have taken the observer to a new experience that in reality tries to create new impressions, which sometimes transfer the observer from a passive state to an active state.

In light of the continuous success, pioneer companies are investing in integrating 3D technology to other fields. Nowadays, there are many internet service providers that are using the 3D technology to build map applications such as Google, Apple... These applications are accessible to 1.75 billion people, using smart phones. This software is also used for touristic purposes, identifying new places, hiking and most probably for military missions.

The success of these applications hugely depends on the quality of the images. We are dedicating this paper to improve the image quality by achieving better stability of the capturing device. The images taken from the aerial station to generate 3D model can be used to evaluate the condition of the building [14,15]. Facades and marble structures are often affected by climatic conditions. For instance, the aesthetic structures in a humid and hot region as in the Middle East, are more prone to be damaged than in France for example. This requires periodic monitoring of the building to diagnose possible damages. Mostly, laser scanning is used to detect cracks using terrestrial setup. This has limitations in scanning difficult angles, requires time to be transported and setup, in addition requires manpower to perform the tasks.

There are two main approaches used for structure scanning, the photogrammetry and the laser scanning. The first is the technology of obtaining information about the status of an object by analyzing captured images. Mostly, it is implemented in aerial scanning [12,13,15,16,17]. Its accuracy is questionable, however it is being optimized using new machine vision algorithms. Photogrammetry is not optimal for real time model generation as it lacks the digitization process.

In parallel, laser scanning is faster for real time process then the photogrammetry, but the risk of losing the data is high when the resolution is low. It is used for terrestrial scanning due to the altitude limitations. Recently, the terrestrial method is combined with the aerial photogrammetry to achieve better scanning and model generating results [12, 13, 17].

2. Building up case study – Aerial Inspection

Several technologies are used to perform building scanning with different advantages and disadvantages [16]. Optimally, scanning setup has to be portable, mobile, fast processing and cost effective. Table 1 provides a general overview on the techniques used to scan civil structures.

Method	Fieldwork	Processing	Manpower
Tachometry	Traversing – 1 day Tachometry – 2 days	Generating the topographic plan – 1 day	Ideally 4 persons
Manned aircraft	Traversing, pre-marking and flight planning – 96 hours	Image scanning and processing – up to 1 month	Ideally 2 pilots and 1 person on the ground
UAV	UAV setup– 20 min Flight – 30 min	Image processing until map production – 4 hours	Ideally 1 person-operator

Tachometry method requires more manpower. Level of automation of the scanning process is limited. A dedicated team has to be always on the ground. The mobility of the team is very crucial for the success of the mission. Climate and condition of the field have a direct impact on the required time for scanning and generation of 3D models.

Using manned aircraft improves the processing time. Although it can be successfully used for city scanning, it is impossible to detect defects or damages all around the building. In addition, the manned aircraft is not optimized to do periodic or repeated trips due to the fuel consumption and requires as much manpower as the tachometry method.

Unmanned aerial vehicle is the optimal solution [1,2,3,4,5,6]. Battery operated aircrafts such as quadrotors are small, cheap, maintenance friendly, can perform several flights in the same day with negligible cost and the most important that it has high maneuverability to reach difficult corners.

On the other hand, quadrotors are not stable and have limited flight range. The latter can be resolved by using backup batteries. Stability problem is the most critical part as it can also affect the quality of the captured videos/ images [11,14,16].

2.1. Quadrotor dynamics

The aim of this case study is to improve theoretically the stability of the quadrotor while mapping sites and inspecting structures. Recently many researches were carried out to improve the stability and control of unmanned aerial vehicles [8,9, 10,11]. In particular, the quadrotor, a miniature vertical take-off and landing rotorcraft has occupied the major share in these researches due to its low manufacturing cost. This has made its procurement accessible to many hobbyists and researchers. While taking-off and landing present the most critical phases of any flight, controlling other flight parameters such as stability and titling is also of great importance. The aim will be to get a zero value of Euler angles while hovering and changing position along roll and pitch axis.

Quadrotor dynamics are represented in the form of differential equations. These equations are already known and have been listed in many literatures [7,8,9,10]. Therefore we will skip the generation of equations and limit ourselves to listing them below. The dynamics of a quadrotor are illustrated in the six differential equations.

$$\ddot{x} = -\,c(\psi)\,s(\theta)\,c(\phi) + s(\psi)\,s(\phi)\,\frac{T}{m} \quad (1)$$

$$\ddot{y} = -\,s(\psi)\,s(\theta)\,c(\phi) - s(\phi)\,c(\psi)\,\frac{T}{m} \quad (2)$$

$$\ddot{z} = -\,c(\theta)\,c(\phi)\,\frac{T}{m} + g \quad (3)$$

$$\ddot{\phi} = \frac{T_\phi}{I_x} \quad (4)$$

$$\ddot{\theta} = \frac{T_\theta}{I_y} \quad (5)$$

$$\ddot{\psi} = \frac{T_\psi}{I_z} \quad (6)$$

Where, s is Sine function, c is Cosine function, $\ddot{x}$, $\ddot{y}$ and $\ddot{z}$ are the second derivative (acceleration) of the quadrotor position along earth axis OX, OY and OZ respectively and $\ddot{\phi}$, $\ddot{\theta}$ and $\ddot{\psi}$ are the second derivative of the roll, pitch and yaw angles, I_x, I_y and I_z are the terns of inertia of the quadrotor while performing a rotational movement, m is the mass of the quadrotor or term of inertia in linear movement and total torque generated per flight regime.

From these equations, we can organize the control system into 4 major loops interconnected:

- *OX* loop designated for the positioning along OX earth axis. It includes the roll angle loop
- *OY* loop for positioning along OY earth axis. It includes the pitch loop
- *OZ* loop for flight altitude
- *Ψ* loop for yaw

2.2. Quadrotor control – Optimized PID regulators

Optimal control is designed based on the task to be carried out. As far as this paper is concerned, it is important for us to have a stable hovering state and quick maneuvering. A comparative chart below shows the results obtained by different control algorithms.

Average control time and stability				
Algorithm	**Positioning loop**		**Euler angles loops**	
	Time [c]	**Overshoot [m]**	**Time [c]**	**Overshoot [m]**
Modular control	4	0.111	5.6	0.136
LQR	3.3	0.136	7	0.6
PID	8.3	0	2.2	0
Fuzzy Logic	8.3	0	7.6	0
Average	5.975	0.0061	5.6	0.184

The results were obtained based on the nonlinearity of the quadrotor. In depth review on comparative analysis between the different proposed control algorithms can be found in [7,8,10]. As a result [7], control scheme with PID regulators proved to be the fastest but with overshoot during the process time as shown in figure1. The control algorithms are simulated taking in consideration displacement of the center of gravity (CG) [18]. Due to the shifted CG, additional accelerations and velocities are sensed by the inertial sensors which have noticeable impact on real time flight.

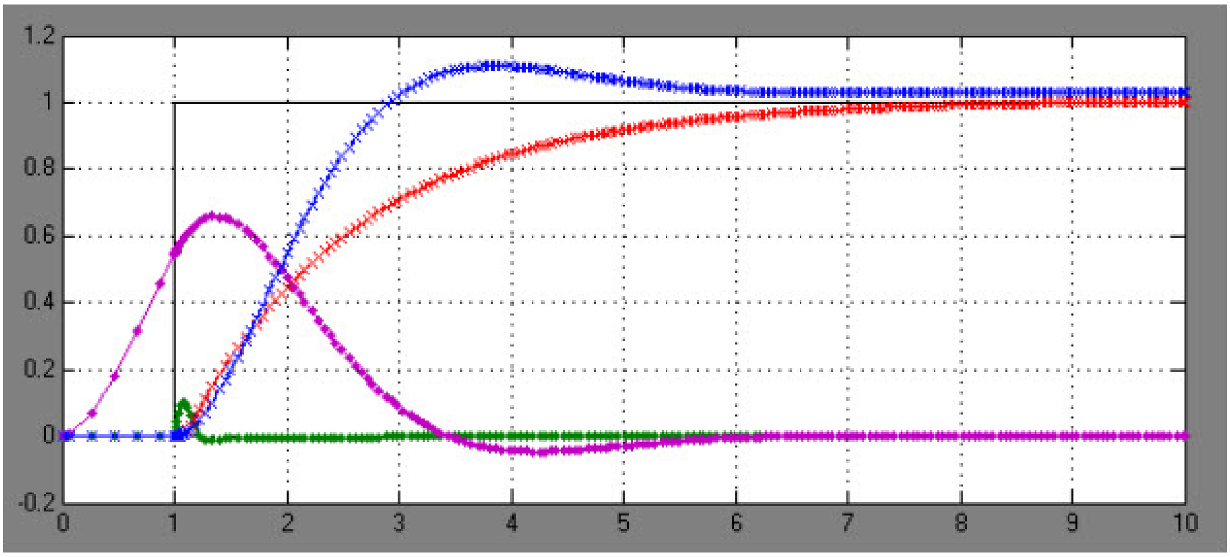

Figure 1. Positioning control using PID regulators

It is of great importance to have the smoothest positioning for better capturing quality. Hence, we decided to improve the PID controller using the particle swarm optimization PSO.

Since the overshoot is of concern, the optimization task can be described as follows

$$F_{\text{оп}}(t) = \int_{tmin}^{tmax} e.dt \qquad (7)$$

Where $F_{\text{ОП}}(t)$ is the cost function, e is the feedback error and t is time.

The PSO will tune the gains of the PID controller in such a way to minimize the feedback error within a limited time [$tmin$,$tmax$]. The optimization method is a Runge –Kutta solver of differential equation. In particular, it uses six functions to estimate and calculate the fourth and fifth tolerance order. The difference between these solutions is taken as an error. This error estimate is very convenient for adaptive algorithms, such as the use of fuzzy logic to control the process.

The optimization algorithm works as follows: each particle in the swarm has a position. PSO determines the next best position the particle should move to with reference to optimality criterion. The cycle continues until the particle reaches the most optimal position. Consequently, the system moves to the global best value updating the swarm positions to the target . Equation (8) serves as mathematical model for PSO

$$V_{\text{оп}}^{k+1} = wV_i^k + c_1(k+1)\left(pbest_i - S_i^k\right) + c_2(k+1)(gbest - S_i^k) \qquad (8)$$

Where, $V_{\text{ОП}}{}^{k+1}$ is the value of the modified velocity, w-weight function, $V_i{}^k$-current moving speed, c_1, c_2 are weights, $pbest_i$ is the personal best value for the particle, $S_i{}^k$ is the current position of the i-th particle and $gbest$ is the global best position or the target. Optimized results are shown in figure.2.

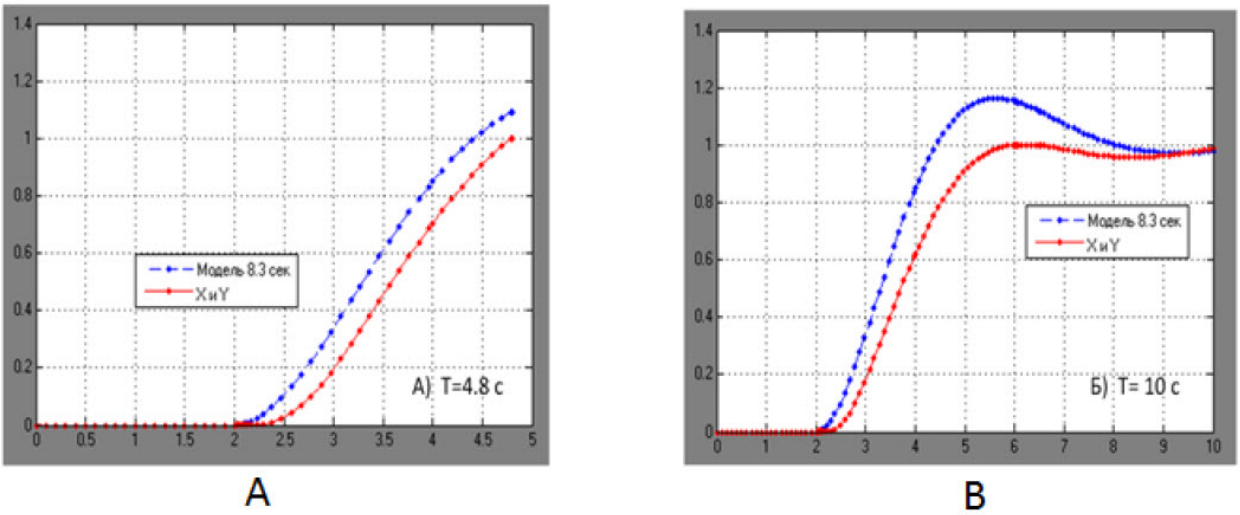

Figure 2. Optimization results for PID controller (A- Results at t= 4.8 s, B- Results at t=10 s.)

3. Simulation Results

The optimized PID controller pushed the quadrotor to new stability benchmark conserving its high maneuverability. The obtained algorithm will be implemented to scan the facades and roofs of structures. Civil buildings will be simulated using repeated sequence with different amplitudes. After each period of 5 seconds, the quadrotor has to meet the amplitude at a landmark point. This is supposed to be the optimal angle to capture the roof of the as well as the edges of the building. This will facilitate the creation of 3D model of the structure using triangulation method.

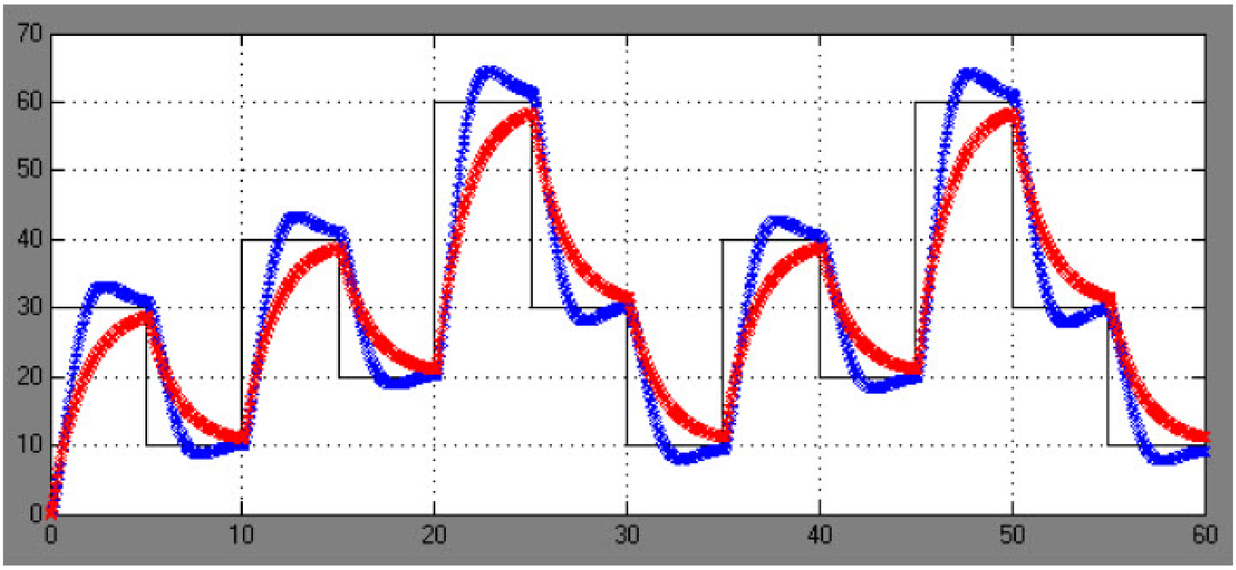

Figure 3. Building scanning using quadrotor

As shown in Figure 3. the optimized control algorithm (red curve) leads for better stability and enhance the capturing quality by meeting the amplitude after a period of 5 seconds. At the same time, flight range is also improved, as the battery is being used with efficiency.

4. Recommendations for real-time flight

Quadrotors can be operated manually, semi-autonomously or autonomously. A manual control allows the operator on the ground to take several captures repeatedly as per his convenience. This can be used to scan single or small group of structures. Semi-autonomous and autonomous flights are more mission oriented. Site mapping is based on

global path planning for outdoor scanning and local trajectory generation methods for indoor mapping. For scanning purposes, the operator has to upload waypoints coordinates to the autopilot before taking off using GPS. Autonomous flights can be achieved using visual odometry. This approach does not rely on GPS to generate the trajectory.

In real time flight, semi-autonomous approach is more adequate for scanning purposes. It still permits the interference of the operator but without changing the path of the mission. Commercial remotely controlled semi-autonomous quadrotors have a radius flight range arround 50 meters from the operating location because they are dependent on Wi-Fi bandwidth. This can be expanded using satellites to increase the range of cover.

Large sites can be divided into clusters and can be scanned simultaneously by several of quadrotors connected to a central hub, where laser scanning and photogrammetry data are collected and analyzed. The results are used to generate 3D models hence the images can be inspected for defects on site.

5. Conclusion

The obtained results have proven that the quadrotor was able to scan the structures based on desired trajectory and timeframe. The same algorithm can be used to control the quadrotor to scan the facades and different edges of the building, depending on the flight mission designated. While five buildings were scanned 2-dimensionally in 25 seconds, being 5 seconds for each building, the overall time necessary to capture three-dimensionally will take approximately 20 seconds for each building.

In a small town with a 1500 population, the average number of structures is equal to 300. Theoretically, to generate 3D model of the town using triangulation method will consume almost 2 hours, which is a very reasonable time. With an average of 6 hours scanning, the quadrotor can capture minute details, difficult to reach corners, landmarks and defects.

In light of the aforementioned analysis, we believe that the quadrotor can be of a great assistance in building inspection tasks.

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Creative Construction Conference 2014

A smartphone-based detection of fall portents for construction workers

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Abstract

The construction industry accounts for nearly half of all industrial-related fatalities in Taiwan. Identified as the leading cause of such fatalities for several decades, falls also contribute to almost half of work-related fatalities. Given the strenuous nature of employment, workers are prone to loss of awareness and balance, increasing safety risk and fall accidents. Previous literatures have indicated that loss of awareness may be the major cause of occupational injuries or fatalities, and identified the strong correlation between fall and loss of balance. Thus, real-time monitoring of the mental and balance conditions of workers may help identify fall portents and thus prevent falls from happening.

This paper describes a framework of developing a personal safety monitoring system based on a smartphone, which receives external-signals wirelessly from motion sensors and brain wave sensors attached to a vest and inside of a helmet, and transmit these signals to a monitoring server for further analysis. The paper also presents an experiment with preliminary findings of detecting fall portents using internal motion sensors of a smartphone. In the experiment, participants performed a tiling task under four physiological statuses on a scaffold. We identified the fall portents based on subjects' self-awareness and actually performing hazardous actions, and outsider observations from experiment administrators. An accelerometer-based threshold algorithm was tested and its performance was evaluated against the identified fall portents.

The result indicates that the work-related motions had limited impact on the detection algorithm. The accuracy under the sleepiness, fatigue, normal, and inebriation statuses were 92.3%, 90.4%, 77.3%, and 68.8%, respectively. With the algorithm exhibiting an overall accuracy of 86%, we conclude that using a smartphone to detect fall portents in a working scenario is feasible and worthwhile studying further.

Keywords: accelerometer; construction safety; fall portent detection; smartphone; threshold algorithm.

1. Introduction

Construction jobsites account for nearly half of all industrial-related fatalities in Taiwan. Fall accidents have been identified as the leading cause of such fatalities for several decades. According to statistics of the Council of Labor Affairs of Taiwan (CLA), approximately 50.55% (1,020 of 2,018) of construction work-related fatalities attributed to fall accidents from 2000 to 2012. Moreover, fall accidents contributed to approximately 67.07% (110 of 164) and 62.5% (90 of 144) fatalities in 2011 and 2012, respectively (CLA, 2014). This indicates the prevention of fall may be still insufficient or ineffective.

Fall accidents are common in the construction industries of many countries. The U.S. Bureau of Labor Statistics reported that 33.76% of fatalities (284 of 817) were related to falls in the U.S. construction industry (BLS, 2012). Falls also contributed to approximately 40% fatalities in the Japanese construction industry (Ohdo et al. 2011). Furthermore, falls represented the highest number of fatalities in the European and Korean construction industry, accounting for 52% and 30% of all work-related accidents (Carbonari et al. 2011; Min et al. 2011), respectively.

Given the heavy physical requirements and an irregular life style (e.g., alcohol abuse, night shift, and insufficient rest period), workers are prone to fatigue, drowsiness, and loss of balance, increasing safety risk and fall accidents. However, most studies focused on safety facilities and personal protective equipment inspection, which only mitigating the injury after a fall instead of preventing the fall itself from happening. Besides, other conventional measures such as safety training and education also have limitations because the characteristics of the industry (e.g., many subcontractors and high labor mobility).

According to the report of CLA, approximately 54% of all workers attributed loss of awareness as the major cause of occupational injuries or fatalities, while only 25% attributed it to equipment failure and the surrounding environment. The strong correlation between fall accidents and loss of balance has been also demonstrated.

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These evidences imply that real-time monitoring and analysis of the physiological status such as mental and balance condition of workers could help identify fall portents and thus prevent falls from happening.

Real-time physiological monitoring and analysis have been extensively studied and evaluated. EEG (electroencephalography) can represent mental condition including fatigue, drowsiness, attention, and alertness. Researchers have successfully applied EEG monitoring to detect driving fatigue for aircraft pilots and car drivers (Borghini et al. 2012). On the other hand, motion sensors such as accelerometers and gyroscope can represent the degree of body sway, and several researchers have used accelerometers with threshold algorithms to monitor daily activities and distinguish each type of motion, especially in fall detection for the elderly and patients (Bourke et al. 2010).

Nowadays a smartphone with built-in accelerometer and gyroscope has emerged as a popular, carry-on personal belonging. Several studies have begun to establish smartphone-based fall detection or activities recognition system (Abbate et al. 2012). Mellone et al. (2012) indicated that smartphone is capable of becoming a pervasive and low-cost tool for the quantitative analysis of balance and mobility. Dai et al. (2010) used a smartphone to detect fall, and the proposed system achieved strong detection performance and power efficiency. He et al. (2012) proposed a smartphone-based fall detection system that automatically sends a warning message including the time, GPS coordinate, and Google map of the location when a fall is detected. In addition, smartphone can also integrate external motion sensors and EEG sensors using Bluetooth or Wi-Fi, and transmit the data to a monitoring server (Wang et al. 2012). Stopczynski et al. (2013) developed a smartphone that displayed real-time images of brain activities. Szu et al. (2013) proposed a wireless, real-time, and smartphone-based EEG system for homecare applications.

Although several monitoring techniques have been proposed to improve safety or jobsite management using location-tracking (e.g., RFID and GPS) or pattern recognition technologies (e.g., PPE and worker inspection), they cannot determine whether a worker is losing awareness or balance. The inability to monitor the physiological status of workers makes the jobsite safety management difficult, and workers working under inappropriate or even dangerous physiological condition without the supervisor knowing it. As aforementioned, the loss of awareness and balance can be appropriate signs for fall portents, and some researchers have successfully detected the mental status of drivers and the fall for the elderly and patients. Such result provides valuable information on developing real-time personal safety monitoring system in a more complex environment such as in the construction industry, which features a large number of interacting workers working simultaneously over a wide area with continuous movement and a constantly changing environment. This paper presents a framework of developing a personal safety monitoring system based on a smartphone, and shows the initial result of our on-going research with the preliminary findings of an experiment designed to evaluate the accuracy of detecting fall portents using internal motion sensors of a smartphone.

2. Smartphone-based detection system

2.1. Conceptual model and use scenario

This study attempts to develop a real-time personal safety monitoring system consisted of an EEG helmet, motion sensing vest, and smartphone, that can predict falls by identifying the fall portents of a construction worker who is wearing it and notify the worker and supervisor if necessary to prevent falls. As depicted in Fig. 1, a construction worker is normally required to wear safety gear, including a helmet, vest, and belt. A variety of sensors, such as EEG sensors, accelerometers, gyroscopes, or smartphone, can be hooked up to this gear. These sensors can detect the physiological condition of the worker and send signals to the smartphone for primary analysis. The smartphone will transmit the signals to administration center for further analysis. When the system detects a fall portent, it should warn the worker with a series of sound and vibration, and notify the supervisor with text message.

The administration center on a jobsite monitors all workers wearing such safety gear and performs personal and group trend analyses, as different workers may require different warning thresholds depending on the level of falling risk to which they are exposed. Statistical data can be represented in several ways using different sensors as a spectrum to show the worker's physiological or fall-prone trends. Based on this information, the supervisor may adjust the work schedule or tasks assigned to fall-prone workers. It should be noted that the dynamic nature of working condition (e.g., changeable workplaces and high-motion activities) of construction workers is significantly different from the use scenario of the drivers, elderly, and patients. The dynamic condition produces noises and makes the fall portent detection challenging.

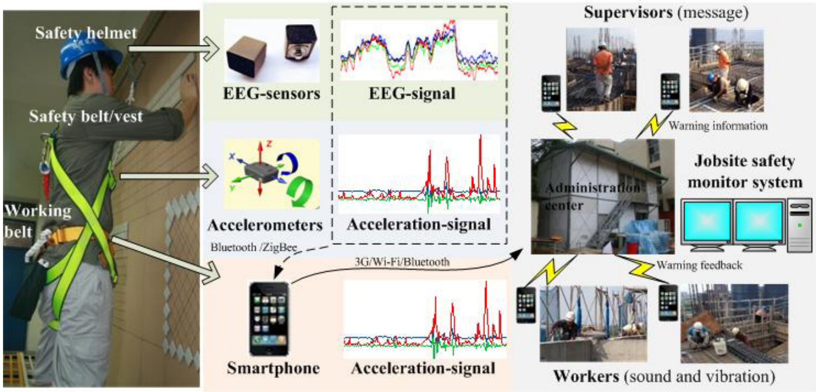

Figure 1. Use scenario

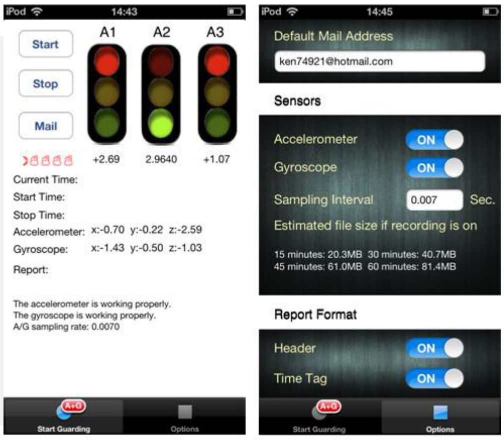

Fig. 3-1 Fig. 3-2

Figure 3. App interface

2.2. Prototype implementation with a smartphone

We developed an application, which runs on Apple's iOS 6, can record the data of a built-in accelerometer and gyroscope, perform a real-time analysis using threshold algorithms, and transmit the original data to the server for further analysis. In the prototype implementation, we used a smartphone (e.g., iPhone 4/iPod) attached to the subject's waist to detect the fall portents. The smartphone consisted of an accelerometer (i.e., LIS302DL), gyroscope (i.e., L3G4200D), processor, wireless receiver, and alarm (with both sound and vibrating abilities).

Threshold algorithms received considerable attention in the field of fall detection and daily activity monitoring due to its simplicity and minimum computing power requirements. Furthermore, the algorithm can accurately represent the degree of sway and is thus suitable for detecting motion. The target detection is determined based on whether the value of the formula composed of sensor data (e.g., accelerometers and gyroscopes) exceeds the threshold. The weight of each data and threshold may be different for different target use scenarios. We adopted several threshold algorithms, including accelerometer-based, gyroscope-based, and hybrid-based ones. For brevity, this paper presents only the best performer in our experiment, which is the accelerometer-based threshold algorithm originally proposed by Karantonis et al. (2006), as shown in Eq. 1.

$$SVM_a(signal\ magnitude\ vector) = \sqrt{|A_X|^2 + |A_Y|^2 + |A_Z|^2}, \qquad (1)$$

where A_X, A_Y, and A_Z are the acceleration in the x-, y-, and z-axes, respectively.

The application consisted of recording, calculating, warning, and transmitting modules. The system architecture is shown in Fig. 2. The recording module acquires raw data from the built-in accelerometer and gyroscope, and then stores such data in the text format in the smartphone. The calculating module applies threshold algorithms such as accelerometer-based, gyroscope-based, and hybrid-based ones. Besides, the user can adjust the weight of each axis of the motion data depending on the characteristics of the target-motion (e.g., sudden sway or loss of balance).

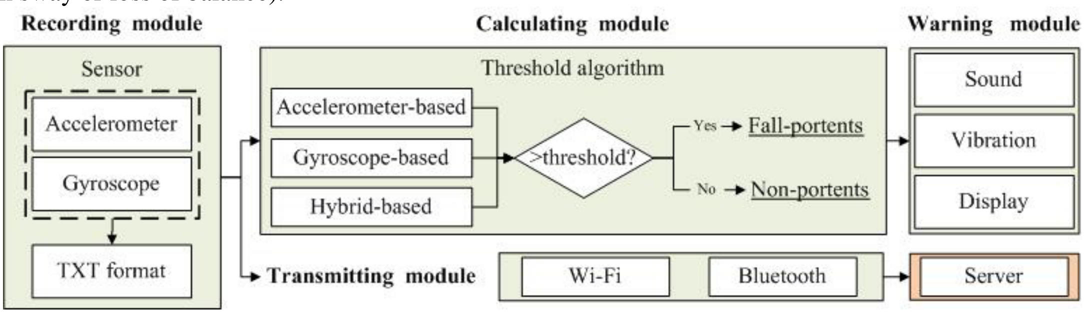

Figure 2. Phone-based system architecture

The warning module is activated when the SVM_a value exceeds the corresponding threshold. Furthermore, the user can adjust the threshold depending on the type of job to control the alarm sensitivity. It should be noted that adjusting threshold results in a trade-off between accuracy and false-detection rate. The result of the experiment described in the next section assumes the threshold with the best accuracy in our experiment. Transmitting module sends the stored data to a monitoring server via Wi-Fi or Bluetooth for further advanced analysis that involves multiple workers.

Figure 3 shows the interface of the App, including "Start Guarding" and "Options" pages. In the "Start Guarding" pages (Fig. 3-1), data recording can be activated or terminated by clicking the "Start" and "Stop" buttons. The traffic lights icons dynamically show the real-time calculation result of three different algorithms depending on how much percentage of the threshold the SVM_a value exceeds. When the SVM_a exceeds the fall-prone threshold, the light is on red and sends out a sound warning with vibration. When the SVM_a exceeds 80% of the threshold without exceeding the threshold, the light is on yellow without warning. Otherwise, the light remains green. Note that, although the yellow signals do not send out any personal warning, their occurrences are monitor in the server and an appropriate warning can be sent to the supervisor if the frequency exceeds a certain threshold.

In addition, the page also shows the recording status as well as the setting information. The user can adjust the setting in the "Options" pages (Fig. 3-2). For instance, changing e-mail address, which the data would be sent to, activating both accelerometer and gyroscope, adjusting sampling rate (i.e., 0.007 second approximately equals 1000/7=140Hz). The user can determine if the header and time tag should be attached to each sampling data in the exported file.

3. System evaluation

We designed an experiment to evaluate the effectiveness of the smartphone-based detection system. The experiment simulated a construction working environment where a subject can perform a designated tiling task on a scaffold. To facilitate the experiment, we prepared a flannelette-covered wall and tiles that were glued with Velcro on the back. The experiment process was recorded by surveillance cameras.

The experiment defined an occurrence of fall portent if any of the following three scenarios occur. First, a subject felt loss of awareness or balance, and self-reported by raising a hand. Second, a subject produced an obvious sway that was identified by the experiment facilitator. Third, a subject crossed over the watch zone on the scaffold board that was painted with a highlighted color. Since we expected few portents could be produced in a normal status, subjects were required to participate in the experiment in different statuses including normal, and other abnormal statuses such as fatigue, sleepiness, and inebriation, The identified portents were assumed to be the detection targets and used to be compared with the detection result of the tested algorithm to determine its accuracy.

Four graduate students from the construction management program of National Chiao-Tung University volunteered to participate in the experiments. Each participant was required to perform the tiling task under four different statuses (i.e., normal, fatigue, sleepiness, and inebriation). To achieve these statuses, the participants were requested to perform the tiling task twice to induce fatigue, stay up all night before the experiment to induce sleepiness, and consume alcohol beverage (350ml with 5% alcohol content) to induce inebriation.

Table 1 shows the experiment results. The number of actual portents identified is 111 (Column a). The number of warning activated based on the SVM_a algorithm is 129 (Column b). Column e shows the accuracy rate, which is the number of correct detections (Column c) over the number of activated warnings (Column b). The false-detection rate is the number of incorrect detections (Column d) over the number of warnings. Based on the accuracy rate under each status, the algorithm performed satisfactory accuracy under the sleepiness (92.3%) and fatigue (90.4%) statuses, a mediocre accuracy under the normal status (77.3%), and the worst accuracy under inebriation status (68.8%). The algorithm performed an overall accuracy rate of 86% with a false-detection rate of 14%. The result indicates that the tiling work-related motions had limited impact on the detection algorithm. The result also indicates that all portents can be detected by the SVM_a algorithm, and detecting the target is much easier than avoiding false detection. Thus, choosing an appropriate threshold value is important to reduce the false-detection rate while maintaining a high detection rate.

The algorithm had a lower accuracy rate under the normal and inebriation statuses (77.3% and 68.8%) compared to the fatigue and sleepiness statuses (90.4% and 92.3%). One possible explanation is that, among the three proposed identification methods of fall portents, most portents were identified by experiment facilitator based on the obvious sways. The regular motions of participants became smaller under the sleepiness and fatigue statuses, and enlarge the difference between the work-related sways and fall-portent sways. Consequently, it was easier for the facilitator to identify the fall portents and define them as the targets. In the normal and inebriation statues, the difference between the work-related sways and fall-portent sways was not so obvious for the facilitator to identify. As a result, some fall portents might not have been identified as the targets. If these fall portents were included as the targets, the false-detection rates would be decreased, and the accuracy rates would be increased. We also noticed that the portents related to loss of awareness without any sudden sway, or the motions without abrupt changes were difficult to be detected using a motion sensor. Adjusting the threshold value to accommodate for this type of targets will result in large amount of false detections. Figure 4 depicts an oscillation example of SVM_a for sleepiness status, marked with the threshold of 1.3 in a red horizontal line and four identified portents marked with red diamonds. Obviously, the algorithm can detect all fall portents. However, the algorithm also generates three false alarms.

Table 1. Results of experiment

Status	(a) Fall portents	(b) # of warning	(c) # of accurate detection	(d) *F* # of false detection	(e) Accuracy rate (c/b)	(f) False-detection rate (d/b)
Normal	17	22	17	5	77.3%	22.7%
Sleepiness	36	39	36	3	92.3%	7.7%
Fatigue	47	52	47	5	90.4%	9.6%
Inebriation	11	16	11	5	68.8%	31.3%
Overall	111	129	111	18	86%	14%

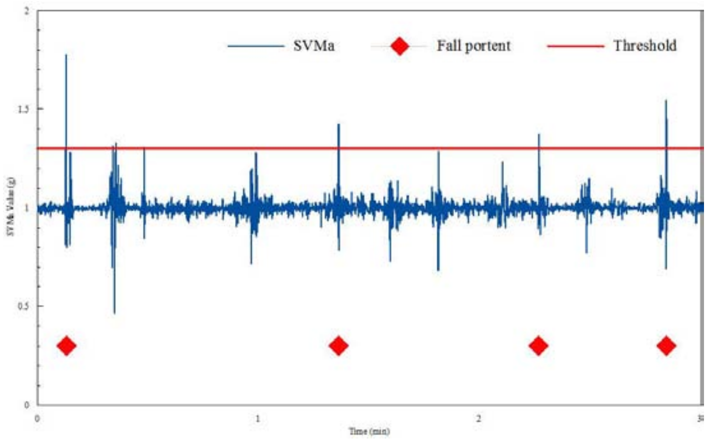

Figure 4. An example of SVM_a for the sleepiness status

4. Conclusion

Fall accidents have been identified the leading cause of fatalities in construction industry for several decades. Previous literatures have indicated that loss of awareness and balance is the major cause of such injuries and fatalities, and several researchers have successfully detected the mental status of drivers and the fall for the elderly and patients. Such successful result provides a foundation for developing real-time personal safety monitoring system in the construction industry.

This paper has described the conceptual model of a real-time personal safety monitoring system consisted of an EEG helmet, motion sensing vest, and smartphone. The physiological signals recorded by these sensors can be wirelessly transmitted to a smartphone, which can act as an individual temporary data center and perform primary analysis. The smartphone can also transmit the preliminary data wirelessly to a monitoring server for further analysis. When the system detect a fall portent (e.g., loss of awareness or balance), it should warn the worker and notify the supervisor, who may adjust the work schedule or tasks to the fall-prone workers.

This paper also presents the preliminary findings in detecting fall portents using a smartphone. We developed an App (iOS 6), which can record the data of the built-in motion sensors, perform a real-time analysis using threshold algorithms, and transmit the original data to a monitoring server. To evaluate the effectiveness of the smartphone-based detection system, the participants performed a simulated tiling task under four different statuses (i.e., normal, sleepiness, fatigue, and inebriation) with a smartphone attached to their waist. Fall portents were identified based any of the three methods, namely self-report, obvious-swaying, and line-crossing behaviors. The identified portents were compared with the detection result of the tested algorithm.

The experiment result indicated that the detection accuracy for the SVM_a algorithm under the sleepiness, fatigue, normal, and inebriation statuses were 92.3%, 90.4%, 77.3%, and 68.8%, respectively. The algorithm performed quite well under sleepiness and fatigue statuses, but not so good under the normal and inebriation statuses. The decrease of the detection quality may be attributed to the situation where the experiment facilitator failed to identify some portents because they were not as obvious in the normal and inebriation statuses as in the sleepiness and fatigue statuses. Overall, all portents (i.e., 111 detection targets) under four statuses were successfully detected, but with additional false alarms that result in an accuracy rate of 86% and a false-detection rate of 14% (i.e., 18 false detections). We conclude that using a smartphone to detect fall portents in a working scenario is feasible and worthwhile studying further.

5. Acknowledge

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Wireless sensor networks configurations for applications in construction

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Abstract

The global wireless sensor networks market is forecasted to increase at a 14.4% annual growth rate through 2016 (TechNavio, 2013). This emerging technology trend is fueled by recent availability of sensors that are smaller, cheaper, and more intelligent. Wireless sensor networks have many potential applications in construction management such as progress tracking, equipment management, surveillance, site safety and others. This paper focuses on designing and configuring wireless sensor networks hardware and software for selected construction applications. The framework is design based on application's objective using a rapid prototyping and iterative system refinement mechanism. The rapid prototyping allows early evaluation of the configured system behavior and performance. The proposed design incorporates a self-adaptive computing concept, which is able to self-control its internal functions and operations, while adapting to the continually changing job site environment. Five prototype designs are presented to support current practices of construction operations in outdoor and indoor environments. The paper articulates the designs objectives, system functionalities, hardware constraints and the performance measures. The developed hardware were tested in real time, and quickly adjusted until targeted performance measures were satisfied. The obtained results show the consistency of the developed prototypes with their experimental applications and their efficiency in comparison to traditional practices.

Keywords: construction operations management; rapid prototyping; self-adaptive computing; wireless sensor networks.

1. Introduction

Recent advancement in computing and information technologies has presented tremendous opportunities for automation in construction industry. These technologies present advanced methodologies in data acquisition, capable of gathering on-site data wirelessly in near real-time. One of the advents in those technologies is wireless sensors networks (WSN). A number of research efforts have investigated the use of WSNs for building management. Kintner-Meyer (2005) installed wireless temperature sensors in two office buildings for energy monitoring and control. The author reported considerable operational and energy benefits of using wireless sensors. Osterlind et al. (2007) tested and confirmed the feasibility of integrating WSNs with building automation systems, and concluded that such integration would lead to cost savings in building management. Huang et al. (2008) reported an integrated deployment tool for ZigBee-based WSNs, and tested it in an office building. Jang et al. (2008) used WSNs for data acquisition in a web based building environmental monitoring system. Data acquired by wireless sensors is processed and stored by a computer, and then reviewed by users via a web-based interface. Hanne et al. (2012) presented a case study and initial testing of a wireless sensor network (WSN) to support building energy management utilizing Web services and middleware technologies.

The application of WSNs has been extended beyond environmental monitoring to building automation. Feng et al. (2008) proposed a WSNs-based smart sensing and control algorithm, which could adjust the thermal quality of the built environments according to the interior and exterior temperature and the behavior of the inhabitants. Huang et al. (2011) proposed a wireless sensor network (WSN) architecture for building HVAC system monitoring and management. Their network architecture utilizes the benefits of energy harvesting and power line communication. Also some research efforts have investigated the use of WSNs for infrastructure monitoring. Sadeghioon at al. (2014) developed a methodology for leak detection in water pipelines using wireless smart sensor networks. Recent research demonstrated that, data collection technologies and sensors coupled with mobile computers can provide cost-effective, scalable, and easy-to-implement progress tracking at construction sites. Several data collection technologies had been utilized for tracking of construction activities. Xia et al. (2012) proposed the use of wireless sensor network (WSN) for monitoring at construction sites. The

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author demonstrated the possible benefits of using WSN such as, improvement of construction safety site safety, enhance schedule and progress tracking of construction projects, and control the construction quality supervision.

Although advanced WSN technologies promise a great advantage of deployment in construction, little research have been pursued to provide a solid understanding for exploitation of their configurations and applications in construction management. This paper focuses on designing and configuring wireless sensor networks hardware and software for selected construction applications. The framework is design based on application's objective using a rapid prototyping and iterative system refinement mechanism. The proposed design incorporates a self-adaptive computing concept, which is able to self-control its internal functions and operations, while adapting to the continually changing job site environment.

2. Rapid Prototyping

The rapid prototyping approach involves production of an early version of the system that illustrates essential features of the later, final operational version. Such process accelerates prototypes development and allows multiple iterations through the refinement process. The iterative mechanism fine tunes the prototype to the needs of the designed application, which leads to a high degree of confidence in the usability of the final end product. In This research modular hardware is used to make rapid prototyping easier, as well as to allow for quicker redesign and the ability to reuse some of the hardware modules. This approach is easy to redesign the platform to adapt the system to different applications. The main features of these modules are low cost, small size, and easy adaptation to different applications. The modular platform used in this research consists of three-layer as shown in Figure 1. This modular platform is divided into three functional layers: processing, communication, and sensing. The processing layer includes a micro-controller, which gives the platform a great deal of processing power as well as flexibility.

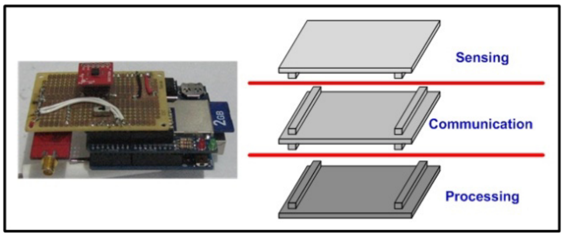

Figure 1. WSN Modular Platform

3. Prototype Design Objectives

When designing wireless sensor networks for applications in construction management, two major classes of design objectives must be considered; network architecture and application requirements.

3.1. Network Topology and Architecture

The topology of a sensor network has significant implications on several network aspects, including network lifetime, routing algorithms, communication range of the sensor nodes and etc. The network architecture requirements contain the physical and logical organization of the network as well as the density of the sensor nodes. In general, the objective of sensor networks is to efficiently cover the deployment area. The logical and hierarchical organization of the network also impacts energy consumption and the selection of communication protocols. In addition, based on topology requirements, sensor networks can have a distributed organization or a clustered organization, where selected nodes can handle data forwarding.

3.2. Application Requirements

The required information that is to be relayed through the sensor network should be classified and quantified. These requirements can be achieved by a comprehensive analysis of the construction automation applications. Based on the application requirements, the properties of individual sensor nodes can also be identified which impact network modeling and communication protocol choices. Full consideration of the different sensor network options and how will they fit the targeted application is critical for a successful implementation.

4. Applications Classes of WSN in Construction

Three application classes are selected: infrastructure data collection, operations monitoring, and location tracking. We believe that the majority of wireless sensor network deployments will fall into one of these class templates.

4.1. Infrastructure Data Collection

A typical infrastructure data collection application is one where an engineer wants to collect several sensor readings from a set of points in an infrastructure over a period of time in order to detect trends and interdependencies. Data is collected from hundreds of points spread throughout the area and then the data is analyzed offline. The data is collected over several months or years in order to look for long-term and seasonal trends. For the data to be meaningful it would have to be collected at regular intervals and the nodes would remain at known locations.

In infrastructure monitoring applications, it is not essential that the nodes develop the optimal routing strategies on their own. Instead, it may be possible to calculate the optimal routing topology outside of the network and then communicate the necessary information to the nodes as required. This is possible because the physical topology of the network is relatively constant. Tree-based routing topology is typically used (Figure 2), where each routing tree is rooted at high-capability nodes that sink data. Data is periodically transmitted from child node to parent node up the tree-structure until it reaches the sink. With tree-based data collection each node is responsible for forwarding the data of all its descendants. Nodes with a large number of descendants transmit significantly more data than leaf nodes. These nodes can quickly become energy bottlenecks (Xu et al. 2001, Yarvis et al. 2002).

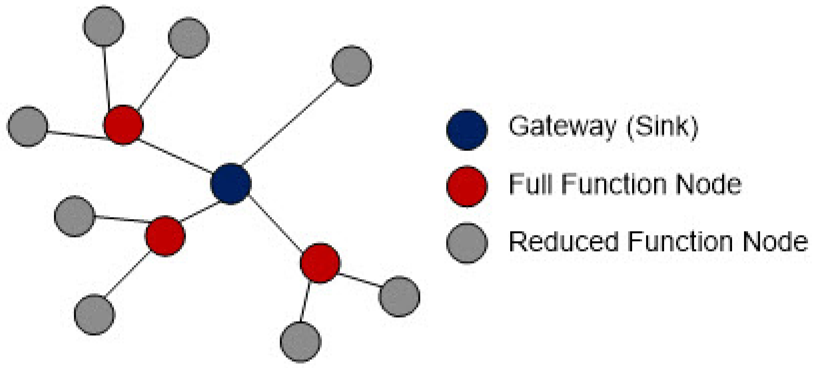

Figure 2. WSN Tree-based routing topology

For illustrative purposes, we consider a WSN consisting of a set of sensor nodes, and each node has three main hardware components, sensors, filters and microcontroller, and radio for wireless communication. Figure 3 is a schematic of the major components of a node. For the measurement of accelerations, a commercially available accelerometer sensor is used to measure the acceleration in the three axels. An Xbee communication module is used to connect and send the collected data through the wireless network. This communication module has a coverage range of 150 m and 250 kbit/s data transfer rate. Table 1 summarizes the empirical performance of the platform we presented in this research. The key performance metric is energy efficiency, which we measure as mj/day to accomplish the task. The measurement is based on data collection every 4 seconds, averaged and transmitted once every 5 minutes. Each node had a maximum of 5 children nodes and one parent node.

In order to meet the strict alarm propagation requirements, each node must also be continually ready to forward alarm messages. This means that they must be frequently checking the RF channel for activity. The relatively high frequency of the wake-up check makes it the single largest consumer of energy in the design. Taken together, the three optimizations (RF wake up, time synchronization, and high-speed communication) reduce energy consumption of the active part of the application by two orders of magnitude.

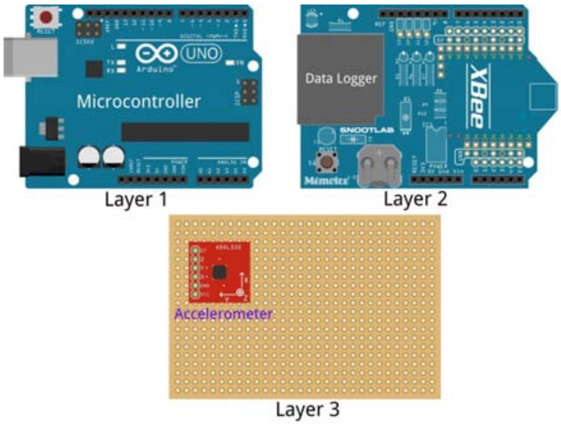

Figure 3. Infrastructure Monitoring Prototype

Table 1. Platform empirical performance.

Application Component	Energy Usage (mj/day)
Data Transmission	458
Rendezvous Overhead	35
Alarm Checking	78
Data Sensing	16
sleep energy	4319
Total	4906
Expected Lifetime on Idealized AA (years)	4.46

4.2. Site Safety and Security Monitoring

Safety and security monitoring networks are composed of nodes that are placed at fixed locations throughout an environment that continually monitor one or more sensors to detect an anomaly. Such networks are not actually collecting any data; this has a significant impact on the optimal network architecture. Each node has to frequently check the status of its sensors but it only has to transmit a data report when there is a safety or security violation. The immediate and reliable communication of alarm messages is the primary system requirement. These are "report by exception" networks. Additionally, it is essential that it is confirmed that each node is still present and functioning. If a node were to be disabled or fail, it would represent a violation that should be reported. The network must be configured so that nodes are responsible for confirming the status of each other. One approach is to have each node be assigned to peer that will report if a node is not functioning. The optimal topology of a security monitoring network will look quite different from that of a data collection network. The optimal configuration would be to have a linear topology that forms a Hamiltonian cycle of the network (Figure 4). The power consumption of each node is only proportional to the number of children it has. In a linear network, each node would have only one child. This would evenly distribute the energy consumption of the network. The accepted norm for such systems today is that each sensor should be checked approximately once per hour. Combined with the ability to evenly distribute the load of checking nodes, the energy cost of performing this check becomes minimal. A majority of the energy consumption in a safety and security networks is spent on meeting the strict latency requirements associated with the signaling the alarm when a violation occurs.

A safety monitoring system consists of a gateway node and a number of mobile nodes assigned to labor and machinery. This system can detect the presence of worker in the red zone of heavy equipment by continually measuring the proximity between them. The network consists of a set of sensor nodes, and each node has three main hardware components, sensors, filters and microcontroller, and radio for wireless communication. The Bluetooth module is used to connect and send the collected data through the wireless network. This communication module has a coverage range of 100 m and 1 Mbit/s data transfer rate, which is required for low data latency. Also each node is equipped a 100 db buzzer for alarming. If a safety violation is detects an audible alarm for the equipment operator and the worker is initiated, also the machine control is disabled for hazard prevention as shown in Figure 5.

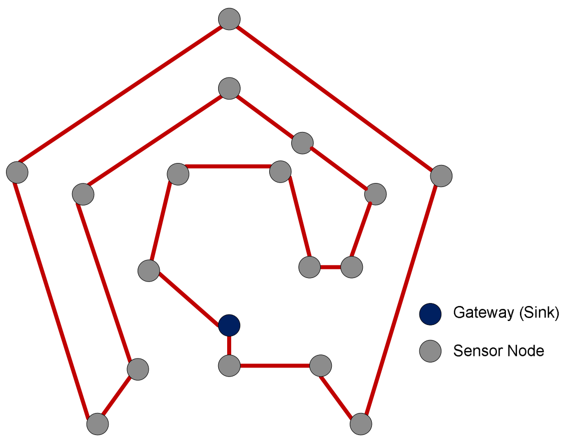

Figure 4. WSN Linear Topology with Hamiltonian Cycle

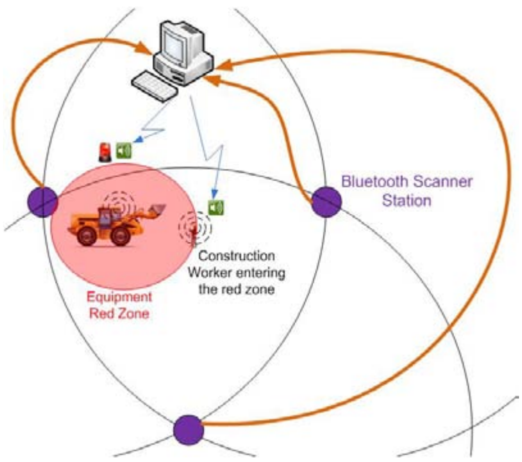

Figure 5. WSN Safety Monitoring System

4.3. Construction Operation Monitoring and Tracking

Monitoring and tracking of construction operation requires tracking of a tagged object through a region of space monitored by a sensor network. Current inventory control systems attempt to track objects by recording the last checkpoint that an object passed through. However, with these systems it is not possible to determine the current location of an object. With wireless sensor networks, objects can be tracked by simply tagging them with a small sensor node. The sensor node will be tracked as it moves through a field of sensor nodes that are deployed in the environment at known locations. Instead of sensing environmental data, these nodes will be deployed to sense the RF messages of the nodes attached to various objects. The nodes are used as active tags that announce the presence of a device. The optimal configuration would be to have a mesh topology with autonomous mobile mesh nodes as shown in Figure 7. The added mobile mesh nodes, which move with their mesh clients, enhance the performance of the typical mesh topology and provide the intelligence to dynamically adapt the network topology to provide optimal service (Wei et al. 2014).

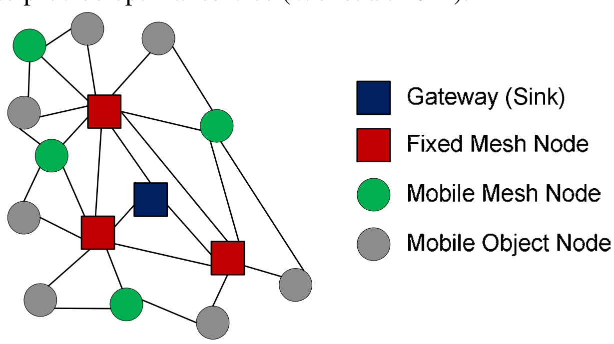

Figure 7. WSN Mesh Topology with Mobile Mesh Nodes

The mobile sensor node is equipped with the Synapse RF300PC communication module and the BMP180 barometric pressure sensor as shown in Figure 8a. The communication between the BMP180 and RF300PC is established through I2C communication. The node is powered by a Li-Ion Rechargeable Coin Cell battery (PD3555). The gateway node collects data from the mobile node; calculates the mobile nodes locations and submits the pre-processed data to the database server. It consists of a Waspmote microcontroller, Synapse RF300 communication module and RN-171 WLAN module as shown in Figure 8c.

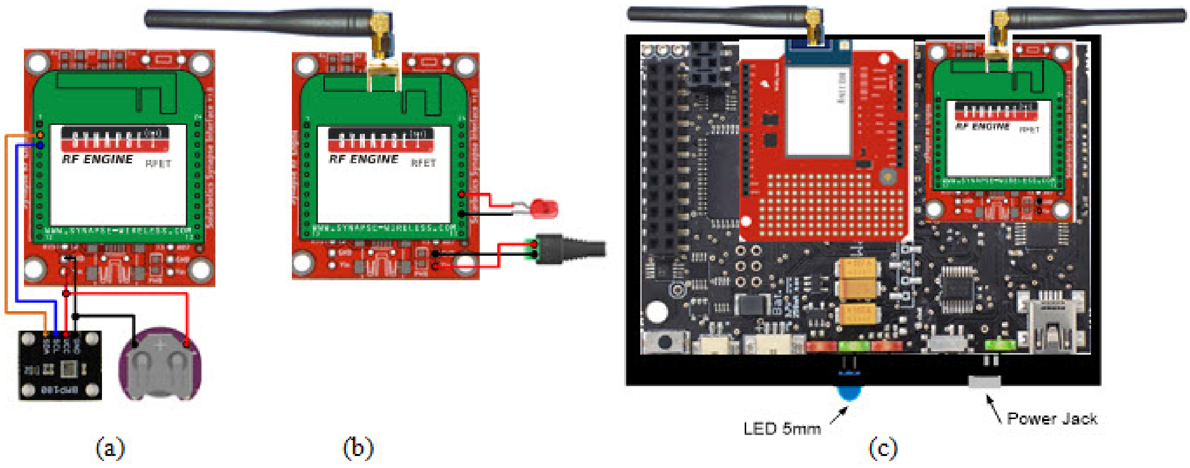

Figure 8. Construction Operations Tracking Prototype. (a) Mobile Node (b) Mesh Node (c) Gateway

5. Conclusion

This paper focused on designing and configuring wireless sensor networks hardware and software for selected construction applications. The framework is design based on application's objective using a rapid prototyping and iterative system refinement mechanism. The rapid prototyping allows early evaluation of the configured system behavior and performance. The proposed design incorporates a self-adaptive computing concept, which is able to self-control its internal functions and operations, while adapting to the continually changing job site environment. Five prototype designs are presented to support current practices of construction operations in outdoor and indoor environments. The paper articulated the designs objectives, system functionalities, hardware constraints and the performance measures. The developed hardware were tested in real time, and quickly adjusted until targeted performance measures were satisfied. The obtained results show the consistency of the developed prototypes with their experimental applications and their efficiency in comparison to traditional practices.

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Creative Construction Conference 2014

Co-adaptation of robot systems, processes and in-house environments for professional care assistance in an ageing society

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Abstract

The recruitment of new workforce for the field of care taking is difficult in highly industrialized countries and the gap between demand and availability of care takers will further increase with the expected increase in aged populations in the future. In particular, service robot systems are able to enhance the capabilities of assisted environments significantly as they add critical capabilities and thus allow environments to actively support care givers and care takers with the full bandwidth of necessary processes, tasks and services. Service robot systems add to assisted environments besides the aspect of hard physical assistance capabilities with flexibility, increased intelligence and situational awareness and provide new ways of intuitive man-machine-interaction. However, the integration of service robot systems into real world assisted environments has been difficult due to the usually separate development of environment and stand-alone robot systems. In this paper, the authors present a conceptual approach for a robotic care environment in which care environment (including room layouts, furniture and distributed sensors), service robot systems and care processes are fully synchronized and co-adapted. The conceptual approach borrows further ideas and methods developed in a series of large research projects (GEWOS, LISA, PASSAge, USA², LISA habitech) in the field of Ambient Assisted Living (AAL) by the authors and integrates them into a new research direction. The ultimate goal of the authors is to systematically investigate tradeoffs related to the distribution of complexity between environment, service robot systems and process structures and identify performance optimized and cost efficient solutions that will boost implementation and commercialization of service robot systems in ambulant and stationary care.

Keywords: Robotics, Care, Robot Oriented Design, Structured Environments, Ambient Intelligence

1. Background

In highly industrialized countries, aging society (*Robine et al., 2005; Doblhammer et al., 2005; Staudinger & Kessler, 2007*), shrinking work force (*Burgiavini et al., 2012*), demand for increased productivity in working and private life (*Börsch-Supan, 2005*) as well as the development towards a society for which scientists predict for the next decades the increased emergence of Centenarians, Super-centenarians (and the enlarging of the average life span by another 20 years, see *Jeune & Vaupel, 1995; Maier et al., 2010*), necessitate novel technological approaches, in-home services and support for ambient assisted living that are fully and invisibly integrated into our daily activities (see, for example, *Wichert & Eberhardt, 2011*).

Already today the recruitment of new workforce for the field of care taking is difficult in highly industrialized countries and the gap between demand and availability of care takers will further increase with the expected increase in aged populations in the future. This is true for both the field of care taking in institutions as care homes and supervised accommodation as well as in the field of home care. Reasons for the ongoing image damage and unpopularity of the care taking profession are, amongst others, low salaries, tough work schedules, high physical burdens, the execution of hygiene critical tasks (washing and cleaning of elderly, etc.), repetitive and monotonous tasks and the increase of documentary administrative work. The often honored personal contact of the care takers to the care givers (which is often used as an argument against the extensive use of technology in the care field) in current care taking reality is already missed out on due to the aforementioned aspects and burdens on the care takers. The situation can be expected to become more severe with the increase in the gap between demand and availability of care taking workforce.

With our research in co-adaptation of robot systems and in-house environments for professional care assistance in an ageing society presented in this paper, we aim to dramatically change the image and performance of the professional and non-professional care taking field and, at the same time, improving the life situation of the care takers in care homes, supervised accommodation and home care. We are not aiming at the substitution of care taking workforce by capital investment in technology but at the substitution and redistribution of individual tasks making care taking a creative, technology-oriented, high-level profession that is attractive for skilled and motivated people. Assisted living environments in which a multitude of assistive subsystems and service robots operate seamlessly allow a complete redesign of the processes and task structures leading to the fact that the care takers become more self-dependent (which enhances life quality and decreases the burden on care takers). On the other hand, such environments allow that the care takers can be relieved, to a large extent, from the aforementioned challenging mental and physical burdens and instead concentrate on increasing the quality of service, personal care and mental and physical treatment and training of the elderly, which definitely demands intensive personal contact.

In particular, service robot systems are able to enhance the capabilities of assisted environments significantly as they add critical capabilities and thus allow environments to actively support care givers and care takers with the full bandwidth of necessary processes, tasks and services. Service robot systems add to assisted environments, besides the aspect of hard physical assistance, capabilities such as flexibility, increased intelligence and situational awareness and provide new ways of intuitive man-machine-interaction. However, the integration of service robot systems into real world assisted environments has been difficult due to the usually separate development of environment and stand-alone robot systems, high cost of highly dexterous service robot systems and lack of seamless integration and user acceptance. Therefore, with our research in this field, we aim at creating the scientific basis for the integration of service robot systems into assisted environments, considering the ultimate goal of creating care and home-care environments that allow a radical restructuring of processes and tasks for dramatically changing the image and performance of future technology-oriented care taking.

2. Research question and research method

Our research focuses on the redesign and structuring of care environments (at home as well as in care facilities) and the processes taking place within them for the creation of modular and mass-customizable robot-compatible assisted living and service environments as well as the redesign and adaptation of existing service robot systems. In an interdisciplinary approach, we will develop optimized care environments in which service robot systems seamlessly interact with the physical environment, embedded medicals sensors and systems, various sets of standardized and non-standardized processes and human beings (care takers as well as care givers) to provide multidimensional assistance and a broad set of modular and customizable services. The basic premise consists of a distributed layered architecture enabling omnipresent communication, and an advanced human–machine communication protocol. The Ambient Intelligence (AmI) paradigm sets the principles to design a pervasive and transparent infrastructure capable of observing people without interfering with their lives, adapting to the needs of the user. It must be noted though that populating a home environment with robotic elements must be performed following a space-efficient utilization scheme. Elderly people, and especially those using assistive devices such as wheelchairs and rollators, require increased barrier-free space for mobility purposes.

A particular focus in our research is on the co-adaptation and creation of compatibility (in a physical and informational sense) of assistive environments and service robot systems. In contrast to usual service robot development (see, for example, *Care-O-Bot, Patient Transfer Assist, RI-MAN*), the complexity of functions (hardware, software, tasks, etc.) will not be concentrated solely in the robot system but distributed strategically between the robot system and the environment. Previous research by the authors showed that such an approach has the potential for significantly reducing the complexity and cost of the service robot system, enhancing their reliability/robustness and above all, creating completely new service and assistance capabilities (*Georgoulas, et al., 2012*).

In this paper, the authors present a conceptual approach for a robotic care environment in which furniture and robot systems are fully synchronized and co-adapted. The conceptual approach borrows further ideas and methods developed in a series of large research projects (*GEWOS, LISA, PASSAge, USA², LISA-habitech*) in the field of Ambient Assisted Living (*AAL*) by the authors. Furthermore, within these research projects, the authors were already able to test individual sub-systems of the now suggested, more comprehensive approach. Primarily in experimental, user oriented approaches, and in these research projects, sub-system prototypes of robot-compatible interiors and building “infill” compatible service robots were developed, and their interaction was demonstrated, evaluated and developed further in several development cycles within relevant use cases. The ultimate goal of the authors is to systematically investigate the tradeoffs related to the distribution of complexity between environment and service robot system and identify optimized effective and cost efficient solutions that will boost implementation and commercialization of service robot systems.

The paper is structured as follows. First, the authors outline the background, need and general direction of our research. Following this, the authors define and outline influencing factors and building blocks for robot adapted care environments. Third, the authors present an analysis of processes taking place in professional car environments, build process categories and relate those to the possible task for robot systems that could potentially be used to support or carry out those tasks. Fourth, the authors present their comprehensive approach for a robotic care environment in which a variety of co-adapted robot systems (mobile robots, manipulators, etc.) interact with human beings and the co-adapted the physical environment. The authors then present – as a proof of concept – exemplarily two individual sub-systems, which they could develop, test and optimize within ongoing research projects. Finally, the authors show the impact their research can have on strategies and business models in the care taking field.

3. Robot Oriented Design for care environments: definition of influencing factors and building blocks for co-adaptation of service robots, processes and environments

Following the methodology developed by the authors in Robot Oriented Design (*Bock, 1989*) and Robotic Micro-Rooms (*Linner et al., 2014*) functions can be arranged in a three-dimensional architectural space so that a smooth and optimum operation of processes and activities is possible: a highly structured care environment can be realized that enables the automation of assistive functions and the efficient integration of robotic subsystems. In this space:

1. Processes and activities widely known and partially standardized are possible.
2. The geometric and functional configuration of the environment is known.
3. Distributed sensor systems are able to recognize and locate robots, objects, persons, vital signs, etc. in a robust way.

This creates, similar to a factory environment for industrial robots, a comparatively structured space for care environments. In this sense, factors that influence the co-adaptation of robots and environments are the environment category, the type of service robot, the type and amount of the embedded system distributed in the environment, the service robot complexity reduction function and, last but not least, the type and composition of the process in which the service robot is embedded.

4. Processes, tasks and robots

In previous research, the authors have developed methods for the systemic development of assistive home environments that support elderly people to live independent based on an analysis of processes that result from activities of daily living (see, for example, *Linner et al., 2011, Linner & Bock, 2012*). Care processes, both in ambulant and stationary settings, are different as the focus, on one hand, is on people that demand a higher level of care but on the other hand, include in some way professional and non-professional care personnel. In particular, in stationary care processes, room layouts and furniture are highly standardized and thus, present a solid opportunity for automation and robotisation. Based on analysis of care processes and discussions with professional care takers and care managers, the authors of this paper have identified the major process categories, related tasks with a high potential for automation and robotisation and robot system suitable for those tasks.

5. Conceptual approach

Our concept aims at the co-adaptation of service robots, environment (including floor layouts, furniture, and distributed sensors) and processes to a total system for professional (stationary and ambulant) care environments. Our concept considers, in particular, a seamless relationship and ubiquitous interaction between the user, robotic systems and smart furniture. Every aspect of the care givers' and care takers' activities can be influenced and enhanced by implementation of the robotic care environment. Each robotic system will work either individually or as a group in order to provide necessary assistance for the user. The smart furniture is equipped with various sensors, which can communicate with the surrounding environment. For instance, the mobile robot platform will provide efficient logistic service within the living environment, such as delivering shopping from the doorway to the kitchen, or delivering food from the kitchen to the bedside table. The telepresence robot could provide a network interface between the health care provider and the user. It can also be utilized as primary mobile communication platform or social network media. The floor and window cleaning robot will operate in an autonomous manor to carry out cleaning duty only when it is necessary. The lightweight robot arm will assist care givers and care takers with essential tasks such as preparation of food, feeding and personal hygiene operations. The above scenarios provide an excellent opportunity to evaluate and validate the overall concept of an embedded robotic care environment. *Figure 1* gives an overview over a fully robot assisted care environment that might be deployed either in a care home (stationary care) in a home to assist ambulant care taking (ambulant care).

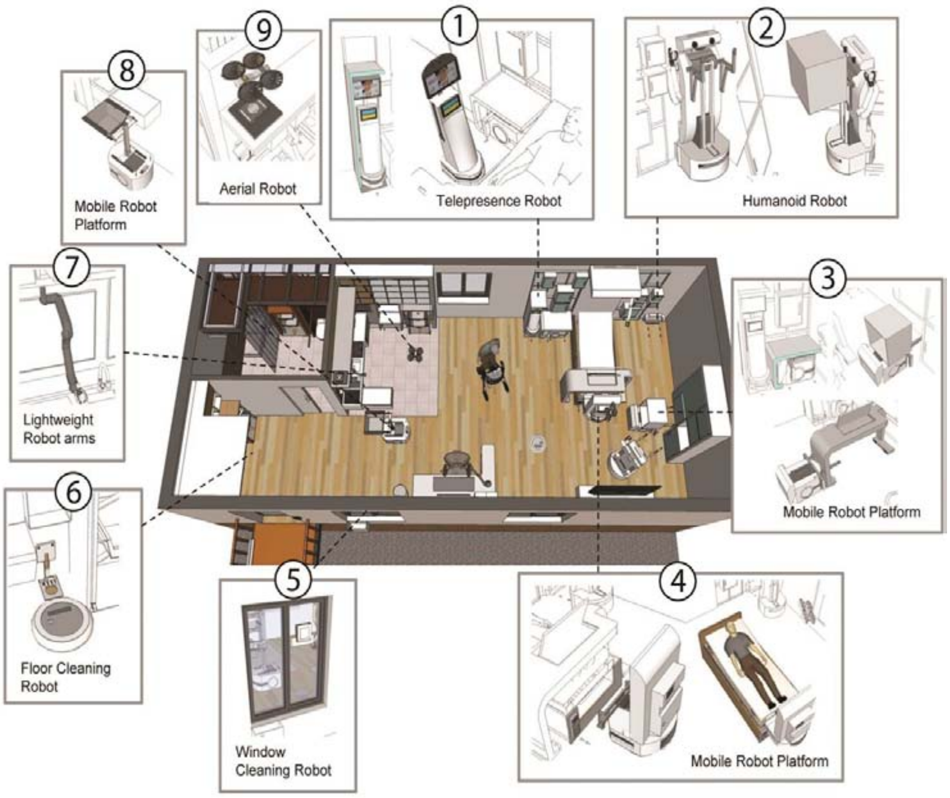


Figure 1. Overview over a fully robot assisted care environment that might be deployed either in a care home (stationary care) in a home to assist ambulant care taking (ambulant care)

6. Proof of concept by implementation and experimentation

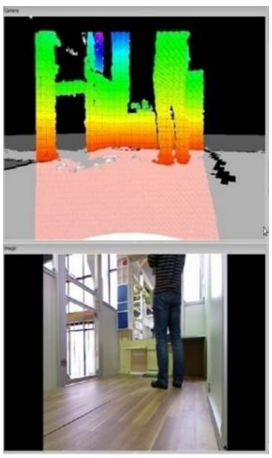
The possibility of co-adaptation, the dimensional space layout and furniture systems was tested and validated by the authors in different use cases and by using variety of robot systems in the AAL projects GEWOS, LISA, PASSAge, USA², and LISA habitech. All of these projects were initialized and conducted in the laboratory run by the authors and involved both commercial and industrial partners. The following two examples demonstrate exemplarily how the authors tackled the co-adaptation process.

The research project LISA investigated the possibilities to embed assistive functions and services into wall "terminal" components and, therefore, to enable an autonomous and independent living upon performing activities of daily living by (partially structured environments) robotic micro-rooms (RmRs). The terminal generated a geometrical known and structured environment for the integrated robot systems (Kinova's *JACO* robot arm; *TurtleBot*) and provided them with additional information (for example, example about location of objects to be grasped) through the embedded systems (for example, RFID readers). Details on the LISA project, the developments, experiments and user test conducted within this project are presented in *Güttler et al., 2014* and *Linner et al., 2014*.

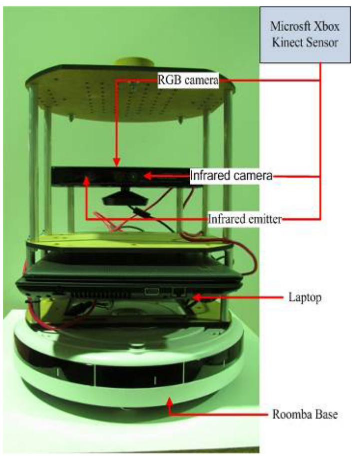
In the project USA², assisted workspaces for decentralized high-tech home production of customized goods were developed. The workspaces developed are embedded in larger Cloud Manufacturing systems and will allow companies to utilize a highly skilled workforce (including highly experienced elderly) worldwide. Within the project, the workspace (its functions and design), the embedded sensors distributed in the environments, novel interfaces (for example, leap motion sensors; for further details, see also *Georgoulas et al. 2014*) and the related work processed were fully co-adapted. Details on the *USA²* project, the developments, experiments and user test conducted within this project are presented in *Linner et al, 2013*.

Figure 2. Development and testing of robot-environment-process co-adaptation strategies within ongoing research projects LISA (left) and USA² (right).

Both in LISA and USA², the TurtleBot mobile rover platform was used to act as the human-machine communication interface. Furthermore, TurtleBot was used to acquire additional visual information (for example, example recognizing dynamic obstacles as human beings) using the Microsoft Kinect Sensor *(Biswas & Basu, 2011*). The depth sensor consists of an infrared laser projector combined with a CMOS sensor, which captures 3-D real-time data. The sensing range of the depth sensor is adjustable, and the Kinect embedded software is capable of automatically calibrating the sensor based on the user's physical environment arrangement, accommodating for the presence of furniture or other obstacles. Due to the fact that the Kinect sensor uses an infrared sensor, it can also provide night-vision abilities. Thus, in the proposed architecture, elderly people can be assisted by TurtleBot, in low lighting conditions and even if lights are switched off, i.e. during the night. The TurtleBot tele-operation is based on ROS open-source software (*Robot Operating System*). The experiments with TurtleBot in LISA and USA² showed that the co-adaptation of environment and mobile platform allows for a multitude of assistive functions (for example, intuitive user interface, transports of goods, detection of emergencies, etc.). The capabilities and technical details of TurtleBot acting in a co-adapted structured environment are presented in detail by Georgoulas et al. (*2014*).



3-D point cloud of actual interior space generated by TurtleBot



TurtleBot Mobile Platform

The compact mobile platform Lynx (Adept) has a payload of 60 kg

Figure 3. Experimentation related to the co adaptation of mobile platforms, environment and processes

In the next step, the authors will use the generated knowledge and implement and co-adapt care environments and mobile platforms with higher payloads (for example, *Lynx*), which will increase the range of possible application significantly. Figures 2 and 3 outline application scenarios for such mobile platforms in professional care settings.

7. Conclusion and future research

The authors have identified the need of and possible use cases for the implementation of service robot technology within professional stationary and ambulant care scenarios. The authors have tested strategies for the adaptation of service robots (for example, example TurtleBot and JACO) in a series of projects in the field of Ambient Assisted Living. In the next step, the authors will apply the knowledge gained so far to create professional care settings in which, in particular, the care takers are heavily supported by a variety of robots. Similar as in the research projects conducted so far, the authors conclude that the co-adaptation of robot systems, physical environment and processes will reduce total system complexity and cost and thus boost implementation and commercialization of service robot systems for ambulant and stationary care.

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Creative Construction Conference 2014

Research on BIM-based drawings query and feedback system with smart hand-held devices

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Abstract

Recently, BIM technology has got a certain development in China, however, it is still lacking of abilities in application and operation, especially in drawings query and real-time data feedback and update on site. The paper is to develop a drawings query and feedback system using technologies of network, two-dimension code and database with smart hand-held devices of android platform, with which the engineers is allowed to consult 3D drawings on site, and feedback timely and achieves data linkage between computer and handheld terminal. Through the case application, it shows that the hand-held terminal drawings query and feedback system can reduce information loss and improve the efficiency of project management to a certain extent.

Keywords: BIM, Smart Handheld Device, Drawings Query, Feedback, Database.

Nowadays, BIM (Building Information Modeling) technology has become a hotspot in the research and application of information technology in construction industry around the world, and its application value has obtained the general recognition of government and the high attention of construction industry. However, the practical application of BIM in the field of engineering construction is still very difficult. Workers require a lot of construction drawings to manage construction process, especially for complex projects, but it is not convenient for the engineer getting drawing of BIM through PC on site, additionally, BIM model is difficult to achieve rapid updates due to the high frequency of project change in construction industry in China. These factors above lead to the decrease in application value of BIM technology in the construction process.

1. Introduction

Under the guidance and support of government policy, academic circles, software companies and design and construction enterprises respectively carried out the research, development and application of BIM technology. BIM has become one of the hottest topics in China's construction industry. Although in recent years research on BIM and the application of demonstration projects have achieve some results and practical experience, BIM is still an unfamiliar technology for the whole of China construction industry.

Wu, etc. writes an investigation about the application of BIM in China's construction industry in the BIM academic magazines published by the American Institute of Building science (National Institute of Building Sciences, NIBS) (Wu Wei, Raja RAIssa,& Jiayi Pan, 2000).It shows that 31.6% of respondents don’t known BIM technology, 23.7% begin to pay attention to BIM technology after 2006. The application of BIM suffers from the short of collaborative design and the participants lack of overall management in different phases and professional areas. It is especially obvious in domestic operation project (Zhang Jianxin, 2010).Now, to solve these application obstacles of BIM technology in our country, many scholars have developed application systems based on BIM. Akcamete, etc. proposed the records of facilities inspection and maintenance to support operational managers to analysis the priority of each task and reasonably arrange operation plan (Akcamete A, Akinei B, & Garrett J H, 2000).Hu Zheng-zhong, etc. developed intelligent management system of mechanical and electrical equipment based on BIM and achieved component positioning with hand-held terminal (Lv Yu-hui, Yu Qiyuan, & Zhang Shang, 2000).Lv Yuhui , etc. developed construction project multi-factors integrated management computer information systems based on BIM and this system is useful for workers to get construction information (Yin Kui,Wang Xingpo, & Liu Xianwei,Hu Zhenzhong Lupton, 2000).

Recently, the study on application of BIM technology in construction mainly focus on how to gather and manage construction information of BIM via personal computer, and there is still few literature studying on BIM-based drawings query and feedback system with hand-held devices on construction site. So for the construction site management, it does not make full use of the technological innovation advantages brought by

BIM technology to improve construction process management. So the paper is to develop a BIM-based drawings query and feedback system with smart hand-held devices to help the better management of construction process.

2. system structure

2.1. System platform

For the development of intelligent handset drawings queries and feedback system, we should first consider the choosing of system platform. Based on Linux kernel, Android uses the structure, of software stack and it is shown in figure 1.The bottom is the kernel, developing by C language, and as abstraction layer between with the hardware and software, it hides the details of hardware and provides a unified service for the upper layers. Above the Linux kernel layer, it is interlayer composed of the Libraries and Runtime layer developed by c ++ language .The role of the Dalvik virtual machine is to provide a runtime environment for each Android application program to make them run in their own process .Above the middle layer is the Android application layer, it includes application software and frame design .

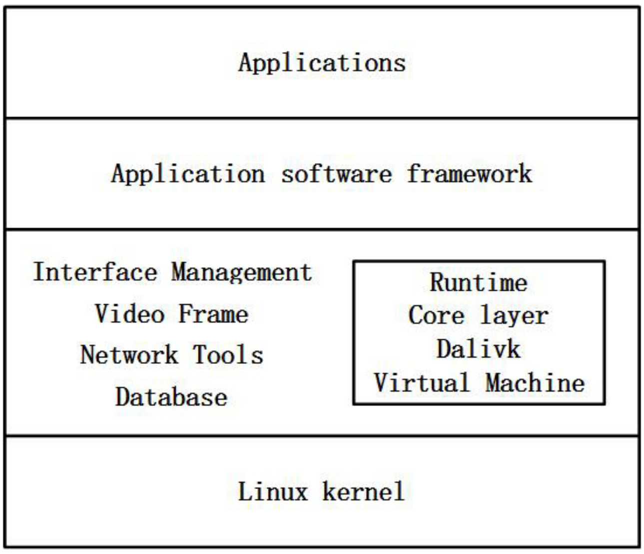

Figure 1. Android Structure

Because the hierarchical structure, developers can make further development by taking application layer as an organic whole without studying other levels. At the same time, the lower layer can provide many services for the upper ones. Such a hierarchical structure minimize dependence between each level, and it will be very conducive to standardized work. Compared to some of the main system platform, the Linux kernel in Android have strong network performance, and broader adaptation of hardware platform .

In view of the above characteristics, Android platform is very suitable for application service of BIM-based drawings query and feedback system, and this system will have a bright application prospect .Therefore, we select Android platform to develop the intelligent handset drawings query and feedback system.

2.2. Two-dimensional code technology

As an information storage and transmission technology, two-dimensional code is geometric plane shapes formed in accordance with specific encoding rules (Russ A, 2002). It can express information in horizontal and vertical directions at the same time, thus can store a lot of information within a small area. It has a large storage capacity, high reliability, strong confidentiality, and low cost. In addition, it can store multinational text, data files, images and other information efficiently.

With the coming of 3G era, the application of two-dimensional code in mobile device is becoming more and more diverse (Lycon S, & Kschischan F R, 2010). As the most popular smartphone platform currently, Android system makes the information stored, read and spread in phone by the form of two-dimensional code. Mobile device can be used as a carrier of the two-dimensional combined with read application equipment. Furthermore, the development of related applications based on implicit information in two-dimensional code can be realized by the identification of the code on commodities with the in -built or downloaded read engines.

In all kinds of QR code, the commonly used code systems are: Data Matrix, Maxi Code, Aztec, QR Code, PDF417, CODE 16 ,etc., among which Quick response Code (Quick Response code, QR Code) is one of the most successful two-dimensional Code. As a matrix code, it have a large capacity of information and 1817 characters, or 7089 figures, or 4200 English letters can be put into a code. Numbers, Chinese character, photo and fingerprints, audio/video information can be embedded in it. Compared to other code, QR code has the advantages of fast read speed, large data density and small occupation space. It has an important theoretical significance and practical value to applying the QR code in the mobile platform, and developing QR code identification system based on Android system .

2.3. Database Technology

BIM model Databases' establishment must satisfy the required conditions of the Relational model, so we used the relational model database system. The calculation system is based on SQL Server 2005 for data management tools between Multithread and SQL database management system. It has a simple, friendly interface with strong scalability, high performance, consistence and can maintain the integrity of the data information. Moreover, it can be implemented with Windows NT, Internet with no difference integration, so it is a common database designing tool. According to the different using scope of the data, these data are stored in each unit interior workstations and servers, it can not only improve the efficiency of data, but also reduce many terminal access, avoid too much burden of server (Marco Bellinaso, 2008).

2.4. System structure

Intelligent handset drawings query and feedback system architecture is the typical C/S structure, as shown in figure 2.

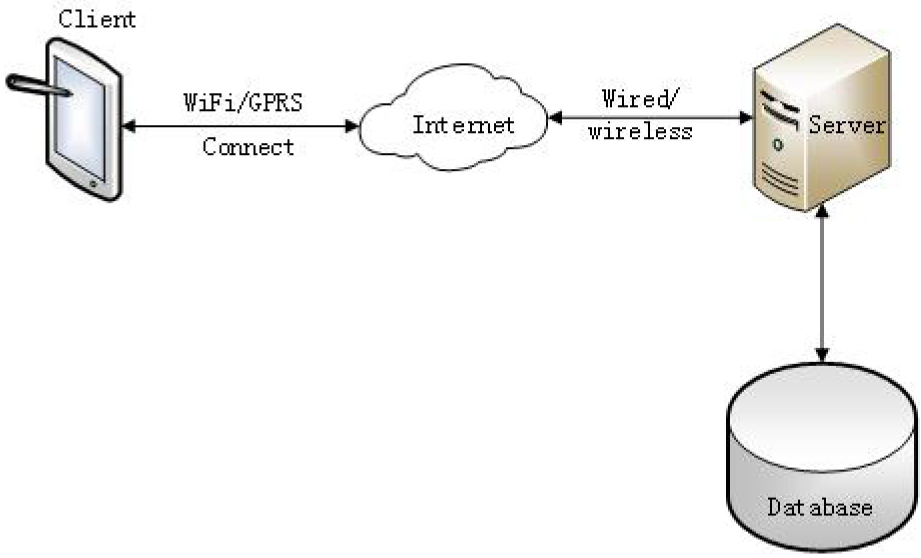

Figure 2 BIM-based Drawings Query and Feedback System Structure

- Client: As the client, an Android phone or tablet can support wireless network transmission and QR code scanning through a configuration file to realize the connection between the current terminal and server
- Network: network is a channel to connect server and client. Usually, the server is set up by the Internet. An IP address and a port number are specified for client to be connected to the Internet and communicate with the server via accessing the server's IP address and port number
- Server: the server consists of routers, firewalls, and SQL Server, which is responsible for providing services such as data storage, access and management

- Database: a BIM data warehouse is to store all of the drawings in the server, according to the level of the relationship between the various devices and build physical path of files, and then build up the drawing description information database. Many things can be achieved by the relational model of database operation, namely, drawing query, attribute information query and drawings of components between logic. Thus the storage structure clear, rationality, priorities, and safety can be guaranteed

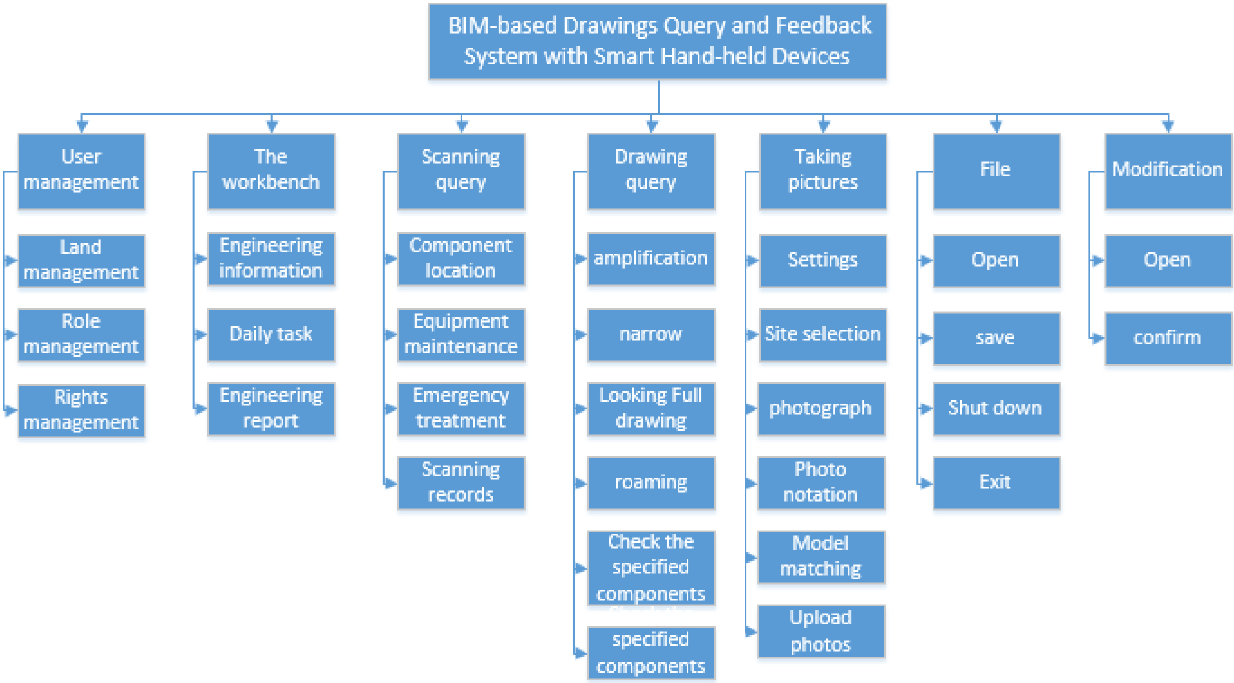

Figure 3. BIM-based Drawings Query and Feedback System Organization Structure

3. The system function design

This system consists of seven main modules including user management, files, drawings query, pictures, workbench, modification and canning query. Its functional organization structure is shown in Fig. 3.

The user interface will appear after entering the system, which consists by toolbar and main window, as shown in Fig. 4.

This system is of an open structure based on components with good reusability and maintainability to adapt to the different application requirements. So it can provide personalized service and is easy to learn and use. The following functions can be realized when engineers use smart handheld terminal as an access to BIM model information:

- Convenient browsing: BIM model is free to be enlarged, narrowed or translated by finger touch. Navigation can also be used to walk around the building. Models can be browsed arbitrarily by skipping in the small map
- Check the model properties: any attribute of components, namely, material, size and so on can be got easily by clicking the components in BIM model
- Filter: models can be filtered according to the dimensions of floor or the types of components
- Viewpoints and notation: some interested part of BIM model can be recorded via view function, and workers can return to this location at any time. Red notation can also be signed to record model problems, which is convenient for engineer to handle it later
- QR code positioning: model component can be associated with QR code, achieving rapid positioning to the required artifacts
- Picture upload: pictures of construction site can be uploaded through the terminal and matched with BIM model, when constructors inspect the onsite construction through hand-held terminal .

4. Application and Feedback

The total construction area of intercontinental hotel project in Wuhan international exhibition center reaches about 200000 square meters, with the 101 meters in height and 21 floors. The on the ground part is used for hotel, office, commercial, catering and other related supporting function rooms, and the underground part is used for garage and equipment rooms. It is a five-star hotel, matching with international conference center, and is one of the largest and highest level of hotel in Hubei province. The quality goal of the project is to get *Luban Prize* which is the highest national construction engineering quality prize. And the safety requirement is to reach the national *3A*standard.Compared with the traditional BIM project management via computer , the use of BIM-based drawings query and feedback system with smart hand-held devices has the following advantages.

Figure 4. BIM-based Drawings Query and Feedback System Main window, barcode detail information and photograph modules

4.1. Access to information

In the construction process, engineers use a mobile terminal equipment to scan QR code on the components, and get other ancillary information associated with the components by connecting to remote database according to attribute information provided by QR code. So the engineers can refer to the information of installation and maintenance manual, component parameters, construction personnel without carrying a lot of paper documents to the ground. Thus the electronization of operation can be realized, as shown in Fig. 4.

4.2. On site photos uploaded

In the process of construction site management, constructors can check and manage the whole constructing areas by smart handheld terminal. And they can take photos and upload to match them to BIM model on site as soon as they find any mismatching between the actual construction site and the BIM model. And then they can refer to the data and analysis it after they return to the office, as shown in Fig. 4.

4.3. Equipment emergency handling

When there is an emergent equipment failure, constructors can scan the QR code by handheld device directly. And then they can get a real-time access to parameter properties of the equipment and locate the position of the broken equipment as well as other ones related to it precisely and directly. It is a good way to help operators deal with emergencies more conveniently and accurately, as shown in Fig. 4.

5. Conclusion

Drawings query and feedback system with smart hand-held devices makes an integrated use of technologies of BIM, computer aided engineering, mobile network, database and QR code. Based on IFC international standards, the real time obtaining and updating of drawing information is realized through the smart feedback system with hand-held devices. As a construction site information management platform, the system provides an efficient information access for constructors and guarantees the quality and safety of the construction process, which is especially suitable for large and complex projects.

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Adaptive forecasting in earthmoving operation using DES and site captured data

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Abstract

Most forecasting techniques for repetitive construction operations use deterministic approaches or stochastic approaches that are based on historical data of similar past projects. Utilizing such data impacts the accuracy of simulation results as it does not account for the unique characteristics of the construction operation being considered. This paper presents an automated tool for earthmoving operations that performs adaptive Discrete Event Simulation (DES) through utilizing actual captured data. Adaptation is curried out utilizing actual captured data from earthmoving operations to forecast productivity and consequently time and cost of these operations. The data was captured by GPS mounted on earthmoving hauling trucks then transferred wirelessly to a central server. A specially designed relational database was developed to store the captured data in addition to the characteristics of the earthmoving operation. The captured data implicitly accounts for factors that give rise to uncertainty such as weather. The durations captured for loading, hauling, dumping and returning activities are used to generate representative Probability Distribution Functions (PDF). Oracle Crystal Ball is utilized to generate best fit PDF for each cycle time components. DES is used to forecast fleet productivity and consequently the forecasted activity's duration and cost. In this research "StroboScope" DES engine was integrated with the relational database and Oracle Crystal Ball in standalone software. The developed tool can be used to detect the bottlenecks in the current operation. The developed automated tool is also used to experiment with different fleet configurations and its impact on forecasted time and cost.

Keyword: Earthmoving Operations, Discrete Event Simulation, GPS, Productivity, Forecasting

1. Introduction

Shannon (1998) defined simulations as "*The process of designing a model of a real system and conducting experiments on this model for the purpose of understanding the behavior of the system and/or evaluating various strategies for the operation of the system*". Simulation of construction operations allows construction planners and estimators to predict productivity and to evaluate construction operations before starting site work. Literature reveals considerable work on computer simulation for modeling repetitive cyclic operations (Zayed, and Halpin, 2001 and Marzouk and Moselhi 2004). Discrete Event Simulation (DES) method is the most famous type of simulation. It serves as a powerful tool in analyzing and breaking down complex problems. Consequently, it grabbed the biggest share of researchers' attention, focusing particularly on construction operations (AbouRizk, 2010).

DES models a system as a network of processes that are sometimes preceded by queues, where state changes occur at discrete points of time. In DES model, each unit flows through the system and reserves resources to complete a job. When, the job is accomplished, the unit releases those resources. Queues temporarily hold units in case resources are not readily available. These actions are called events (Hajjar and AbouRizk, 1999). Tremendous efforts have been exerted by many researchers in the construction field to model and simulate various construction operations. Halpin (1973) developed a powerful modeling element called CYCLONE, which simplified the simulation and modeling process for users with limited simulation background. CYCLONE was later used as a base for other simulation systems. In 1996, Martinez produced a more evolved simulation tool (STROBOSCOPE). This tool is capable of handling uncertainty not only in time, but also for different resource quantities. Once again, in 1999, Martinez and Ioannou developed the system (EZSTROBE). EZSTROBE's main objective was to reduce the complexity associated with their previous model (STROBOSCOPE).

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2. Background

Estimating actual productivity of construction jobsites is essential in forecasting time and cost required to complete construction operations with good accuracy (Oglesby et al, 1989). Recent advancements in automated site data acquisition technologies made it feasible to track and monitor construction operations in near real time (Navon and Goldschmidt, 2002, Caldas et al., 2006 and Montaser and Moselhi, 2012). GPS has been used in many aspects of construction operations such as collision avoidance of equipment, calculation of durations of earthmoving activities. As well, GPS was used to monitor the compaction level of various layers of road construction. The construction industry has already embraced the use of GPS in control of site surveying and earthmoving operations.

GPS can be used to track the location of workers and equipment over a wide range of geographic and geometric scales. The use of GPS for earthmoving operations has reportedly led to an increase of 22 % in productivity and 13 % in cost savings for short haul distance projects. However, for long haul distance, the advantages were less, a productivity increase of 5.57% and cost savings of 4.79% (Han et al 2006). Caldas et al. (2006) developed a system integrating GPS and GIS, in which GPS was used to record the position of pipe spools on a construction project. Moselhi and Alshibani (2008) presented a new model for the tracking and control of earth moving operations. Their model uses spatial technologies, including GPS and GIS, to facilitate automated data acquisition. Their proposed system is designed for highway construction projects.

Simulation of earthmoving operations allows construction planners and estimator's prediction and assessment of operations productivity (Halpin and Riggs 1992). The literature reveals considerable work on simulation for modeling earthmoving operation (Shi and AbouRizk 1995, Hajjar and AbouRizk 1999 and Marzouk and Moselhi 2003). Traditionally, simulation works through utilizing historical data in the form of statistical distributions to represent different processes. The highly dynamic environment of construction projects adds a sense of uniqueness to each project, which questions the validity of using historical data of other projects to represent a project at hand. Hence, there is a need for a method that puts together the capabilities of traditional modeling of construction operations and real time field data acquisition. Many researchers explored real time simulation, such as Guo et al. (2008) and Song et al. (2008). So far, most researchers focused their work on earthmoving construction operations (Montaser et al., 2011, Song and Eldin, 2012, Akhavian and Behzadan, 2012 and Vahdatikhaki et al., 2013).

Despite the advantages of computer simulation, it requires trained staff for model development and data entry, specialized simulation software and past historical data to generate operations probability distributions. In order to rectify the limitations of the current models, a new automated tool is developed. This paper presents automated tool that stochastically forecast productivity of earthmoving operations. The tool uses spatial technologies (GPS/GIS) for automated site data acquisition to measure actual performance. As well, it utilizes DES in forecasting module making use of captured data from GPS/GIS to take into account the uncertainty associated in the operation. This paper builds on earlier work and related developments made by the authors (Montaser et. al., 2011).

3. Research Methodology

The process of capturing earthmoving operations data starts by assigning GPS to the hauling truck. The assigned GPS reports the hauling truck exact location. Then, the data is transferred to the web server. The data is then processed automatically, without any human intervention, to calculate total cycle time for each truck and its respective loading, travel, dumping and return durations, for more details refer to (Montaser et. al., 2011). Truck characteristics and excavated soil properties are retrieved from the database to calculate the actual productivity of the hauling truck. Actual productivity is a function of hauling truck number of trips made at certain period, which requires calculating truck different cycle time durations. Consequently, calculating cycle time accurately is key element for estimating onsite actual productivity. Truck cycle time consists of four main components, which are loading, traveling, dumping and return. The loading time is the time that the truck is inside the loading area. Travel time is the time spent between exiting loading area until entering dumping area. Dumping time is the time that the truck is inside the dumping area. Return time is the time required for the truck to travel back from dumping area to loading area to start new cycle.

Most forecasting methods for repetitive cyclic construction operations use deterministic approaches or stochastic approaches but based on historical data of similar past projects. These methods did not consider uncertainty. Utilizing such data is an obstacle for accurately simulating the status of these operations on current projects. For example in case of earthmoving operations, the cycle time differs as the travel time of trucks can be affected by several dynamic factors, such as weather conditions, operating conditions in the excavation area and traffic on travel roads. Accordingly, Discrete Event Simulation (DES) is utilized in this research to forecast activity future performance. Therefore, the developed method demonstrates the stochastic value of hauling trucks captured data and uses the actual collected data of the elapsed periods. Since, this data naturally inherits in itself variables of stochastic nature such as weather. DES is used to forecast fleet productivity and consequently the forecasted activity's duration and cost. It is also used to experiment with different fleet configuration and its impact on forecasted time and cost. The captured data for loading, hauling, dumping and returning are used to generate representative Probability Distribution Functions (PDF). Those PDFs are used as an input for the DES model to evaluate the current operation and to highlight the performance bottlenecks and to experiment the fleet configuration if needed.

In addition, if the activity during the elapsed period experienced delay, corrective actions could be planned based on generating different fleet configurations using DES. This method is automated but requires human intervention in selecting different scenarios such as the number of excavators, hauling units and their capacity. It is built based on the interaction between the system and the central database where the past period cycles time and its component has been stored. Figure1 shows the method general flowchart, starting by generating the PDF for cycle time components from the captured data retrieved. PDF should be generated for each cycle time component (i.e. loading time, travel time and dumping time) that best fits the process including its associated parameters (e.g. mean value and standard deviation). The fitted functions are then used as an input for the simulation model to generate and evaluate different scenarios.

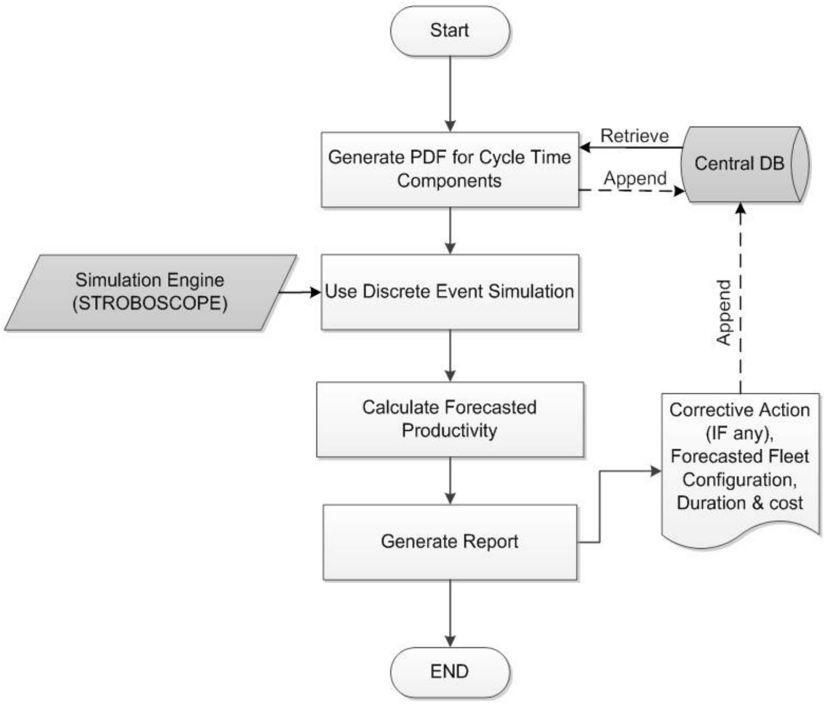

Figure 1. The process of stochastically forecasting productivity

In this research StroboScope discrete event simulation engine was utilized. Specially designed DES model for earthmoving operations is deployed as depicted in Figure 2. This DES model is a typical model and used for data manipulation and processing to calculate the stochastic forecasted productivity and to experiment different fleet configurations in case of any corrective action. The DES model retrieves the earthmoving operation data such as total quantity of earthwork, number of hauling trucks and excavators, hauling truck capacity and PDF for different cycle time components from the database. To facilitate data storage, fusion and processing a relational database was developed. The database has 9 entities; interconnected with one-to-many, many-to-one and many-to-many relationships. Due to space limitation, the Entity Relationship (ER) diagram is not included. The DES reports to the user the forecasted fleet productivity and its associated cost and time. The user interacts with the DES model to change the fleet configuration only. Then, different scenarios are generated for the user, which could help in time or cost optimization and making informed decisions.

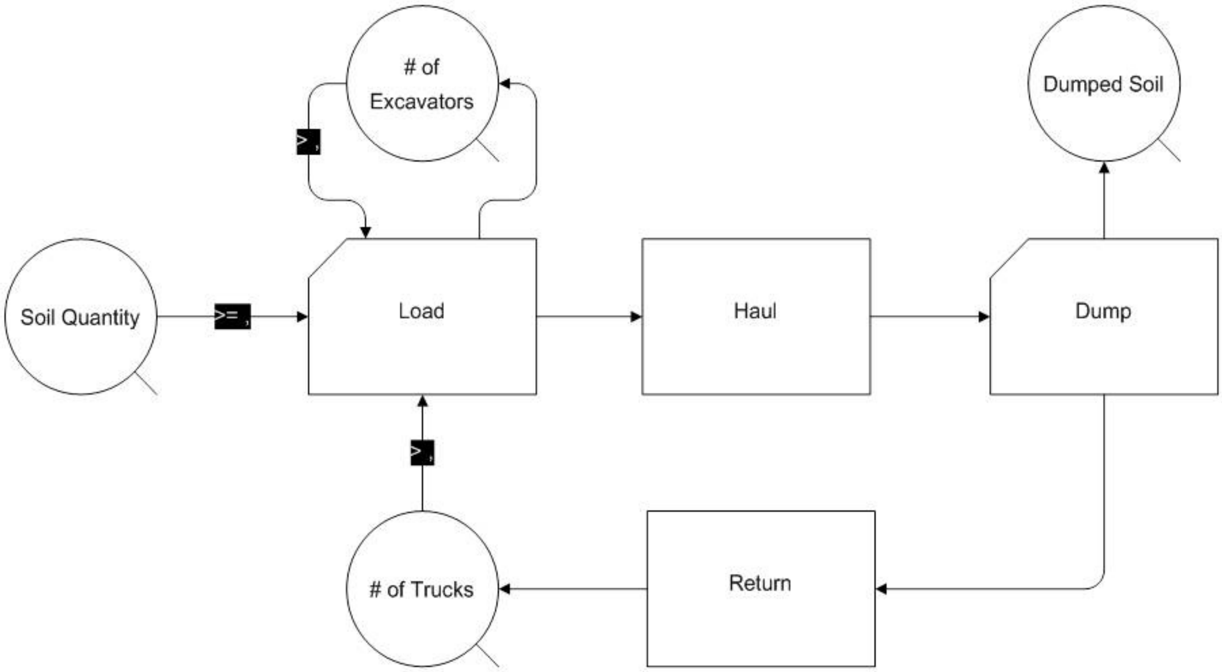

Figure 2. Specific purpose earthmoving operation DES model

The simulation model equations are as following:

- Excavator Idle Ratio = The time weighted average of the content of Excavator Queue / Number of Excavators
- Excavator Utilization = 1 – Excavator Idle Ratio
- Truck Idle Ratio = The time-weighted average of the content of Truck Queue / Number of Trucks
- Truck Utilization = 1 – Truck Idle Ratio
- Time of operation in hours = Simulation Time / 60
- Production rate (m3/hr) = The current content of Dumped Soil Queue / Time of operation in hours
- Total cost of operation = [Truck cost ($/hr) * Number of Trucks + Excavator cost ($/hr) * Number of Excavators] * Time of operation (hr)
- Unit cost ($/m3) = Total cost of operation / The current content of Dumped Soil Queue

DES requires Probability Density Function (PDF) for each operation. So, Oracle Crystal Ball was utilized to generate best fit PDF of the cyclic operations. Therefore, Stroboscope was integrated with Oracle Crystal Ball to stochastically forecast progress of earthmoving operations. In addition, this integration was used also to experiment the different fleet configuration impact on productivity, time and cost of the operation. The variables in the DES model are the number of hauling trucks, truck capacity, number of loaders, the quantity of remaining excavation, truck cost per hour and the loader cost per hour. The system retrieves all this data from the database. To generate PDF for each cycle time component, the user specifies the data range (i.e. start date and finish date). Then, the system extracts the cycle time components from the database and filters it to the specified data range. In addition, there is an option to exclude dates from this data range. This enables removing specific time periods during which exceptional conditions are known to have prevailed and are not likely to be repeated. Oracle Crystal Ball is utilized afterwards to generate best fit PDF for each cycle time component based on the captured data specified date range, as shown in Figure 3.

When the user presses simulation reporting, the results is send to an excel file on the user computer desktop. The results are the operation forecasted loader utilization, truck utilization, production rate, time, total cost and the unit cost of excavated material. Since, the forecasting process was done stochastically through PDFs. Then, the results is not crisp values, it is in the form of average, standard deviation, maximum and minimum values, as shown in Figure 3. In case, the user wants to experiment with the different fleet configuration but with the same PDFs. Then the user could enter the minimum and maximum number of trucks and loaders in the form. Similarly, the same procedure is followed but with different scenarios.

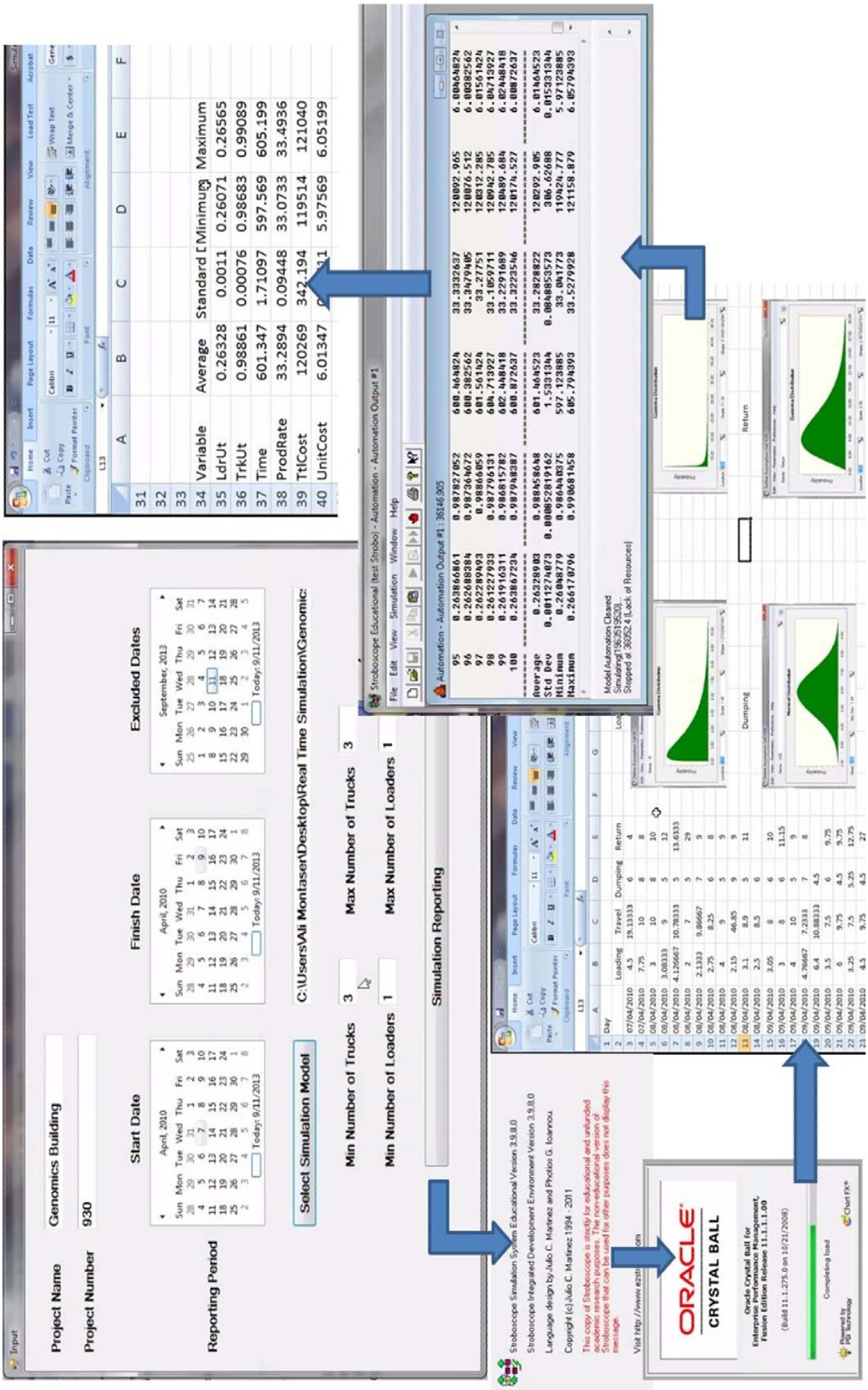

Figure 3. Stochastic forecasting overview

4. Conclusion

The present study demonstrated the significance of integrating GPS data with computer simulation for modeling earthmoving operations. It presents a practical and easy to use tool for estimating productivity of earthmoving operations The developed tool was used to model the earthmoving operations of a construction project in the west end of Montreal. The results of the analysis performed indicate how the presented automated tool can be helpful in facilitating timely corrective actions. This useful feature of the developed method can be attributed to its utilization of actual near-real-time data captured by GPS receivers, which supports timely corrective actions. The developed method can assist project teams in estimating realistic and more reliable productivity of earthmoving operations; accounting for factors such as weather and traffic conditions.

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Mathematical modeling of sediment transport in coastal waters on a multiprocessor computer system in problems of construction and modernization of ports

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Abstract

With the increasing anthropogenic load on the coastal shelf areas, the implementation of the concept of sustainable development is possible only with taking into account all factors that determine the coast state. Coastal dynamics and coastal bottom topography largely depend on the nature of sediment transport in the coastal zone under the influence of waves and currents. The necessity of simulation of such phenomena arises, for example, in the construction of new and modernization of existing ports. The article considers the unsteady spatially two-dimensional model of sediment transport in the coastal zone of reservoirs, taking into account the following physical parameters and processes: soil porosity , the critical shear stress at which sediment begins moving , turbulent exchange, dynamically changing geometry, and function of the elevation level, wind-induced flow, bottom friction. The software on a cluster of distributed computing for spatially two-dimensional and three-dimensional hydrodynamic coastal water model, and the model of suspended particle transport have been constructed and implemented. The results of numerical experiments have been given.

Keywords: Sustainable development of coastal shelf areas; distributed computing; mathematical modeling; multiprocessor computer system.

1. Introduction

Among great variety of natural phenomena, special place belongs to the processes, which take place in coastal waters due to their complexity, diversity and practical significance. With the increasing anthropogenic load on the coastal shelf areas, the implementation of the concept of sustainable development is feasible only if all the factors that determine the coast state are taken into account. Coastal dynamics and coastal bottom topography largely depend on the nature of sediment transport in coastal zone, which is influenced by waves and currents. In the process of topography transformation it is necessary to take into account the dynamics of bottom profile in coastal waters under the influence of waves. Relevant calculation methods are required in order to make reliable prediction of dynamic processes in coastal area. Mathematical modeling is currently becoming one of the most efficient research methods for actual hydrodynamic processes. Therefore, the subject of the given work, i.e. mathematical modeling for prediction of bottom profile formation due to sedimentation in coastal waters is highly relevant. Particularly, the damage to fisheries during repair-scooping into channel Podhodnyi to the docks of Arkhangelsk terminal has been calculated with using developed software.

2. The Task of Sediment Transport

To investigate the dynamics of sea sediment we use equations describing re-shaping of coastal areas where water and solid particles move in the same direction. The equations of sediment transport process can be written as follows (Leontiev, 2001):

$$(1-\varepsilon)\frac{\partial H}{\partial t}+\frac{\partial Q_x}{\partial x}+\frac{\partial Q_y}{\partial y}=0,\ \vec{Q}=\begin{cases}A\varpi d\left|\vec{\psi}\right|^{\beta-1}\vec{\psi}, & |\tau|\ge\tau_{bc},\\ 0, & |\tau|<\tau_{bc};\end{cases}\qquad \vec{\psi}=\frac{\vec{\tau}}{(\rho_1-\rho_0)gd}, \tag{1}$$

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where H represents the depth of the bottom measured if the surface is at rest; ε is soil porosity; $\vec{Q}=\{Q_x, Q_y\}$ – sediment discharge, $|\vec{Q}|=Q$; x, y – horizontal Cartesian coordinates; τ_b – bottom shear stress; τ_{bc} – critical shear stress, at which sediment movement begins, g – acceleration due to gravity, ρ – fluid density, A and β – nondimensional numbers (A equals to 19.5, β equals to 3), ϖ – wave frequency, d – sediment characteristics.

Shear stress for inclined bottom surface can thus be written as follows

$$\vec{\tau}=\vec{\tau}_b-\alpha\sin S\vec{n}, \tag{2}$$

where $S(x,y,t)$ represents the acute angle between normal vector to the bottom surface and vector of gravity force at a moment of time t, $\vec{n}$ is unitary vector, directed towards depth gradient, $\alpha\sin S$ is additional shear stress on the bottom caused by gravity forces.

The case $|\vec{\tau}_b|=0$, $|\vec{\tau}|=\tau_{bc}$ means that: $\tau_{bc}=\alpha\sin\varphi_0$, where φ_0 is the angle of natural soil slope in the water. Therefore, the system of equations for the Shields parameter is as follows:

$$\vec{\psi}_S=\frac{\vec{\tau}_b-\sin S\tau_{bc}\vec{n}/\sin\varphi_0}{(\rho_1-\rho_0)gd},\quad \vec{n}tgS=gradH, \tag{3}$$

where ψ_S is the Shields parameter for inclined bottom.

Considering the limitations of shear stresses on the bottom, the system of equations (1)-(3) goes as:

$$(1-\varepsilon)\frac{\partial H}{\partial t}+div\left(k\vec{\tau}_b\right)=div\left(kgradH\right),\; k=\frac{A\varpi d}{\left((\rho_1-\rho_0)gd\right)^{\beta}}\left|\vec{\tau}_b-\frac{\tau_{bc}}{\sin\varphi_0}gradH\right|^{\beta-1}h\left(\left|\vec{\tau}_b-\frac{\tau_{bc}}{\sin\varphi_0}gradH\right|-\tau_{bc}\right), \tag{4}$$

where $h(x)=\begin{cases}1, & x\ge 0\\ 0, & x<0\end{cases}$ represents the Heaviside function.

The equation (4) is complemented with the initial condition $H(x,y,0)=H_0(x,y)$. On the boundary of analyzed area, there is no flow caused by gravity forces: $H_0'(x,y)=0$.

3. Numerical Experiments on Bottom Transformation with the Use of 2D Hydrodynamic Model

The system of shallow water equations is used to describe water motion (Roache, 1998), (Vasiliev & Sukhinov, 2003), (Sukhinov, 2006), (Iakushev, Sukhinov, 2003). The equations of hydrodynamic model are:

$$\begin{aligned}
&\left((H+\xi)u\right)_t'=(H+\xi)uu_x'+(H+\xi)vu_y'=-g(H+\xi)\xi_x'+\left((H+\xi)\mu u_x'\right)_x'+\left((H+\xi)\mu u_y'\right)_y'+\frac{\tau_{x,p}}{\rho}-\frac{\tau_{x,b}}{\rho},\\
&\left((H+\xi)v\right)_t'+(H+\xi)uv_x'+(H+\xi)vv_y'=-g(H+\xi)\xi_y'+\left((H+\xi)\mu v_x'\right)_x'+\left((H+\xi)\mu v_y'\right)_y'+\frac{\tau_{y,p}}{\rho}-\frac{\tau_{y,b}}{\rho},\\
&\xi_t'+\left((H+\xi)u\right)_x'+\left((H+\xi)v\right)_y'=0,
\end{aligned} \tag{5}$$

where ξ is the level elevation, $V=\{u,v\}$ is the water velocity vector, μ is the turbulent exchange coefficient, τ_b and τ_p are the shear stresses on the surface and the bottom, H is the depth. The system (5) is considered at the following boundary conditions: $u_n'=0, v_n'=0, \xi_n'=0$, where n is the normal vector to the surface of computational area. The system takes into account turbulent exchange, bottom geometry, and wind currents and bottom friction.

Fig. 1 – 2 show the results of numerical experiments on simulating the dynamics of bottom topography change. Herein, the size of computational mesh is 200×200, mesh spacing for spatial variables is 0,1 *m*, time spacing is 0,01 *s*, wind speed is 5 *m/s* and is directed from left to right. **Fig. 1** illustrates the initial bottom topography (from below) and the position of free surface (from above).

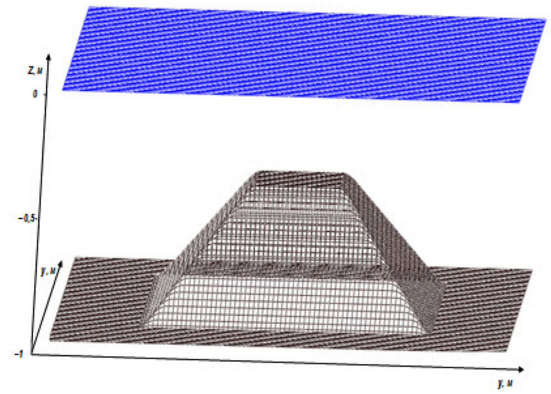

Figure 1. Initial bottom topography and position of free surface

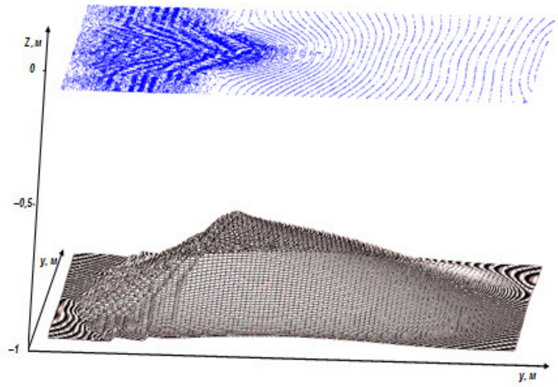

Figure 2. Bottom geometry and level elevation after 80 minutes

The simulation has shown that after 20 minutes, the bottom geometry starts to form a cone shape. Velocity has maximum in the peak part of the area (at minimal depths). The function of level elevation is positive in the left side of analyzed area (from windward side) and negative in the right side. After 40 minutes we can see that the function of level elevation has wavy shape not only in the left size but also in the areas with peak depth values. After 60 minutes oscillations of the level elevation function become more evident in its left part and in the area of peak depth. At the bottom of analyzed area the ripples are formed. After 80 minutes the area with peak depth values continues to shift leftwards, the area extends to the sides perpendicular to wind motion (**Fig. 2**). After 100 minutes the area with peak depth values continues shifting to the left, the area extends to the sides perpendicular to the wind motion, the level elevation function has clear oscillations from the windward side and the area also extends to the sides. The experiment results allow analyzing the dynamics of changes in bottom geometry, level elevation function, formation of wave structures and sediments. The given mathematical model and designed software complex allow to forecast the dynamics of bottom topography change, formation of sea ripples and shoals, their growth and transformation.

4. Modeling of Suspended Solids Movement

For this model we use Cartesian coordinate system in the horizontal plane and σ – coordinate system was used in the vertical direction (Ezer & Mellor, 2000): $\sigma=(z-\eta)/(h+\eta)$, $x_\sigma=x$, $y_\sigma=y$, $t_\sigma=t$, here $\sigma=a=0$ on the free surface, $\sigma=b=-1$ on the bottom; $H=h+\eta$ total depth to free surface, $h=h(x,y)$ is the depth of water body, $\eta=\eta(t,x,y)$ is the height of free surface with regard to geoid (sea level). For the description of suspended solids transport, we used the diffusion-convection-reaction equation, which can be written as follows:

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}+\frac{a-b}{H}(w-w_s)\frac{\partial C}{\partial\sigma}=\frac{\partial}{\partial x}\left(D_h\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_h\frac{\partial C}{\partial y}\right)+\left(\frac{a-b}{H}\right)^2\frac{\partial}{\partial\sigma}\left[D_v\frac{\partial C}{\partial\sigma}\right]+F$$

where C is the sediment concentration; $V=\{u,v,w\}$ are velocity vector; w_s is fall velocity or settling velocity of suspended solids in vertical direction; H is the depth; D_h, D_v are turbulent diffusion coefficients; x, y are horizontal coordinates; σ is coordinate in vertical direction; t is time; F describes the contamination sources. On the free surface Γ_s, the vertical direction flow equals to zero, thus: $\left(\frac{a-b}{H}\right)D_v\frac{\partial C}{\partial\sigma}+w_sC_k=0$. Near the bottom surface Γ_b: $\left(\frac{a-b}{H}\right)D_v\frac{\partial C}{\partial\sigma}=E-D+w_sC_k$, where E is erosion flow; D is the rate of sediment fall; C_k is the mass concentration of suspended solids n is the unit normal vector to the open boundary Γ_{open}.

$$D=\begin{cases}0, & \tau_b>\tau_{kr},\\ w_sC_k\left(1-\frac{\tau_b}{\tau_{kr}}\right), & \tau_b\le\tau_{kr};\end{cases}\qquad E=\begin{cases}0, & \tau_e<\tau_{krE},\\ M\left(\frac{\tau_e}{\tau_{krE}}-1\right), & \tau_e\ge\tau_{krE};\end{cases}$$

where τ is shear stress on the bottom; τ_{kr} represents the critical shear stress on the bottom which is evaluated on the basis of lab tests as a value with magnitudes from 0.05 to 0.15 [N/ m^2].

5. 3D Hydrodynamic Model

Consider the continuity model of hydrodynamics in water body:

– Navier-Stokes equation (Reynolds):

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+\frac{a-b}{H}w\frac{\partial u}{\partial \sigma}=-\frac{P'_x}{\rho}+\frac{\partial}{\partial x}\left(D_h\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_h\frac{\partial C}{\partial y}\right)+\left(\frac{a-b}{H}\right)^2\frac{\partial}{\partial \sigma}\left[D_v\frac{\partial C}{\partial \sigma}\right],$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+\frac{a-b}{H}w\frac{\partial v}{\partial \sigma}=-\frac{P'_y}{\rho}+\frac{\partial}{\partial x}\left(D_h\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_h\frac{\partial v}{\partial y}\right)+\left(\frac{a-b}{H}\right)^2\frac{\partial}{\partial \sigma}\left[D_v\frac{\partial v}{\partial \sigma}\right],$$

$$\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+\frac{a-b}{H}w\frac{\partial w}{\partial \sigma}=-\frac{P'_\sigma}{\rho}+\frac{\partial}{\partial x}\left(D_h\frac{\partial w}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_h\frac{\partial w}{\partial y}\right)+\left(\frac{a-b}{H}\right)^2\frac{\partial}{\partial \sigma}\left[D_v\frac{\partial w}{\partial \sigma}\right],$$

– Continuity equation:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{a-b}{H}\frac{\partial w}{\partial \sigma}=0,$$

– Total hydrodynamic pressure is related to the depth as

$$P(x,y,z,t)=p(x,y,z,t)+\rho g(z-\eta).$$

For the equations, the following boundary conditions are assumed: $V'_n=0$ and $p'_n=\rho\Pi/\tau S$ for side boundary where the source is set; $V'_n=0$ and $p'_n=0$ for side boundary without a source; $V'_n=0,\quad p=0$ for output side boundary; $\rho D_h(u')_n=-\tau_x(t)$, $\rho D_h(v')_n=-\tau_y(t)$, $w=0$, and $p'_n=0$ for lower boundary; $\rho D_h(u')_n=-\tau_x(t)$, $\rho D_h(v')_n=-\tau_y(t)$, $w=-p'_t/\rho g$, and $p'_n=0$ for upper boundary: water surface. Where Π is the flow rate of velocity through the surface; S is surface area; $\tau_x(x,y,\sigma),\tau_y(x,y,\sigma)$ are the shear stress components; $V=\{u,v,w\}$ is velocity vector; g is acceleration due to gravity; P is pressure; D_h is horizontal turbulent exchange coefficient; D_v is vertical exchange coefficient; ρ is the density. The components of shear stress for free surface are: $\tau_x=\rho_a C_p(|\vec{w}|)w_x|\vec{w}|$, $\tau_y=\rho_a C_p(|\vec{w}|)w_y|\vec{w}|$, where $\vec{w}$ is the vector of wind speed with regard to water; ρ_a is the density of air, C_p – is dimensionless coefficient. The components of shear stress on the bottom are $\tau_x=\rho C_p(|\vec{V}|)u|\vec{V}|$, $\tau_y=\rho C_p(|\vec{V}|)v|\vec{V}|$. The coefficient of vertical turbulent mixing, which is non-homogeneous in terms of depth, calculates through measured velocity oscillations: $\nu=C_s^2\Delta^2\sqrt{\left(\partial\overline{U}/\partial z\right)^2+\left(\partial\overline{V}/\partial z\right)^2}\;/2$, where $\overline{U}$, $\overline{V}$ are time-averaged oscillations of horizontal velocities, Δ is the characteristic mesh spacing, C_s is dimensionless empirical constant, which can be defined through the attenuation process of homogeneous isotropic turbulence.

6. Solution method for discrete equations

Discrete equations obtained from finite-difference approximation can be written in form $Ax=f$, where A is a linear, positive definite operator ($A>0$). We use the implicit iterative process (Samarskij, Matus., & Vabiščevič, 2002):

$$B\frac{x^{m+1}-x^m}{\tau_{m+1}}+Ax^m=f,$$

where m represents the iteration index, $\tau>0$ is the iteration parameter, and B is some reversible operator, which is called preconditioner or stabilizer. To find B we work on additive assumption about operator A_0 , which is the symmetrical part of operator A: $A_0=R_1+R_2$, $R_1=R_2^*$, where $A=A_0+A_1$, $A_0=A_0^*$, $A_1=-A_1^*$. So, operator-preconditioner can be written as $B=(D+\omega R_1)D^{-1}(D+\omega R_2)$, $D=D^*>0$, $\omega>0$, where D is some operator. The operators R_1, R_2 are defined and ways to determine parameters τ_{m+1} , ω and operator D are indicated (Sukhinov, 2005).

Algorithm of adaptive modified alternating-triangular method of minimal corrections for calculating discrete equations with non-self-adjoint operator can be written as follows (Konovalov, 2002), (Sukhinov, Chistyakov, Timofeeva, Sheshenya, 2012):

$$r^m = Ax^m - f\ ,\ B(\omega_m)w^m = r^m\ ,\ \tilde{\omega}_m = \sqrt{\frac{\left(Dw^m, w^m\right)}{\left(D^{-1}R_2w^m, R_2w^m\right)}}\ ,\ {s_m}^2 = 1-\frac{\left(A_0w^m, w^m\right)^2}{\left(B^{-1}A_0w^m, A_0w^m\right)\left(Bw^m, w^m\right)}\ ,$$

$$k_m = \frac{\left(B^{-1}A_1w^m, A_1w^m\right)}{\left(B^{-1}A_0w^m, A_0w^m\right)}\ ,\ \theta_m = \frac{1-\sqrt{{s_m}^2k_m/\left(1+k_m\right)}}{1+k_m\left(1-{s_m}^2\right)}\ ,\ \tau_{m+1} = \frac{\theta_m\left(A_0w^m, w^m\right)}{\left(B^{-1}A_0w^m, A_0w^m\right)}\ ,\ x^{m+1} = x^m - \tau_{m+1}w^m\ ,$$

$$\omega_{m+1} = \tilde{\omega}_m\ ,$$

where r^m is the error vector, w^m is the correction vector, the diagonal part of operator A is used as operator D.

The algorithm of adaptive alternating-triangular method is performed by multiprocessor computer system (MBC) ROTs NIT SFU. (Sukhinov, Chistyakov, & Bondarenko, Iu., 2011), (Debol'skaya, Yakushev, & Sukhinov, 2005), (Alekseenko, Roux, Sukhinov, Kotarba, & Fougere, 2013). Peak capacity of MBC is 18.8 TFlops. MBC includes 8 computer racks. Computational field of MBC is built on the basis of infrastructure HP BladeSystem c-class with integrated communication modules, power supply and cooling systems. As comutational nodes here are used 128 16-core Blade-servers of the same type HP ProLiant BL685c, each of them being equipped with four 4-core processors AMD Opteron 8356 2.3GHz and Random Access Memory of 32GB. Total amount of computational cores is 2048, total RAM capacity is 4 TB.

7. Example of practical application of software complex for calculating bottom surface transformation during dredging works

On the basis of the complex developed for MBC, the calculation has been performed to assess the damages to fishing industry during maintenance dredging of entrance waterway to the docks of Arkhangelsk terminal. Dredging works in the entrance waterway are performed by a trailing suction dredger of ZS-TR 1300/2-2162 type, in the water zone of terminal docks the works are done by a grab dredger (crane barge). In terms of dredge spoils the equipment capacity is 122.4 m^3/h for grab dredger and 778 m^3/h for trailing suction dredger. Characteristics of trailing suction dredger of ZS-TR 1300/2-2162 type: hopper volume at sand dredging is 1000 m^3; loading capacity of the hopper is 741 $м^3$; duration of dredge spoils disposal on a dimp site is 0.1 h. Characteristics of grab dredger (clamshell): transportation of dredge spoil to the underwater dump site is performed by 2 dump scows of ShS-TR500/2-442 type with hopper volume - 500 m^3; loading capacity of the hopper with dredge spoils is 455 m^3. We performed modeling of suspended solids distribution during disposal of dredge spoils from the hopper of trailing suction dredger to the dump site.

The initial data is as follows: water depth - 10 m; loading capacity - 741 m^3; flow velocity is 0.2 m/s; settling velocity 2.042 mm/s; soil porosity 1600 kg/m^3; percentage of silt particles (d less than 0.05 mm) in sandy soil — 26.83%. Characteristics of computational domain are as follows: length – 3 km, width — 1.4 km; spacing in the horizontal spatial coordinate is 20 m; spacing in the vertical spatial coordinate is 1 m; assumed interval - 2 hours. **Fig. 3** shows the result of calculating the profile of horizontal water velocity vector. **Fig. 4** illustrates correlations between time (hour) and water volumes (mln. m^3) with the following content of suspended solids (1 has more than 100 mg/l, 2 has more than 20 mg/l, 3 has more than 0.75 mg/l). The experiment results allow analyzing the dynamics of bottom geography change, formation of ripples and sediments, transfer of suspended solids in water area as well as the level of water pollution. 2D mathematical model of sediment transport in shallow waters has been developed in line with the basic conservation laws. It takes into account two spatial variables and the following physical parameters and processes: soil porosity, the critical shear stress at which sediment begins to move, turbulent exchange, dynamically changing bottom geometry and the function of level elevation, wind-induced flow and bottom friction. The given work describes the software complexes and results of their implementation, using sediment transport models in coastal waters. To calculate velocities, 2D and 3D models have been used.

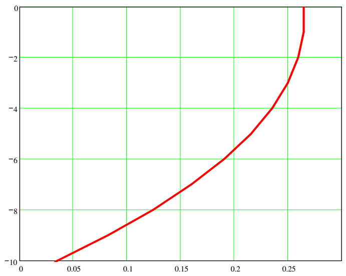

Figure 3. Profile of water velocity vector

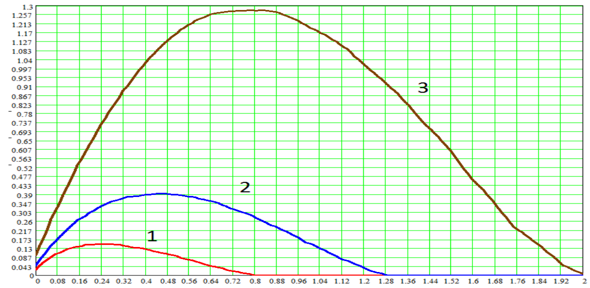

Figure 4. Correlations between time and water volumes (mln. m^3) with the following content of suspended solids: 1- has more than 100 mg/l, 2- has more than 20 mg/l, 3- has more than 0,75 mg/l

The damage to fisheries during repair-scooping into channel Podhodnyi to the docks Arkhangelsk terminal has been calculated with using developed software (Debol'skaya, Yakushev, & Sukhinov, 2005), (Alekseenko, Roux, Sukhinov, Kotarba, & Fougere, 2013). Total damage from the production dredging consists of the following losses: death of benthic feeding organisms on the area of dredging and silting area; ichthyomass shortfall as a result of loss of ichthyoplankton and planktonic food organisms during work hydromechanized equipment; death of aquatic organisms in an area of high turbidity during stacking soils.

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Optimum utilization of fly ash for achievement of ordinary concrete C 25/30 – comparison of results using Kosovo's and Japan's fly ash

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Abstract

Coal fly ashes discharged from coal-fired plants and it is expected to use it in industrial world. However, it's known that fly ash highly resembles cement properties, in its chemical and physical composition but depending on content of CaO in fly ash there is a difference in hydration process of the concrete mixtures. In light of this fact, this study intended to develop further. So, the objective of this research is to investigate using of fly ash, with different content of CaO, in producing concrete by replacing cement in different percentage until finding the optimum utilization of this industrial waste in ordinary concrete C 25/30. The research conducts fly ash engineering properties, basic chemical and physical properties, strength test of concrete samples for various contents of fly ash and comparing achieved results by using fly ash produced in Kosovo as high CaO content and in Japan as low CaO content. All results are based on experimental tests according to EN 206-1, JIS A 1204, JIS A 1202 and entire work took place in concrete laboratory in Kosovo and in Japan. To develop this research more than 250 concrete samples have been prepared in both countries and they are tested in different period of time, after: 3, 7, 21, 28, 56 and 90 days to find the compressive strength.
Based on results of this test, benefit of partial substitution of cement by industrial waste, such as fly ash is not only economical but also improves the properties of fresh and hardened concrete besides safe disposal of waste material thereby protecting the environment from pollution by reducing emitting of chromium VI.

Keywords: chemical analyses, comparison, compresive strength, fly ash, optimization.

1. Introduction

Coal fly ash is the combustion residue in electrical power plant after process of producing electrical energy. This substance content aluminosilicate glass modified by the presence of large amounts of calcium and magnesium. [1] These ashes is major part of all remnant after producing energy and it can be categorized as high –calcium fly ash (FH) when CaO is greater than 20%, middle-calcium content (FM) when CaO is between (10 and 20) % and if content of CaO is less than 10% than fly ash is considered as the one with low content of CaO (FL). [2]

In Kosovo, current electricity production and its generation is depended largely based on coal burning power plants. Currently 97% of electrical energy is produced only from coal, and based on reserves of this mine and the situation of other resources it seems that for long time coal will be the only source of energy. [3]

On the other hand in Japan, rapid industrial growth impact on increase consumption of energy. At 1976, with only 3% of the world's population Japan was consuming 6% of global energy supplies. Resources of producing energy were different, but main one was nuclear energy until 2011 when earthquake and tsunami has damaged some nuclear reactors, causing much uncertainty and fear about release of radioactive material. Afterward, focus was in fire plants and as a main resource is considered coal. [4]

Based on situation of both countries, amount of coal fly ash is going to increase constantly in coming years. In addition, storage of fly ash in landfills or dumping in water will effect in environment pollution meanwhile this has to be realized at a considerable price. Therefore, saving energy, recycling waste material, developing environmentally friendly technology, high cost of cement, increasing quality of concrete are some of reasons why in many researches fly ash is recommended to utilize as cement replacement in producing concrete but the literature is rich in publication regarding the effect of fly ashes, especially of low-calcium fly ash (FL) on concrete [5-10]. Whereas the use of FL in concrete is common practice, FH suitability for concrete is still

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anticipated with skepticism [11]. This is regarding to chemical composition. High free of CaO and sulfur content can react with water and form calcium hydroxide-pozzolanic process; consequently, it affect in almost doubling its volume. This process will contribute in risk of stability and durability of concrete. Meanwhile, this pozzolanic process reactions leads to reduce high temperature of hydration process and high impermeable denser concrete, thus increasing its compressive strength and compactness of mass. [12-14].

That's the main relevance of investigation of Kosovo fly ash as high-calcium (KFH) content and Japanese fly ash as low-calcium (JFL) content and finding out the difference between the effect of FH and FL in strength for ordinary concrete C25/30.

The dosage of substituent of fly ash in binder material, respectively in cement, depends from variety of conditions: engineering applications, different curing conditions, quality of components of concrete including fly ash, exposure of concrete in different environments etc. As example, based on different research for reinforced and prestressed concrete, amount of content of fly ash is supposed to be 25% until 30% on ratio of fly ash-binder. [15] For underground concrete amount of fly ash can be from 50% until 70% for roller compacted concrete [11]. But, still it is not fixed exactly. Amount of fly ash content in concrete depended firstly from its fundamental properties which can change depends on mine, area, working process of power plant, etc.

In this paper, an experimental investigation of the activity of FH and FL in concrete is carried out, and first approach of comparison of CaO effect in strength of concrete is presented. Aim of this research was to find optimum percentage of FH and FL to replace cement for achieving ordinary concrete C25/30. Percentages of cement replacement will be various from 10%, 15% until 50% which is considered as high volume fly ash. Another aim is to find out if the percentage of chromium VI will reduce after mixing fly ash with concrete components.

2. Materials used in the investigation

2.1. Cement

Conducting experiment in two cases, Japan's cement (JC) and Kosovo's cement (KC), were used Portland cement PC 20M (S-L) 42.5R, which conforms to the current specifications as described in Sl. List SFRJ no. 34/85 and 67/86. Their chemical compositions are given in table 1. The Specific gravity for JC and KC were 3.15 respectively 3.05 g/cm³ while specific surface areas were 3360 and 4140 cm²/g.

2.2. Fly ash

In Japanese case used fly ash was taken from the dump of HitachiNaka power plant, in Ibaraki prefecture. In Kosovo case fly ash was discharged directly from power plant Kosova B, in Obiliq near Prishtina. According ASTM C618 [8] Japanese fly ash (JFL) is classified as low calcium and is obtained from bituminous coal while Kosovo's fly ash (KFH) is classified as high calcium content since is obtained from lignite coal. The chemical composition and physical properties are given in table 1 and 2. The specific gravity for JFL and KFH are 2.10 respectively 2.83 g/cm³ and specific surface areas were 2950, 6600 cm²/g in the same respect.

Based on standard specification ASTM C618 [16] depends on chemical compositions fly ash is divided in two classes: class F – SAF>70% and class C- SAF>50%. So, JFL belongs to the class F since its SAF is 89.44% while KFH does not belong to any of these classes, because its (SiO_2 + Al_2O_3 + Fe_2O_3) is only 29.8%. ASTM [16], BSI [18] and EN [17] restricted content of the SO_3 content in fly ash 5%, 2.5% and 3.0%, in this situation JFL satisfy this criterion but KFH failed. Also MgO content is restricted by ASTM [16] and BSI [18] in 5% respectively 4% and this requirement were satisfied from both fly ashes.

Remains of fly ash in sieve of 0.200 mm, which is considered an indication of fineness for JFL and KFH, were 28% respectively 25.6%. This amount is restricted by EN [17], ASTM [16] and BSI [18] should not be greater than 40%, 34% and 22.5%. Both fly ashes satisfied standards [12, 14] and both of them failed BSI [18]. Other important criterion is loss in ignition (LOI) and its value was restricted by standards too. In ASTM [16], BSI [18] and EN [17] the maximum of LOI was allowed to be 12%, 7% and 5%. LOI of JFL and KFH were 4.27% respectively 2.30%, so this criterion was satisfied from both fly ashes.

Table 1. Chemical composition of cement and fly ash

Elements	JC	KC	JFL	KFH
SiO_2 %	21.55	19.79	69.35	19.28
Al_2O_3 %	5.23	6.13	16.37	5.67
Fe_2O_3 %	2.88	2.73	3.72	4.85
CaO %	64.82	63.86	3.02	42.92
MgO %	1.19	2.42	0.57	4.31
SO_3 %	2.07	2.98	0.29	19.41
Na_2O %	0.64	0.19	1.50	0.58
K_2O %		0.68	1.05	0.36
MnO %			0.045	0.08
LOI %	0.53	4.14	4.27	2.30
Chromium VI mg/l			0.037	0.395
Moisture 105˚C %			0.06	0.29
CO_2 %			0.71	0.70
Insoluble residue in HCL/Na_2CO_3 %			88.85	11.05
Insoluble residue HCl/KOH %			30.43	6.58
Reactive CaO %			1.91	28.44
Reactive SiO_2 %			43.23	15.69

Table 2. Physical properties of fly ash

Fineness	JFL	KFH
• 0.200 mm	0.0	0.1
• 0.090 mm	4.0	4.9
• 0.063 mm	8.0	8.1
• 0.043 mm	16.0	12.5
Capacity mass g/cm³	2.10	2.83
Specific surface cm²/g	2950	6600
Pozzolanity MPa		
• Flexural	2.9±0.4	4.5±0.3
• Compressive	6.5±0.2	21.1±0.7

However fly ash contain trace amount of the toxic substances, one of them is chromium VI. After fly ash leaching test according to standard JLT-46 amount of chromium VI was proved and JFL content 0.037 mg/l while KFH content 0.395 mg/l. The results express that KFH content big concentration of this substance; around eight times more than Kyoto protocol allow it. Well, only disposal of coal fly ash in landfills or in water enables easy emission of this harmful substance into the environment.

2.3. Aggregate

Conducting this experiment were used crushed-clean aggregates in both cases but with some differences in compositions.

Japanese aggregate (JA) – was divided in two fractions; fraction I (0-5) mm or sand and II (5-15) mm. Composition of these two fractions in concrete was 45% and 55%. Absorption value for sand was 1.3% while for aggregate was 0.6%.

Kosovo aggregate (KA) – was divided in three fractions; fraction I (0-4) mm or sand, fraction II (4-8) mm and the third (8-16) mm. Composition of them in concrete was with 45%, 22% respectively 33%.Absorption value of sand was 1.1% while for aggregate was 0.7%.

3. Mixture proportions and experimental program

In this study two different fly ashes were used JFL and KFH. The amount of them change in different mix design, starting from 0% for control concrete until 50%, in function of cement content, which can considered as high volume fly ash. Proportions of other components for control concrete mixtures were around 1:2.3:3 for cement, sand and aggregate respectively, and the quantities of cement in two cases were 340 kg/m³.

To develop further this experiment first important step was to determine water content; for the control concrete ratio w/c was 0.62% and it continue around this value for all other mix designs, considering w/ (cement + fly ash). The focus was to reach quality of fresh concrete conform curve S3 based on European standards, where the slump is determined to be in between (10–15) cm. The values of slump test measurements are given in table 3 and, in the same table it's included also concrete mixture composition produced and tested. In Japanese case six different mix designs (M1-M6) were prepared including control design underwent in testing procedures, in Kosovo case eight different mix design (M7-M14) were prepared. In both cases the main objective was changing percentage of cement replacement with fly ash from 10%, 15%, 20%,...and finding effect of high and low content of CaO in concrete meanwhile determining correlation with class C25/30 of concrete.

Table 3. Mixture proportions for 1m³ of three types of mix design

Materials	M1/M7	M2/M8	M3/M9	M4/M10	M5/M11	M6/M12	M13	M14
Cement (kg)	340	306	298	272	255	238	204	170
Fly ash (kg)	0	34	51	68	85	102	136	170
Sand (kg)	791	787	784	782	780	777	779	780
Gravel (kg)	968	961	958	956	953	950	952	953
Water (kg)	211	211	211	211	211	211	211	211
W/C ratio	0.62	0.61	0.66	0.65	0.65	0.66	0.64	0.65
Slump (cm)	12	15	12	13	14	14	13	13.5

After casting of concrete specimens, next step was vibration until complete compaction was obtained, and for 24 h samples were stored in laboratory environment, demolded and then curing regime was under constant temperature (20-22) ºC and in 99% humidity environment until examination day.

It must be emphasized that to reach results of compressive strength of concrete was applied European standard EN 206-1. In Japan case there have been prepared (10 x 20) cm cylinder samples, while in Kosovo case were used cubic samples (15 x 15 x15) cm and each value was average of minimum three results from different samples in different period of time (after 3, 7, 21, 28, 56 and 90 days).

4. Results and discussion

4.1. Properties of fresh concrete

During conducting experiment in all mix designs (from M1 until M14) was recognized good workability and it was measured by slump which varied between 12 and 15 cm. The spherical geometry of the fly ash particles contributes to gain more compact, fluid and sticky mas of fresh concrete by reducing the friction at the aggregate paste interface perhaps was produced a ball-effect at the point of aggregate contact. [16] It was not observed any segregation that occurred in any of the mixes produced. The mixtures were stable and they did not bleed. These properties of fresh concrete were increased in proportion of increasing the content of fly ash in comparison of concrete with pure cement, while ratio water/cementitious for all mixtures was in the range of 0.62 ± 0.04 (see table 3).

4.2. Strength results

In tab 4, the compressive strength results from all tested mortars are presented. The data's show that the strength of concrete decreases with increasing of fly ash content, this happen at early ages in all mixing designs and in both cases. Including of 30% of fly ash as cement replacement causes reduction of concrete strength at 3 days for 81 and 34% respectively, as compared to the concrete with pure cement. At 28 days cylinders/cube strength for 30% replacement of cement also decrease the strength about 56 and 8.5% respectively, as compared to the control concrete. Strength reduction in 56 days was lower as compared to that of early age's values. In Japan case (JFL) strength reduction was 50% while in Kosovo case (KFH) was only 5%. Similarly, at 90 days strength of concrete samples for 30% fly ash replacement, Japan case strength is still low 23.6MPa, meanwhile in Kosovo case the strength value of sample is higher than control concrete for around 4%.

Table 4. Case 1 and 2 - compressive strength (MPa) for ordinary concrete C 25/30
Case 1. Compressive strength (MPa) for ordinary concrete C 25/30

Age	M1	M2	M3	M4	M5	M6
3 Day	22.3	14.7	10.9	12.1	5.5	4.1
7 Day	27.5	18.0	14.6	17.2	10.2	5.9
21 Day	39.4	22.2	21.0	17.2	17.9	15.8
28 Day	41.9	25.2	23.1	18.9	17.3	18.1
56 Day	45.3	38.1	31.3	32.0	23.7	22.4
90 Day	48.2	39.8	33.5	34.1	25.8	23.6

Case 2. Compressive strength (MPa) for ordinary concrete C 25/30

Age	M7	M8	M9	M10	M11	M12	M13	M14
3 Day	20.8	18.8	18.2	13.7	13.4	13.2	5.7	2.5
7 Day	28.6	28.7	24.9	20.0	17.1	16.8	8.7	5.3
21 Day	38.0	37.7	34.6	34.1	32.0	27.0	14.4	9.8
28 Day	38.3	40.7	35.5	37.7	36.2	35.1	16.5	13.2
56 Day	41.7	44.7	46.2	44.5	44.5	40.0	21.1	19.5
90 Day	43.4	48.9	47.6	46.8	46.3	45.1	36.2	30.1

However, the rate of strength gained during period of 90 days is 36 and 38% respectively. It seems that for this time the strength was increased around same value, more than 35% in both cases, but the difference was that since in the early ages with Japanese coal fly ash strength of concrete was lower compared to the samples with Kosovo coal fly ash, afterwards this increase continue in linear way, even that JFL satisfy almost all criteria of ASTM [16], BSI [18] and EN [17].

After results of M12, it was proved that substituting of cement with KFH until 30% in period of 90 days strength can exceed value of concrete with pure cement, has served as motive to develop further the same experiment with more amount of fly ash content until 50%-high volume fly ash concrete. At early ages, results were very low but they increased by time and at 90 days M13-40% content of KFH were 36.2MPa and M14-50% content of KFH was 30.1MPa, it is expected to reach the value of control concrete in long term examination.

Results in both cases shows that fly ash have effect to delay hardening on strength of concrete, but based in expression fcm=fck+8 (MPa) quality of concrete C 25/30 was reached with mix design M4 – 20% content of JFL and M12 – 30% content of KFH at ages of 56 days old.

The big difference in results comparing Japan case and Kosovo case has happen because of chemical composition and physical properties of JFL and KFH. First reason it's supposed to be high content of CaO, especially reactive CaO in KFH until 28.44% compare to 1.91% of reactive CaO in JFL, which is known as fundamental substance to come of pozzolanic process of fly ash. And second reason can be specific surface of KFH which is more than double compare to JFL, 6 600, 2 950 cm^2/g respectively. It seems the bigger specific surface allow easily to develop pozzolanic process.

5. Conclusions

From the experimental work carried out and the analysis of the results following conclusions apparently are valid in utilization of FH and FL as concrete component.

- Use of fly ash in concrete improves workability of fresh concrete. By increasing of fly ash content the workability increase too. Bleeding in fly ash concrete was reduced significantly and other properties like surface finish area, cohesiveness is improved.
- Results proved that it is possible to achieve ordinary concrete C 25/30 by replacing cement with FH/Fl and the simple optimum percentage of substituting is proposed, but the study showed that the efficiency factor is not constant; it depends in different parameters, including curing time, chemical and physical properties of fly ash, replacement ratio, etc.
- Quantity of CaO in the fly ash can determine the course of hydration and influence the strength of concrete.
- The compressive strength in both cases at early ages was low for all mixtures, but it continues to develop in time, and it present like linear increase. Based on some results, after long term examination

the some mix design with FH content can reach and even exceed the value of concrete with pure cement.

- According to this middle time examination replacement of cement with more than 30% with KFH and more than 20% of JFL will indicate to develop moderate strength in concrete. However, it becomes a possible alternative to use for application of lean concrete, subbase, etc.

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Development of a first prototype of a liquid-shaded dynamic glazed facade for buildings

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Abstract

This paper will report on the development of a prototype of actively controlled facade module, which is capable of adapting its solar transmittance to changeable solar gains. Hence this new facade offers additional features with respect to the most popular currently used glass facades, which have fixed solar transmittance indeed. The novel technology is made possible by the creation of an additional 1.5-mm-thick sliding shielding liquid, which flows internally, in order to dynamically adapt the window's solar transmittance. As compared with competitive technologies, this shielding system has low manufacturing costs, is durable, is completely reversible and always transparent, irrespective of its transmittance state. Specifically, the manufacture of a full size window prototype and the engineering of the window was carried out; moreover, glass pane bending when subject to hydrostatic pressure was eventually assessed. All this information has been used to set up the industrial process needed for its manufacturing.

Keywords: active solar control, liquid shading window, smart buildings.

1. Introduction and scientific background

The careful use of energy in buildings is becoming increasingly important as they are responsible for a great percentage of the total energy consumed. Windows and glazed facades strongly influence energy consumption due to lighting, cooling and heating. Considering that energy requirements generally vary over the four seasons, the same solar gains, which must be shielded in summer, should be maximized in winter, as they balance some of the heat losses and reduce the burden of the heating system.

Traditionally, shading systems are classified according to their position in relation to the glass: external shading, internal shading devices and integral (between-glass) shading systems [ASHRAE, 2001]. Some options for external shading are roof overhangs, awnings, exterior louvers, shading screens. Internal and integrated devices include venetian blinds or shading rollers, located inside glass panes or in the air gap of double or triple glass stratifications. In addition, glass coatings that can modify the optical and thermal properties of glass are generally adopted. Relevant examples, which are also being widely marketed, are solar-control and low-emission glass stratifications. Successful installations have demonstrated their high reliability, although their thermal and optical parameters cannot be varied dynamically. The use of switchable windows may determine day lighting control, which allows major energy saving and reduction of glare discomfort [Lee et al., 2006] [Piccolo et al., 2009]. Electrochromic windows vary their optical and thermal properties due to the action of an electric field and change back again when the field is reversed [Papaefthimiou et al., 2006]. These windows run on very low voltage (1–3 V) and require energy only to change their condition, but not to hold any particular state. However electrochromic glazing for architectural applications is not able to reach a lifetime longer than 20 years, according to a number of aging tests, due to fast degradation under cycling. In addition, there have been a few indications of decomposition and delamination of some electrochromic glass prototypes owing to UV radiation [Wilson, 2003]. Another drawback is given by the high manufacturing costs of large electrochromic glass panes [Heusing et al., 2006]. Liquid crystal switchable glazing is controlled electronically, too [Nitz & Hartwig, 2005]. This laminated unit contains two PVB films enclosing a thin film encasing tiny liquid crystals, and wired to a power supply. When there is no power to the glazing, light is diffused in all directions. When an electric current is applied between the two conductive coatings, light passes through it relatively unobstructed. Although useful for privacy control, liquid crystal glazing does not provide energy filtering. Inserting silica aerogel granules through an automated and reversible mechanical device between glass panes, combines a very low U-value with a high visual transmittance [Reim et al., 2005]. However this method prevents transparency and it is not completely reversible, because aerogel granules leave powder inside glass cavity when they are removed to rise U-value or improve visibility. Inserting Phase Change Materials (PCM) between glass panes was shown to

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perform better as a passive technology than absorbing gases filling air gaps [Ismail et al., 2008]. More complex stratifications of a different kind for active windows have also been presented, made up of three layers and two cavities: the first ventilated with air and the second shaded with Venetian blinds [Lollini et al., 2010], leading to load reductions higher than 30%. In addition, water-flow windows, hosting a stream of water flowing upwards within the space between two glass panes, have been presented. A numerical study estimated water-flow windows to be advisable for temperate climates where there are no extreme outdoor conditions [Chow et al., 2011].

This paper reports a new technology, currently being developed, which integrates a switchable liquid shielding system in order to make windows and glazed facades dynamically adaptable, in terms of visual and thermal properties, to external conditions. The novel liquid-shaded dynamic system is made possible by the creation of an additional 1.5-mm-thick layer, hosting a sliding shielding liquid, which flows internally, in order to constitute an infrared radiation barrier adaptable to real needs. The solution proposed provides the advantages of preserving glass transparency in both its working modes (i.e. high and low solar transmittance states), being fully reversible, durable, requiring short switching time to change from high to low solar transmittance and being of rather low cost. In addition, it exhibits very low g-values when kept in its shading mode, as shown by the comparison with other commercially available transparent stratifications.

Previous research focused on physical-chemical problems in order to identify the most suitable liquid mixture and kind of glass, in terms of durability, high temperatures resistance, elimination of interstitial condensation, minimizing fluid-glass adhesion. Solar properties were estimated to be comparable to, and in some cases even better than, some other commercial glass stratifications. Recent experimental measurements of solar transmittance on this technology, performed by means of a spectrophotometer and a Fourier transform IR spectrometer, have shown that the proposed triple glass stratification with no liquid has a solar transmittance of about 50%, which, when the liquid rises, drops to about 15% [Carbonari et al., 2010]. Similar results derived from reduced scale experiments [Carbonari et al., 2011].

In this paper the manufacture of a full size window prototype will be presented (Fig. 1). During that process the whole engineering of the window was carried out, which includes the choice of the frame, the design of micro-circuits for deploying the shielding liquid, the assembly of all components and particularly the assessment of the glass pane bending when subject to hydrostatic pressure. This research allowed us to demonstrate the technological feasibility of the system and to make possible assumptions to solve glass deformation problems due to hydrostatic pressure.

2. Functional models of the liquid-shaded module

The presence of a switchable liquid layer calls for a slight change in the window configuration, due to the need to insert a cavity to host the liquid layer in the stratification and some devices to store and deploy the liquid in the frame. As depicted in the middle part of Fig. 1, to pursue such a goal the window was designed with the following stratification (from the exterior to the interior):

- one shielding liquid repellent glass layer;
- a cavity which holds the shielding liquid characterized by a low viscosity and weak chemical bonds with glass (about 0.0015 m thick);
- another shielding liquid repellent glass layer;
- standard air cavity (about 1 cm thick);
- standard glass layer towards the interior.

Past research focused on the development of a proper shielding liquid, capable of sliding up and down inside the inner cavity without leaving fragments (such as drops, powder, etc.) on the inner surfaces of the encasing glass layers. The liquid was obtained by blending different substances that would assure it to work properly under cycling and repellent glasses to its main component were individuated. Additives were added to lower as much as possible the solidification temperature and raise the evaporation temperature [Carbonari et al., 2011].

In the bottom side of the window frame, a hydraulic pump pushes liquid from the storing tanks to the window cavity when solar shielding is needed, and pumps it back when solar gains should be maximized. This window is able to dynamically react to external disturbances. In the summer, when the sun is high in the sky and external temperatures are rather high, windows are likely to be shielded so that solar energy cannot enter. The opposite should be done in winter, leaving the liquid down in order to increase the solar gains as much as possible.

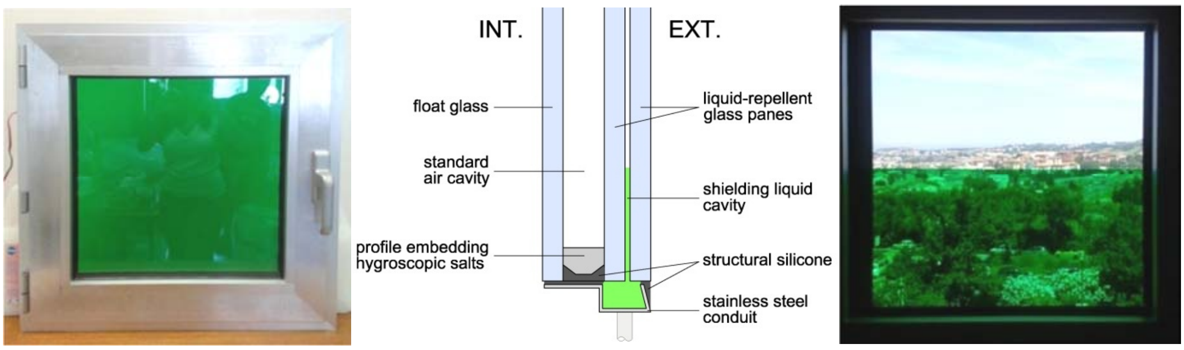

Figure 1. Cross-section showing the basic window stratification (in the center) and the window in operation (on the left and on the right).

3. Overview of the manufacturing process

Referring to the involved professional figures, we envisaged the following manufacturing steps:

1. assembly of the glass stratification;
2. production and integration of the deployment and actuation apparatus in the frame;
3. fitting of glass stratification in the window frame.

In the first step, the presence of the liquid layer required to add another liquid-repellent glass panel to a standard double glass with air layer. The two panes embedding the shielding liquid were of liquid repellent type and sealed through structural silicone. Two spacers were inserted on the long sides to create the 1.5-mm-thick liquid layer and two steel conduits were fixed at the bottom and top sides, in order for the liquid to be evenly distributed in the cavity.

In the second step an “intermediate assembler” provides the realization of deployment and actuation apparatus, composed by the hydraulic circuit, the electrical circuit and the pumping system. The hydraulic circuit was made up of two 1.0-mm-thick PVC tanks placed inside the window post, a peristaltic pump (12V) placed in the lower part of the frame, a liquid deployment system consisting of polyurethane pipes (∅ 6 - 4 mm) and three-way taps in order to permit the maintenance of each element separately. The system was powered by a low voltage electrical circuit which allows the passage of electricity only if window is closed thanks to an hidden contact.

Finally, the third step is up to a “frame assembler” who closes the window frame ensuring the inclusion of all components previously manufactured. A (0.5 by 0.5) m operable window was assembled, in order to check what modifications to the frame (drilling and milling) were necessary for the subsequent inclusion of the actuation system.

4. Development of the full-scale prototype

The phases of the production process, such as metalworking and assembly of glass, were carried out with the cooperation of local companies specialized in specific areas and identified through market analyses.

4.1. Glass stratification

The components of the glass stratification are as follows:

- no. 2 glass panes, 50 x 50 cm, 6-mm-thick each, with liquid-repellent treatment;
- no. 1 float glass, 50 x 50 cm, 6-mm-thick;
- no. 4 anodized aluminum spacers for the 1.5-mm-thick liquid cavity;
- no. 2 stainless steel conduits, 1-mm-thick, on top and bottom of the glass stratification, provided with a central hole and graft to allow the connection with the polyurethane pipes; the one at the bottom was provided with a double inner slope of 2%, made by pouring epoxy resin, to facilitate the outflow of the liquid during the draining of the cavity.

The production steps required first to produce the three glass panes, the two stainless steel conduits and two anodized aluminum spacers. Then, the realization of the dual-slope into the conduit by pouring epoxy resin, after checking the contact compatibility with the liquid used. Again, the construction of a traditional glazing consisting of two panes and the assembly of the third pane by means structural silicone and spacers. Finally, gluing of the steel conduits to the triple glass stratification using structural silicone was made.

4.2. Liquid storage and deployment

The necessary elements for the realization of the liquid storage and deployment system are as follows (Fig. 2):

- elastollan 1.0-mm-thick polyurethane pipes (1), ∅ 6 mm and 0.65-mm-thick polyamide pipes, ∅ 4 mm;
- no. 4 three-way taps (2) for medical use, to allow the system to be closed/emptied for transport/maintenance and no. 4 brass linear fittings with automatic clutch for 6 mm pipes, geared to connect pipes coming from the PVC tanks (5) with the hydraulic circuit.
- no. 2 brass T-fittings (3) with automatic clutch for 6 mm pipes, the lower one for the connection to the peristaltic pump (6) and the upper one acting as overflow;
- no. 1 brass silencer (4) for compressed air with porous bronze, grafted on a polyamide pipe, acting as a filter for ventilation;
- Loxeal 32 instant glue (ethyl-cyanoacrylate), used to connect polyamide pipes with three-way taps;
- plastic coated iron wire used to connect 4-mm-thick pipes to 6-mm-thick ones;
- shielding liquid [Carbonari et al., 2010].

For the proper operation of the device two tanks were used, connecting them to the peristaltic pump, using a T-fitting and two three-way taps. Other two taps and one T-fitting were inserted in the upper part of the circuit to connect the upper conduit with the two tanks, acting as overflow. Aeration provided for the system has the important and not negligible task to ensure that all the liquid flowing operations take place at atmospheric pressure, thus avoiding possible unwanted overpressures between glasses. The vent will be properly protected by a filter, made with a silencer for compressed air, to prevent the access of foreign matter into the system. The hydraulic circuit was realized by means of polyurethane pipes, ∅ 6 mm, while polyamide pipes, ∅ 4 mm, were used for the connection of pump and taps to the circuit. This flexible pipes allow accentuated bending, after heating, with considerable savings in space.

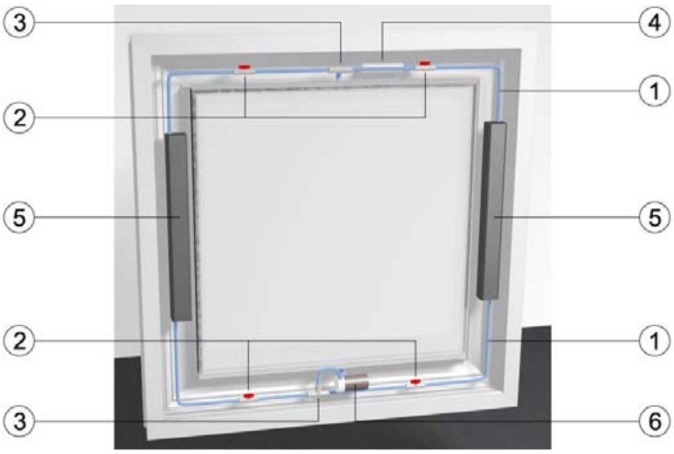

Figure 2. Location of the system's components inside the window frame; (numbers are mentioned in the text).

4.3. Electrical circuit

The 12V electrical circuit necessary for normal operation of the system, was achieved by a specific transformer connected to the activation control. Contact between the fixed frame and the mobile one occurs through a special spring contact allowing the operation when the window is closed.

4.4. Window frame

The frame required some milling on the top and bottom of the casing and the drilling of the mounting brackets to allow the passage of the tubes. All openings are designed to be closed by means of the frame rails commonly used for scrolling the closing boards activated by handle. In this way maintenance operations will be made possible simply sliding the covers. Tanks and connections between electrical parts, cables, pipes, taps, filter, fittings, pump were included in the frame and all the related links were run. Finally, glass stratification was inserted, the frame closed, handle mounted, pump wrapped with sound absorbing material and all the accessible openings were closed.

4.5. Laboratory tests of the prototype

4.5.1. Operation and reversibility tests

The test was prepared by placing the frame in a vertical position, the two tanks were filled, through the bottom taps, using a syringe and keeping the window open. Providing power to the circuit, the prototype was also submitted to some cycles in order to record the time required for filling and emptying. Using a 7.5V actuation, fluid takes 7 min to go up and 8 min to completely go down. If the pump operates at full power (12V), the time reduces to 3.10 min and 3.45 min for filling and emptying. Even with reduced voltage, prototype shows filling and emptying times perfectly compatible with common dynamic shielding requirements.

4.5.2. Glass bending tests

The pressure at a point, exerted by a fluid in static equilibrium, only depends on the height of that point and not on the horizontal dimension or characteristics of the container. As a consequence, it is extremely important to study the problem of hydrostatic pressure even considering the small cavity containing the liquid.

On previous tests on a 50 x 50 cm prototype, the maximum deflection value recorded was 1.54 mm, in correspondence of 22 cm ordinate point. Such deformation entails on the one hand a different gradation of colour due to the different thickness of the cavity, on the other hand an increase in the amount of liquid to be used, but especially it is not compatible for possible future use on larger structural facades of buildings.

The design solution tested in this research phase consists of impressing a negative strain on the glass panes, which may counteract the positive hydrostatic pressure. The idea is to use another pump to extract air from inside the air layer containing the liquid. In this way, the liquid, always introduced from below upwards, will go up due to depression inside the cavity going to occupy the space left by the air. The prototype was equipped with both the pumping systems to be tested separately: the pump for liquid positioned below, connected with the tanks containing the liquid, and the pump for air extraction fixed on the top and connected with the upper conduit (Fig. 3). The test involved a sequence of cavity filling and emptying, taken alternately with both pumping systems. A 7.5V transformer was used for the pump operating with liquid, and a 3V transformer for the pump extracting air.

Measurements recorded during the deformability test, made by a dial gauge positioned at a height of 22 cm (maximum deflection point on previous tests) confirmed the effective positive deformation, i.e. outward, (δ = 0.83 mm) produced on glass panes by the hydrostatic pressure of the liquid pumped inside the cavity (Fig. 3 left part). The glass fully recovered that deformation after the emptying phase, going back in rest condition (δ = 0.00 mm), in a few minutes. The air pumping system, instead, worked in depression and such air removal from cavity produced a negative deformation, i.e. inward, which is maximum when the sliding up liquid reached height 22 cm (position of the gauge), and then it kept constant until the complete filling of the cavity. This negative deformation value recorded (δ = -0.88 mm) is therefore the peak value for the glass tested (Fig. 3 right part).

Hence, a possible solution to the excessive deformation problem may lie in an appropriate coupling of the two pumping systems. The two pumping systems tested separately, at the moment, have potentials to be installed together; so a control system might be able to set the two pumps combined work in pressure and depression on the liquid, so as to restore the equilibrium condition, with null deformation of the glass panes.

Alternatively, it is also feasible to imagine a system which provides a single pump working in depression, coupled to an electrovalve located near the bottom conduit. Depression should be generated, so as to fill even the upper conduit; once filled in, the glass cavity and the upper conduit, keeping the electrovalve close and reversing the pump action, it would be possible to regenerate the right pressure inside the cavity in order to restore liquid equilibrium condition.

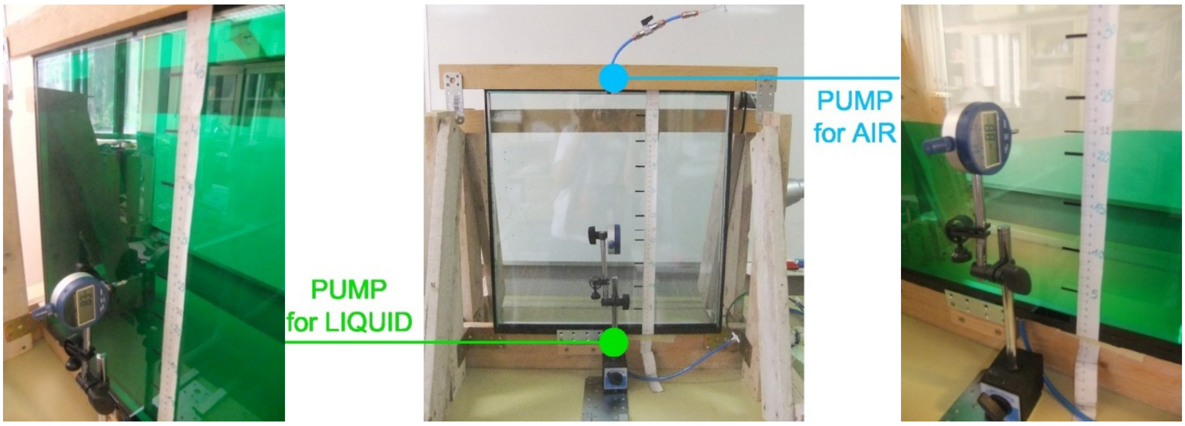

Figure 3. Glass bending tests: maximum deformation +0.83 mm with cavity under pressure (on the left), maximum deformation -0.88 mm with cavity in depression (on the right).

5. Conclusions

Research carried out allowed to demonstrate technological feasibility of the liquid-shaded dynamic system which constitutes an effective and technologically competitive response to the problem of protection from solar radiation, with the huge advantage due to lower production costs if compared with other dynamics shielding systems. The prototype design and construction of the novel dynamic window was developed resembling the industrial process. This approach allowed to define the guidelines for a future large-scale production.

Specific experimental tests were carried out in order to assess the glass pane bending when subject to hydrostatic pressure. The analysis of the data allowed to formulate possible hypotheses of solution to the problem of glass deformability, in fact preparing future developments.

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Model for evaluation of cantilever methods for construction of bridge superstructures

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Abstract

The terrain of Taiwan is characterized by large areas of mountains, while lands in urban areas have become increasingly difficult to acquire for developing infrastructures. To reduce environmental impacts and to improve traffic conditions, highway projects have adopted more and more bridges over the years and many advanced bridge construction methods have been introduced. In terms of construction of bridge superstructures, the cast-in-place cantilever method has seen wider use with many successful examples. This study investigated the false-work systems that may be selected for use in implementing the cast-in-place cantilever method in Taiwan, with the objective of developing a model for evaluating possible options. Based on a review of related researches, an evaluation framework for the false-work systems has been proposed first, which consists of six factors: system controllability, structural stability, initial cost, operating cost, segment cycle time, and closing segment construction time that are categorized into three aspects: reliability, cost, and speed. Because of the interdependencies among the factors, the model uses the analytic network process (ANP) to produce the weights of the factors and the ratings of the options in given project conditions. An illustrative example is provided, in which three false-work systems considered for a hypothetical box-girder bridge project are evaluated. The rankings of the options obtained for the example from best to worst were triangular truss, diamond truss, and suspension truss. Practitioners may use the model as a decision aid in evaluating and selecting false-work systems for the cast-in-place cantilever method for construction of bridge superstructures.

Keywords: bridge construction; cantilever method; false-work system; analytic network process

1. Introduction

The terrain of Taiwan is characterized by large areas of mountains, while lands in urban areas have become increasingly difficult to acquire for developing infrastructures. To reduce environmental impacts and to improve traffic conditions, highway projects have adopted more and more bridges over the years and many advanced bridge construction methods have been introduced. In terms of construction of bridge superstructures, the cast-in-place cantilever method has seen wider use with many successful examples. This study investigated the false-work systems that may be selected for use in implementing the cast-in-place cantilever method in Taiwan, with the objective of developing a model for evaluating possible options. The model consists of six criteria categorized into three clusters. To deal with the dependency relations among the criteria, it is proposed to employ the analytic network process. The model is illustrated by using an example scenario in which three false-work systems for a hypothetical box-girder bridge project are evaluated for determination of their priority ordering.

2. Cantilever Method for Construction of Bridge Superstructures

Bridges constructed using the cast-in-place cantilever method can have a maximum span up to 300m. By extending the superstructure segment by segment in both directions from a column that is built in the conventional way, the method does not require support on the ground during erection of the superstructure, making it feasible for bridge construction over deep valleys or traffic flows (Schlaich and Scheef, 1982). Fig. 1 below shows a cast-in-place box-girder cantilever bridge over a river.

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Figure 1. A cast-in-place cantilever bridge.

The false-work system for supporting the traveling form is an essential component of the cast-in-place cantilever method and greatly affects the safety, cost, and time of overall construction (DYWIDAG, 1997). The false-work system is fixed to the completed concrete segments by an anchoring method. There are three false-work systems available in Taiwan: suspension truss, triangular truss, and diamond truss; see Fig. 2, Fig. 3, and Fig. 4, respectively. The differences in characteristics between them are provided in Table 1. Their purchase prices range between NT$2,000,000 and NT$3,500,000 and their costs in bridge construction range between NT$1,600 and NT$2,500 per square meter of deck area. In the example below, a hypothetical box-girder bridge project, 1000m long, 16m wide, and with a maximum span of 150 m, is assumed for evaluation of the three systems using the proposed model.

Figure 2. A suspension truss false-work system for the cantilever method

Figure 3. A triangular truss false-work system for the cantilever method

Figure 4. A diamond truss false-work system for the cantilever method

Table 1. Comparison of characteristics between the three false-work systems

Support type	Suspension truss	Triangular truss	Diamond truss
Position	beneath deck	above deck	above deck
Size	smaller	larger	largest
Weight	lighter	heavier	heaviest
Controllability	more complex	easier	more difficult
Cycle time	longest	shorter	longer
Closing segment placement	easiest and simplest without additional preparation task	requiring more time for dismantlement of truss	requiring more time for dismantlement of truss
Others	● more working space on the deck, less clearance below ● fixed by suspending bar ● segment length 3~3.5 m	● see most cases of usage in Taiwan ● fixed by anchoring bar at the back	● fixed by anchoring bar at the back ● segment length up to 5 m ● can adapt to various box sections

3. ANP Model for Evaluating False-work Systems for Cantilever Bridges

In selecting the construction method for a project, engineers often have several alternatives and consider multiple objectives as criteria. Assessing and comparing their performance in each criterion so as to identify the overall best alternative for implementation is crucial to project success. The analytic hierarchy process (AHP) proposed by Saaty (1980) using paired comparisons to generate criteria weights and priority scores of alternatives with a function for checking comparison consistency is a widely used model for evaluation, e.g. Skibniewski and Chao (1992), but it cannot incorporate the effects of dependency relations among the criteria. As an improvement on AHP, Saaty (1996) proposed the analytic network process (ANP) as the generalized AHP method to include impacts of dependency relations that are absent in the AHP, while the basic formats and rules of the AHP, i.e. the 1-9 scale for measuring relative importance, the comparison matrix, and the consistency ratio for checking, are still used in the ANP. The ANP method has found increasing application in many areas, e.g. Chao (2013).

To accommodate the effects of dependency relations among the criteria for selecting the false-work system for a cantilever bridge project so as to achieve a more thorough and realistic evaluation, this study developed an ANP model to produce the criteria weights. First, based on a review of related studies, a framework for evaluating false-work systems has been proposed, which consists of six factors grouped in the clusters of reliability, cost, and speed: system controllability, structural stability, initial cost, operating cost, segment cycle time, and closing segment construction time that have influence on each other. See Fig. 5.

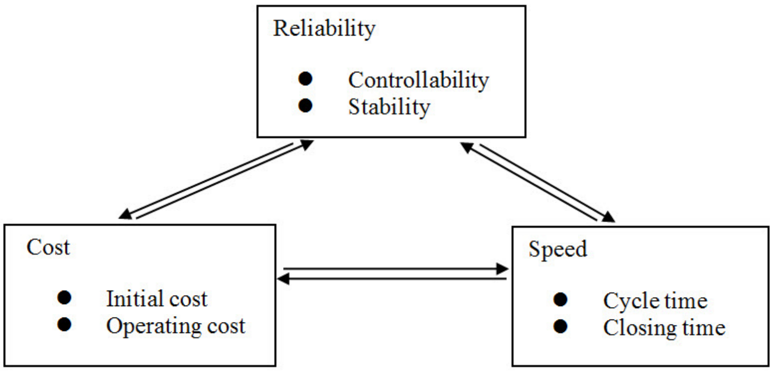

Figure 5. The network model for evaluating false-work systems for cantilever bridges.

Next, based on the collected technical data, the three false-work systems are pair-compared in their performance on each criterion in the manner of AHP. The comparison matrices and principal eigenvectors (P.E.-V.) indicating the systems' performance scores are shown in Fig. 6. It can be seen that the suspension truss is best in closing time, the diamond truss is best in stability, and the triangular truss is best in all remaining four criteria.

(a)

Controllability	Suspension	Triangular	Diamond	P. E.-V.
Suspension	1	1/5	1/2	0.128
Triangular	5	1	2	0.595
Diamond	2	1/2	1	0.277

(b)

Stability	Suspension	Triangular	Diamond	P. E.-V.
Suspension	1	1/3	1/5	0.105
Triangular	3	1	1/3	0.258
Diamond	5	3	1	0.637

(c)

Initial cost	Suspension	Triangular	Diamond	P. E.-V.
Suspension	1	1/3	1/2	0.163
Triangular	3	1	2	0.540
Diamond	2	1/2	1	0.297

(d)

Operating cost	Suspension	Triangular	Diamond	P. E.-V.
Suspension	1	1/5	1/3	0.105
Triangular	5	1	3	0.637
Diamond	3	1/3	1	0.258

(e)

Cycle time	Suspension	Triangular	Diamond	P. E.-V.
Suspension	1	1/7	1/5	0.072
Triangular	7	1	3	0.649
Diamond	5	1/3	1	0.279

(f)

Closing time	Suspension	Triangular	Diamond	P. E.-V.
Suspension	1	3	3	0.600
Triangular	1/3	1	1	0.200
Diamond	1/3	1	1	0.200

Figure 6. The comparison matrices for the three alternative false-work systems' performance.

To determine the criteria weights using the ANP, the criteria within each cluster are compared with respect to every criterion in other clusters, indicating their relative importance from different viewpoints or relative influence on other factors. The resulting 12 principal eigenvectors of two elements are placed under the corresponding headings into an initial super-matrix, *W*, in Table 2. It can be seen that stability, initial cost, and cycle time are more important than the rest.

Table 2. Initial super-matrix for the example, *W*.

Attributes	Controllability	Stability	Initial cost	Operating cost	Cycle time	Closing time
Controllability	0	0	0.125	0.25	0.25	0.5
Stability	0	0	0.875	0.75	0.75	0.5
Initial cost	0.833	0.875	0	0	0.875	0.75
Operating cost	0.167	0.125	0	0	0.125	0.25
Cycle time	0.875	0.875	0.875	0.833	0	0
Closing time	0.125	0.125	0.125	0.167	0	0

The initial super-matrix showing the local priorities is not column-stochastic, i.e. the columns each do not sum up to one. Therefore, a cluster weights matrix (Table 3) obtained from comparing the relative influence of the clusters on each other is used to weigh *W*. Each element in the cluster weights matrix is taken to multiply the corresponding block of elements in *W*. The weighted super-matrix, $\dot{W}$, is shown in Table 4. Finally, the power of $\dot{W}$ is raised until the product converges and the limit super-matrix, $\dot{W}^{29}$ (Table 5), contains the global priorities of the criteria. It can be seen that initial cost with a final weight of 0.370 is the most important criterion overall, followed by stability (0.348) and cycle time (0.135).

Table 3. Cluster Weights Matrix.

Clusters	Reliability	Cost	Speed
Reliability	0	0.8	0.5
Cost	0.833	0	0.5
Speed	0.167	0.2	0

Table 4. Weighted super-matrix for the example, $\dot{W}$.

Attributes	Controllability	Stability	Initial cost	Operating cost	Cycle time	Closing time
Controllability	0	0	0.1	0.2	0.125	0.25
Stability	0	0	0.7	0.6	0.375	0.25
Initial cost	0.694	0.729	0	0	0.438	0.375
Operating cost	0.139	0.104	0	0	0.062	0.125
Cycle time	0.146	0.146	0.175	0.167	0	0
Closing time	0.021	0.021	0.025	0.033	0	0

Table 5. Limit super-matrix for the example, $\dot{W}^{29}$.

Attributes	Controllability	Stability	Initial cost	Operating cost	Cycle time	Closing time
Controllability	0.070	0.070	0.070	0.070	0.070	0.070
Stability	0.348	0.348	0.348	0.348	0.348	0.348
Initial cost	0.370	0.370	0.370	0.370	0.370	0.370
Operating cost	0.057	0.057	0.057	0.057	0.057	0.057
Cycle time	0.135	0.135	0.135	0.135	0.135	0.135
Closing time	0.020	0.020	0.020	0.020	0.020	0.020

The criteria weights in Table 5 are arranged in a vector which is then multiplied by the performance scores of the three false-work systems, i.e. the principle Eigen-vectors in Fig. 6, which are arranged in a matrix to produce their final scores as below. It can be seen that the triangular truss at a score of 0.459 ranks first, followed by the diamond truss (0.407) and the suspension truss (0.134).

$$S = W' \times P = \begin{bmatrix} 0.070 \\ 0.348 \\ 0.370 \\ 0.057 \\ 0.135 \\ 0.020 \end{bmatrix}' \begin{bmatrix} 0.128 & 0.595 & 0.277 \\ 0.105 & 0.258 & 0.637 \\ 0.163 & 0.540 & 0.297 \\ 0.105 & 0.637 & 0.258 \\ 0.072 & 0.649 & 0.279 \\ 0.600 & 0.200 & 0.200 \end{bmatrix} = [0.134 \quad 0.459 \quad 0.407]$$

4. Conclusions

The rankings of the options obtained for the example from best to worst are triangular truss, diamond truss, and suspension truss. The results can be explained by the strengths and weaknesses of each option together with the priorities of the six factors considered from various viewpoints with the overall goal of selecting the best option. The study has shown that, by incorporating the effects of dependency relations among the factors, the ANP can sensibly establish the global priorities of the factors. Practitioners may use the model as a decision aid in evaluating and selecting false-work systems for the cast-in-place cantilever method for construction of bridge superstructures. However, the model with higher complexity demands greater input effort from the user than an AHP model, so its use requires discretion and justification.

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Housing delivery in Nigeria and the opportunity for offsite manufacturing

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Abstract

The problem of housing delivery is of great concern in many countries of the world. This problem is especially prominent in developing countries and Nigeria is not an exception. In Nigeria, this challenge has been magnified as a result of a myriad of issues, not least, a high population growth rate, shortage of necessary skills, disintegrated supply chain etc. Seminal literature has evidenced that offsite manufacturing (OSM) can help improve housing delivery efforts both in terms of quantity and quality. The aim of this research was to investigate the current housing delivery problems in Nigeria in order to evaluate the feasibility of adopting OSM within this market. To achieve this, the study conducted substantial literature review to: explore the benefits of OSM, identify the problems of housing delivery in Nigeria and explore different dimensions and the issues that can be associated with using OSM in Nigeria. The results revealed that there are a good number of benefits promised by OSM; notable among these are: less wastage on site, faster construction time, quality improvement and reduction in wet trades. Moreover, some of the problems of housing delivery in Nigeria included: skills shortages, reliance on conventional construction techniques, slow pace of construction, and low quality of housing. The study also showed that adoption of OSM has been quite useful in other countries facing the similar issues of housing shortage, e.g. Malaysia. As such, this study posits that OSM could be applied in Nigeria to address many of these issues. However, it is argued here that in order to address the problems of housing delivery in Nigeria, it is important that further study is conducted to explore certain angles of its impacts in the context of Nigeria in accordance – especially considering the myriad of socio-cultural, technological, economic and political factors.

Keywords**:** housing delivery, housing shortage, Nigeria, offsite manufacturing

1. Introduction

Nigeria currently has a population over 140 million, and this figure is increasing at an annual growth rate of about 3.2% (Ayedun & Oluwatobi, 2011). the country has a very large and ever-increasing housing deficit which stood at approximately 8 million housing units in 1991 and at about 16 million housing units currently (Nkah, 2013; Subair, 2013). The problem of the housing deficit in Nigeria is a result of rapid growth in population, skills shortages, the high cost of building materials, logistical challenges etc.(Makinde, 2014). Consequently, there is a wide gap between housing demand and housing supply in Nigeria (Ademiluyi, 2010; Kabir & Bustani, 2009; Ukwayi *et al.*, 2012). There is work going on to reduce the current housing deficit in Nigeria but there is still so much work that needs to be done. In the UK for instance, several reports have advocated change within the built environment. Notable among these reports are the Latham report of 1994 (Constructing the Team) and the Egan report of 1998 (Rethinking Construction). As a result, the construction industry was challenged to view construction as a manufacturing process (Wolstenholme, 2009). This call for change is not however peculiar to the UK only. In Nigeria, there have been suggestions that emphasis should be laid on other forms of construction such as prefab building (Nkah, 2013). In the opinion of some experts in the Nigerian construction industry, to solve the problem of inadequate housing, there is the need for a shift from the conventional systems of construction to a more adaptable and faster way of construction. As such, 'Dry Construction' has been recommended by these experts (Ashkin, 2013; Dada, 2013). Dry Construction is described as a method of construction where majority of the components of the building are pre-fabricated off site and brought to site for assembling (Dada, 2013). As identified by (Azman *et al.* (2010); Blismas *et al.* (2010); Experian and SamiConsulting (2008); Fussell *et al.* (2007)), there are opportunities for greater use of offsite manufacturing in the area of housing delivery. In other countries like UK, USA, Japan, Scandinavian Counties, Australia, New

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Zealand, Malaysia etc, (OSM) has been adopted as a means of improving construction processes and also to improve housing delivery efforts (Blismas *et al.*, 2010; Goodier & Gibb, 2005; McGraw-HillConstruction, 2011; PrefabNZIncorporated, 2013).

2. Problems of Housing in Nigeria

Housing (adequate shelter) is seen world-wide as one of the basic necessities of life and a pre-requisite to the survival of man and it is also important to the welfare, survival and health of individuals (Ademiluyi, 2010). As opined by Olayiwola *et al.* (2005), housing remains one of the best indicators of a person's standard of living and his or her place in the society. In spite of the high importance given to housing, it is unfortunate that only 10% of Nigerians who desire houses can afford to acquire it either by purchase or personal construction, this is very low compared to 72% USA, 78% UK, 60% China, 54% Korea and 92% Singapore (Ayedun & Oluwatobi, 2011). The problem of housing in Nigeria is caused by a number of factors (Emmanuel, 2012; Kabir & Bustani, 2009; Subair, 2013). Among these problems are; rural-urban migration, high cost of materials, inadequate regulatory and legal environment affect housing development, poor housing finance structures, skills shortage, limited diversity in construction processes and over reliance on cement (Adenuga, 2013; Makinde, 2014; Suleiman, 2013). Notable among these problems are:

Akinmoladun and Oluwoye (2007) noted that the origin of housing inadequacy in Nigeria was as result of high population growth rate experienced in the country which exceeds the rate of economic growth experienced in the country. This high population growth rate causes an increase in the demand for shelter and efficient supply and distribution of basic amenities and services for the city dwellers. In most urban centres in Nigeria, the problem of housing is not only restricted to quantity but also to the poor quality of available housing units (Kabir & Bustani, 2009). There are strong indications that OSM has the capacity to deliver housing units at a faster speed and with higher quality compared to traditional construction (Arif *et al.*, 2012a; Blismas & Wakefield, 2009; Lu, 2009). For instance, in UK, aside from the fact that there was a move for change in the construction industry, OSM came into prominence after World War I (Taylor, 2009). However, if OSM to be adopted in Nigeria, it is essential for barriers like the lack of guidance, paucity of information, negative image etc. to be address. These issues have been cited by several authors (Goodier & Gibb, 2005; Jaillon & Poon, 2008). In addition, Chan and Dainty (2007), noted the problem of skills shortage within the construction industry has been recurring over the past 30 years. This issue of skills shortage exists in almost all parts of the world to varying degrees, in the studies conducted by CIOB (2008) and Schäfer (2010), in U.K and Germany respectively, it was identified that skills shortage existed in those countries. In the Nigerian context, Ayedun and Oluwatobi (2011) identified skills shortage as one of the problems hampering the effective delivery of housing. One of the drivers to the uptake of OSM identified was skills shortage (Arif *et al.*, 2012a; Blismas & Wakefield, 2009; Gibb & Isack, 2003). OSM takes away most of the construction processes to a controlled environment (factory), as such the number of operatives needed a reduced since minimal work is done on site.

Ayedun and Oluwatobi (2011) observed that the Nigerian Construction Industry as a whole is guilty of not accepting new technologies. This is also similar to the U.K construction industry (Nadim & Goulding, 2010). With the call for the shift from the conventional system of construction to a more adaptable and faster way of construction (Dada, 2013), it is important for the Nigerian housing sector to put modalities in place for OSM to be incorporated into its fold. Adopting this method will not be an easy one as there are barriers associated with the uptake of OSM identified in other countries where OSM is used (Arif *et al.* (2012a); Fussell *et al.* (2007); Goodier and Gibb (2005); Jonsson and Rudberg (2013); Pan *et al.* (2004); Rahman (2013); Zhai *et al.* (2013)). Housing delivery in developed and developing countries of the world are faced with many challenged, in the case of developing countries like Nigeria, the problem is higher compared to developed countries. The population of the world is increasing at an enormous rate and most of this increase is expected in developing countries (Ademiluyi, 2010). With this kind of statistics, it is important for developing countries to think of the way forward with regards to housing delivery.

3. Offsite Manufacturing and the Opportunity for its adoption in Nigeria

There are various terms and acronyms associated with OSM. They include OSM, manufactured construction, offsite construction (OSC), offsite production (OSP), pre-assembly, prefabrication, modern methods of construction (MMC) etc and these terms are all used interchangeably (Arif & Egbu, 2010; Goulding & Arif, 2013; Goulding *et al.*, 2014; Taylor, 2010). For the purpose of this study, it will be referred to as OSM. Nadim and Goulding (2010), argued that, offsite manufacturing falls under the broad umbrella of Modern Methods of Construction (MMC). Over the years, quite a number of definitions have been used to describe offsite manufacturing (Taylor, 2010). OSM can be defined as processes that incorporate prefabrication and pre-assembly to produce units and or modules that are then transported to site and positioned to form a permanent work (Emmitt & Gorse, 2010; Gibb, 1999; Gibb & Isack, 2003; Jaillon & Poon, 2008). In the opinion of MBI (2010), offsite manufacturing refers to any part or aspect of a construction process that is carried out in a controlled condition away from the actual site where the building is or will be situated. But Gibb and Pendlebury (2006), went a step further and defined OSM as a term used to describe a range of applications where structures, buildings or parts are manufactured and assembled away from the site before they are finally installed into positions. In a nutshell, offsite manufacturing involves moving operations that are traditionally completed onsite to a manufacturing environment (Gibb & Pendlebury, 2006) and this in turn improves the quality, customer satisfaction, efficiency, predictability of delivery timescale and sustainability of project (Nadim & Goulding, 2010). Several benefits are obtainable from the use/adoption of OSM. These benefits have been categorized into sustainable benefits and process and objective based benefits. These benefits were highlighted in the works of (Arif *et al.* (2012a); Arif and Egbu (2010); Boyd *et al.* (2013); Gorgolewski (2003); Jaillon and Poon (2010); Pan *et al.* (2004); Taylor (2010)). The benefits of offsite manufacturing are highlighted in Figure 1. Gorgolewski (2003) identified the sustainable benefits of OSM, they are: 1) Less Impact on the Surroundings; 2) Reduced Level of Defect; 3) Less Waste in Manufacture; 4) Transportation; 5) Greater Efficiency in the use of Resources, Both Materials and Labour.

Pitt *et al.* (2009) asserted that 40 per cent of all UK waste (including greenhouse gas emissions) is produced by the construction industry. It has also been observed that most of these wastes generated from construction sites are deposited in landfills (Gorgolewski, 2003). Also, it was observed that, about 13 per-cent of materials delivered to sites are never used and are therefore turned into waste(Gorgolewski, 2003). In the case of Nigeria, as opined by Ajayi *et al.* (2008), a large volume of waste is generated in an average Nigerian site. It was found out that most wastes were generated from demolition works on site and material handling. To reduce waste generated on site, based on a research conducted by WRAP (2007), it was observed that between 70 per cent and 90 per cent of waste reduction could be achieved with the use of OSM (depending on the particular OSM process being adopted). Also, it is easier to gather and recycle waste generated from OSM than it is when using traditional construction method (WRAP, 2007). Also, with regards to the project objective and process, there are many benefits obtainable (Figure 1).

In the opinion of Gibb and Pendlebury (2006), "time is a big-plus for offsite". The time spent on the site depends on the amount of factory produced components and those produced traditionally (Taylor, 2009). Construction time is normally affected by material shortage, skills shortage and bad weather conditions. In the case of OSM, these issues have been tackled because most the building components are manufactured in factories and transported to site, this drastically reduces the amount of time spent on site (Taylor, 2009). As a result of the short time spent on site, it is easier to predict completion dates and also access restricted site areas, for example airport closures and school holiday (Gibb & Pendlebury, 2006). As identified by Taylor (2009), the issues of material shortage and weather were also found to be similar to Nigeria, as argued by Taylor (2009) to tackle these issues, the use of OSM can be adopted, this will help reduce the overall time spent on projects. In the works of (Arif *et al.* (2012a); Blismas and Wakefield (2009); Gibb and Isack (2003); Lu (2009)), it was observed that one of the most important benefits of OSM was time, i.e. reduction in the time spent on site and faster pace of delivery of projects.

OSM is believed to be more expensive than more established techniques (traditional method) NationalAuditOffice (2005). But Gibb and Pendlebury (2006) argued that, savings from OSM can be achieved in the areas of cost certainty and reduced risk, less overall life cycle costs, better quality of building which will in-turn lead to reduced maintenance cost, reduced preliminaries and site overhead, reduced construction time which can result in cost benefit from early occupation of the property. In the opinion of WRAP (2007), based on research conducted, it was observed that savings can be achieved in the use of OSM as a result of reduction in waste of building materials especially bricks. In Nigeria were sandcrete blocks are generally used, incorporating OSM will go long way in reducing waste on site.

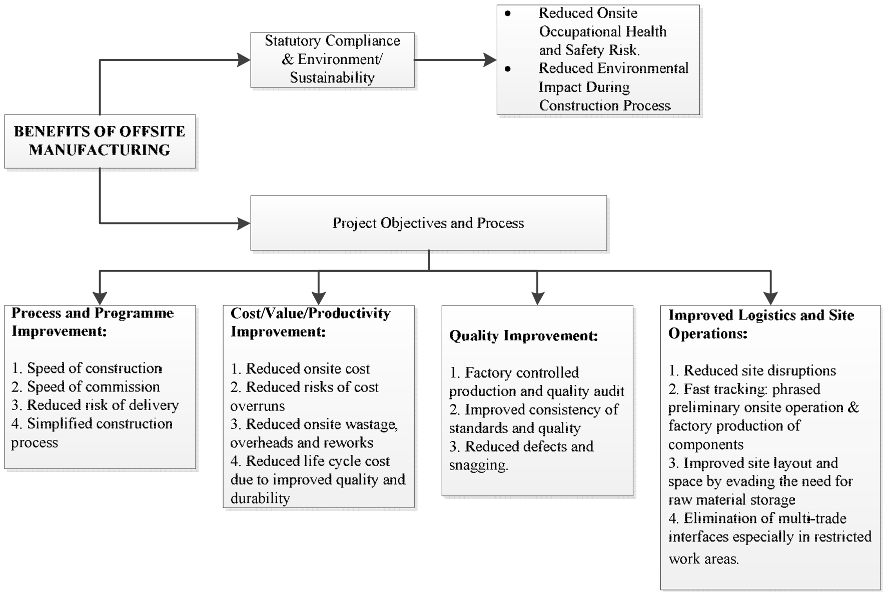

Figure 1. Benefits of OSM (Fussell *et al.*, 2007)

In the opinion of the NationalAuditOffice (2005), OSM meets the three quality requirements of durability, whole life cost and performance. In the works of (Arif *et al.* (2012a); Fussell *et al.* (2007); Gibb and Isack (2003)), based on researches conducted in India, Australia and UK respectively, it was realised that achieving greater quality was one of the major benefits of OSM and also one of the key drivers to its adoption in those countries. Quality can better be achieved within a factory and also products consistency can be better achieved while working in a controlled environment (factory) (Gibb & Isack, 2003). The problem of housing is Nigeria is not only in terms of quantity but also quality (Olayiwola *et al.*, 2005), as such adopting OSM will improve housing delivery efforts in terms of quantity and quality. Reduction in wet trades, site disruptions and having more certainty over the control of projects, was found to be an important benefit of OSM (Gibb & Isack, 2003). A good example cited by Gibb and Isack (2003) is, working in a prison, were contractors have to be escorted to and from their site and all employees have to be properly scrutinised, but if OSM is adopted, the amount spent on security will be reduced as less time will be spent on site by the contractor. Also in the case of airports, roads and rail projects, site access and working space are normally limited; as a result, OSM was seen to be of great benefit. OSM is a construction technique that has been adopted in a good number of countries for different reasons. In Nigeria, the current housing deficit demands that housing units need to be provided at a faster pace and from the experiences of other countries, OSM can deliver housing units faster and with superior quality compared to traditional construction.

4. Discussion

There are numerous factors hindering housing delivery in Nigeria (Emmanuel, 2012). One of the factors identified was high population growth (Akinmoladun & Oluwoye, 2007). As a result of rapid increase in population, there is pressure on the available housing stock. As stated by (Arif *et al.* (2012a); Gibb and Pendlebury (2006); Lu (2009)), time is a big plus for OSM, as such the use of OSM in the Nigerian housing sector will help increase the rate of housing delivery. There are suggestions that OSM can save the time spent on construction by between 30 – 50% compared to traditional construction technique (MBI, 2010). Another problem of housing delivery in Nigeria as identified by Ayedun and Oluwatobi (2011) was skills shortage. The current situation in Nigeria suggests that there is a shortage in manpower necessary for adequate delivery of the needed housing units. One of the drivers to the uptake of OSM in some countries as found by (Arif *et al.* (2012a); Blismas and Wakefield (2009); Gibb and Isack (2003)) was skills shortage. Since OSM requires fewer tradesmen (Blismas & Wakefield, 2009), its adoption will eliminate the problem of skills shortage. The issue of unwillingness to innovate is one that is associate with the construction industry all over the world, Ayedun and Oluwatobi (2011) identified this problem with the Nigerian construction industry. OSM is a construction technique that is being used in a number of countries as various counties have found different reasons to incorporate OSM into their construction processes. For OSM to be adopted in Nigeria, effort needs to be put by all the stakeholders involved. Whilst it is important to acknowledge the benefits associated with OSM, there are some barriers that have been found to hinder its uptake (Arif *et al.* (2012a); Fussell *et al.* (2007); Goodier and Gibb (2005); Jonsson and Rudberg (2013); Pan *et al.* (2004); Rahman (2013); Zhai *et al.* (2013)). Some barriers that have been found to be hindering the uptake of OSM include; negative image, reluctance to innovate, perception of stakeholders, perceived higher cost, quality etc. Goodier and Gibb (2005) identified negative image as one of the barriers to the uptake of OSM; and for the Nigeria housing sector to adopt OSM, it will need to present a good image about OSM. Arif *et al.* (2012b) suggested that the OSM industry should focus more on visualisation and simulation technologies as a means of creating awareness on OSM. This way, when people see what is achievable using OSM, it is easier for it to be accepted. Notwithstanding this, the uptake of OSM is influenced by the perception of housing developers as to the advantage and disadvantage of OSM (Pan *et al.*, 2004). The issue of perception does not only lie on the developers, surveyors are also not familiar with OSM, as such, they do not really understand how to asses such properties (Pan *et al.*, 2004). Also, customers/clients are not really aware of what OSM is all about and as a result, they are more inclined to follow the traditional method of construction (which stifles OSM adoption). Given this, if OSM was to be adopted in Nigeria, it is important that such bodies as the Nigerian housing sector (and other allied professionals), critically reviews extant literature and seminal reports where OSM is already in use elsewhere.

5. Conclusion

With the housing deficit of approximately 17 million housing units, there is an exigent need to address this imbalance. From the experiences of other countries, OSM has the potential of improving housing delivery in terms of quantity and quality. Even though OSM has extolled many benefits, it is important to also note that there are barriers that have been found to hinder its uptake in other countries. For the Nigerian housing sector to incorporate OSM into the sector, it is important to learn from the experiences of other countries that have already incorporated OSM. Also, the government should try to encourage research and development in the area of improving housing delivery efforts in order to procure policies that will move the housing sector forward and help reduce the housing deficit.

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Renovation of educational buildings to increase energy efficiency

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Abstract

The article presents results of energy inspection of an educational building "Hydrotechnical building-2" of the Saint-Petersburg State Polytechnical University. The energy audit was carried out to estimate energy resources performance and define opportunities for its increase. According to the results of energy audit the analyses of state of energy consumption are provided. The class of energy efficiency is defined. The recommendations and prospective opportunities to save energy and increase power efficiency of "Gidrokorpus-2" are presented as a resume of this article.

Keywords: energy building, energy saving; efficiency; external enclosure structures; insulation coating; renovation of facades.

1. Introduction

Nowadays the term «energy efficiency» is referred to as rational use of energy resources; however sense and importance of this definition was beyond advisory measures and started to be an essential requirement. Thus it is necessary to set the priority for effective use of the fuel and energy resources (FER) and energy produced in the construction industry of Russia It's also a must to change a classical approach of accumulation of the volumes extracted and production which is managed much more expensively than introduction of actions for its savings. The important reason of squandering of FER involves inefficient and sometimes even irrational energy consumption in the sphere of housing and public utility services, in the field of construction manufacturing industry.

The main task of energy saving is to discover opportunities to reduce energy consumption without causing damage to the consumers and the environment. International systems meant for estimation of ecological efficiency of buildings develop and work over the standards of quality in the modern construction industry.

Renovation can be considered as one of the energy efficiency aspects. Reconstruction of buildings and structures has become one of the main directions in the modern construction business development. Reconstruction of facades does not imply a radical change in the building but only sets the goal to improve its image with the use of special technologies.

The goal of energy inspection of "Hydrotechnical building-2" is a search for possible solutions of energy saving and increase of power efficiency of an object. For scientific research of an object the following is required:

- to conduct thermal sensing;
- to fulfill thermotechnical calculations;
- to draw up energy performance of an object;
- to identify class of energy efficiency of an object ;
- to develop facade renovation design to increase energy efficiency.

2. Overview

The issue of energy efficiency increase to be solved was considered by the following scientists: Gorshkov A.S., Gagarin V. G., Trutnev M. S., Butovsky I.N. Efimenko M. N., Tabunshchikov Yu. A. Boguslavsky L.D. Monastyrev P. V., Klychnikov R. Y., Petrichenko, M.R., Vatin N.I. and many others.

The most consistent and reasonable approach was developed by Gagarin V.G. who proposed to improve the mathematical model of the payback of cost with rise of thermal protection level that takes into account discounting savings of operating costs.

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According to his model the most important parameter in determining the economic conditions concerning increase of the thermal security enclosure in the country or region is the limit for the one-time costs and also he suggested to use a complex indicator (a specific coefficient of a heat transfer of a cover of a building which includes parameters of heat-shielding of all protecting designs of a building) with the aim of rationing of heat-shielding of a cover of a building—. This indicator is natural development applied earlier for an assessment of energy saving of the specific thermal characteristic of the building [1].

Gorshkov A. S. develops the schedule of dependence of thermal losses per 1 sq.m of a design protecting from the specified resistance to a heat transfer from where it is visible that change is shown in hyperbolic dependence. However the possibility of economically inefficient capital expenditure for construction designs by decrease in expenses on heating has been noticed. The author cites the schedule to determine the optimum thickness of the wall structure by the method of reduced costs. He produces the diagram to determine the optimum thickness of the walls of aerated concrete with different service life values [3-6].

The technology of use of the liquefied gas to secure centralized supply of energy resources for a complex of buildings remote from the network energy resources have been considered by Nemova D. V.,,Vatin N.I. and Tseytin D.N. in the works consider The advanced scheme of installation has been developed. It has been offered to use an economic-mathematical model for the first stage of a concept of a settlement, allowing determining costs of energy obtained and equipment payback periods. The method also allows calculating payback periods of the energy saving actions targeted at an increase of thermal protection level of protecting designs of buildings, analyzing the economic efficiency of investments in energy saving activities. The scientists have offered also the model allowing to carry out the specified analysis [7-11].

Petrichenko M.R. has proposed procedure that makes it possible to assign the rate of drop in water level in the upper pool which eliminates failure of earthen structures in the surveys [12-13]. Petrichenko M.R offered to replace the traditional Dupuis formula by the condition of the minimum of the functional reflecting the average quadratic norm of the departure of the curvilinear profile of the free surface from a straight line in the surveys [14-15].

Petrichenko M.R. has revealed that successful plotting of the depression curve for the plane problem of filtration in homogeneous soils can solve many engineering problems of hydrotechnical construction while organizing surface drawdown or maintaining a difference in the levels of a filtering embankment. To solve this problem it is important to have a representation of an actual position of the depression surface to evaluate the stability of soil masses subject to filtration activity. Determination of the position of the depression curve is based on use of Dupee's hypothesis for an average filtration rate and integral formulas for the flow rate through a homogeneous soil mass. It is explicitly presented that the equation of nonuniform motion is a required condition of the minimum for F(h) (in uniform motion, F(h) = 0). Dupee's depression curve has minimum length and maximum free-surface gradient [16-17].

Petrichenko M.R. has derived an energy-balance equation for an integral flow with a variable flow rate over a particular length. The equation has been applied to the confluence of flows [19-21]. Unsteady heat and mass transfer in combustion chambers of internal combustion (primarily Diesel) engines have been analyzed and experimental data have been reviewed. A stable correlation has appeared to exist between the instantaneous local heat transfer coefficients and the thermal resistance of the pseudolaminar boundary layer on the chamber wall. Other major factors have been also analyzed [18]. Petrichenko M.R has presented [22-23] an algorithm for the problem of flame propagation rate in combustion of a homogeneous fuel-air mixture in a cylinder of an internal combustion engine. It is assumed that the mixture is not 'overturbulized' and that the front flame is spherical. The model used for the phenomenon is based on a turbulent transport mechanism. In the near-wall area the combustion mechanism follows a fine-scale mechanism, but in the core, a large-scale mechanism. Experiments have allowed determining the character and numerical value of coefficients which consider the effect of turbulence on front flame propagation in the combustion chamber of the engine ZMZ-4021. The principles presented can be used as the basis of an algorithm for heat liberation rate in an internal combustion engine with external mixture formation.

Possibilities of utilizing quasi-stationary techniques in calculating flows through exhaust ducts of internal combustion engines have been discussed in some studies [25] with two major assumptions entertained: gas parameters obey laws and relations prevailing in fully stationary flow, in circumstances of quasi-stationary flow, and pressure remains the same throughout the entire volume of the internal combustion engine system at any fixed instant of time. An approximation analysis has been conducted.

The paper [26] reveals the problems concerning the formation of an oil film in the clearance between a piston ring and the internal combustion engine cylinder liner. An expression is derived for the lift force of the piston ring. The variation of the lift force with piston speed and the speed of the radial movement of the ring has been shown. The results of calculation of oil film thickness under the sealing piston ring in the diesel engines of 1ChN16/17 type have been presented.

The purpose of work [27] has been to obtain a description of the fluctuation for component of the induced difference of the scalar potential in transducers of correlation flow meters and to refine the limits of the non-inductive approximation and possibilities of meeting the requirements imposed on transducers.

New experimental data have been presented [28] on non-stationary and transient operating conditions of closed liquid metal loops with MHD pumps. The investigations have been made by utilizing the automated system of experiment staging, ″control system - experiment″. It has been shown that the type of the transient process as well as the type of external characteristics of pumps is determined by the magnitude of the system drag coefficient. Characteristic ranges of flow rate and pressure pulsations, both as regards the amplitude and frequency of transient processes as well as the nonlinear effects connected with the startup of high-capacity pumps in a liquid metal loop, have been specified.

The measurement of volumetric flow rate of a liquid-metal heat transfer agent in heat transfer loops is a serious technical problem, which may be solved by applying correlation methods of measurement. The object of the present study is to derive an equation describing the change in the space-time correlation functions of the velocity fluctuation components with increasing the spatial separation and solve this equation for a well-developed turbulent flow of a conducting liquid with axisymmetric mean velocity profile [29].

3. The initial data for calculating heat and power parameters of the building

3.1 The general descriptions of the building

The State Higher Education Institution is located at St. Petersburg, Polytechnicheskaya st, 29 (figure 1).

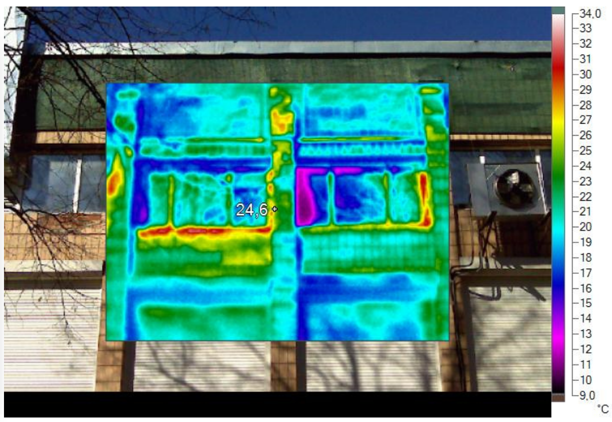

Figure 1. Hydrotechnical building-2

Figure 2. Thermovision photography of “Hydrotechnical building-2”

The general characteristics necessary for further calculations are the following ones:

- the overall height of the building - 24,8 m;
- the heated area - 11180.79 m2;
- the heated volume - 43,605.08 m3;
- the total area of the exterior walls - 14,155.57 m2.

The general data of building services systems have been identified. The heat supply source is the municipal network. The coolant of heating system is water with the parameters of 90 - 70 ° C. HSS is located in the basement of the building. Heating system represents two-pipe vertical system with the lower adherence to the transit pipelines. The heaters represent tube-type radiators. The stop valves (ball valve on the return) and control valves are installed on the all heating appliances. There is a mechanical ventilation.

3.2 Climate and power characteristics

Design temperature of outdoor air during the cold period is equal to 26 ºC. The duration of the heating period amounts to 220 days. Mean temperature of outdoor air of the heating period is equal to 1, 8 ºC. Heating degree day Dd accounts for 5016 ° C•day. Required heat transmission resistance of exterior structure:

- for the exterior walls - R_w = 3,08 (m^2 • ° C) / W;
- for coverings - R_c = 4,6 (m^2 • ° C) / W;
- for windows - R_F = 0,51 (m^2 • ° C) / watt.

Upon thermal camera inspection it has been found out that there were some problematic spots in the buildings envelope. The shooting carried out by thermal imagery device has revealed defects of windows, doors and external envelops. The thermal image reveals the main spots where there are most heat losses. The heat losses are caused by leakage of air through the gap that is between the window and the installation frame. Therefore there is a massive leakage of indoor heat. Because of the non-functioning ventilation system users of the building often open the windows or just the smaller ventilation windows in order to refresh the indoor air (natural ventilation) (figure 2).

4. Thermotechnical calculations

4.1 Calculated (design) value of heat transmission resistance of external envelops

The value of heat transmission resistance of external envelop has been calculated (design. The results have shown that the actual values of the building (values on the left) are a lot lower than the national norms (values on the right). This means that the buildings structure causes a lot of heat losses.

External walls	R_w = 0,8 (m^2 · ºC)/W < 3,08 (m^2 · ºC)/W
Coverage	R_c = 0,88 (m^2 · ºC)/W < 4,6 (m^2 · ºC)/W
Windows	R_F = 0,3 (m^2 · ºC)/W < 0,51 (m^2 · ºC)/W
Doors	R_{ed} = 0,26 (m^2 · ºC)/W < 0,79 (m^2 · ºC)/W

5. Calculation of heat and energy data of buildings

Total heat losses of the building through external envelop including ventilation:

$$Q_h = 0,0864 \cdot K_m \cdot D_d \cdot A_e^{sum} = 0,0864 \cdot 1,67 \cdot 5016 \cdot 14155,57 = 10245074 \left(MJ \right) \qquad (1)$$

Genre heat gain:

$$Q_{\text{int}} = 0,0864 \cdot q_{\text{int}} \cdot z_{ht} \cdot A_l = 0,0864 \cdot 10 \cdot 220 \cdot 7793,6 = 14281407 \left(MJ \right) \qquad (2)$$

Heat gain through windows and glasses from sun radiation:

$$Q_s = \tau_F \cdot k_F \cdot \left(A_{F1} \cdot I_1 + A_{F2} \cdot I_2 + A_{F3} \cdot I_3 + A_{F4} \cdot I_4 \right) + \tau_{scy} \cdot A_{scy} \cdot I_{hor} =$$
$$= 0,78 \cdot 0,76 \cdot \left(1228,1 \cdot 455 + 210,09 \cdot 455 + 787,96 \cdot 902 \right) = 809241 \left(MJ \right) \qquad (3)$$

The amount of energy used for heating of buildings during heating season:

$$Q_h^y = \left[Q_h - \left(Q_{\text{int}} + Q_s \right) \cdot \nu \cdot \xi \right] \cdot \beta_h = \left[102450074 - \left(1481407 + 809241 \right) \cdot 0,8 \cdot 0,95 \right] \cdot 1,11 = 111787191 \left(MJ \right) \qquad (4)$$

ν – coefficient of lowering heat gain at the expense of heat inertia external envelops; recommended value ν = 0,8;

ξ – coefficient of efficiency auto regulation heat supply in heater system (in double-pipe scheme with thermostats and with central auto regulation on bus ξ = 0,95);

β_h - coefficient , inclusive coefficient additional heat consumption of heater system , bond discontinuity of nominee heat flow of nomenclative range of heating apparatus, their additional heat losses through parts of external envelops, higher air temperature in rooms, heat losses of pipes, get through unheated rooms, equal to β_h =1,11.

The external envelops of 5-store building social educational services do not meet standard requirements. Value of defection calculates specific drain of energy for heating of building from standard requirements is -9%. So, it is a building of E class («Very low») on energy efficiency.

The necessary measures to solve the problems of the buildings:

- Modernization and automatization of ventilation system , heater system;
- Exchange of window to plastic double-glazed windows;
- Rise of thermal properties of external envelops;
- Reconstruction of facades.

6. Reconstruction of facades

The calculation results revealed that the level of thermal protection of the subject of the building is considerably lower than current regulatory requirements for the thermal resistance of the building envelope. Thermal imaging survey has showed the most part of heat through the building envelope. The most effective way to solve the problems mentioned above is a reconstruction of the facades with application of highly effective heat-insulating materials for facade insulation.

Today the most efficient insulation include insulation having a thermal conductivity of not exceeding 0.06 W/(m2 * c). The data material must be characterized by the availability of raw materials, low energy consumption and low production costs, have the water resistance and frost resistance, mechanical strength, ecological and fire safety.

It was decided to use insulation system ITE PARISO, which includes:

- insulation;
- layer of the adhesive composition for installation of insulation boards to the bearing wall;
- protective coating.

To determine the minimum thickness of a heater it is necessary to conduct a thermal calculation.

$$R_0 \geq R_{req} \tag{5}$$

$$R_{req} = 3,08\left(m^2 \cdot {}^{\circ}C\right)/W \tag{6}$$

R_1- heat transmission resistance of ceramic solid brick;
R_2- heat transmission resistance of gypsum plaster;
R_3- heat transmission resistance of insulation
R_4- heat transmission resistance of air gap;

$$R_0 = \frac{1}{\alpha_{\text{int}}} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_{ins}}{\lambda_{ins}} + R_{a.g.} + \frac{1}{\alpha_{ext}} = 3,08 \tag{7}$$

$$\delta_{ins} = \left(3,08 - \frac{1}{8,7} - \frac{0,55}{0,64} - \frac{0,005}{0,87} - 0,14 - \frac{1}{23}\right) \cdot 0,051 = 98\,mm \tag{8}$$

δ- the thickness of material;
λ - coefficient of thermal conductivity.

Take a thickness of insulation equal to 100 mm. The section of the wall is shown on a figure 3.

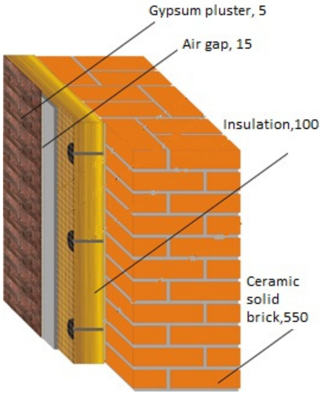

Figure 3. Section of the wall.

Reconstruction of the facades of the building is shown in the figures 4,5. A project of reconstruction has been developed where classic and contemporary styles are combined. In general it is called neo-classicism. The following architectural elements have been used in the project: architectural Doric column, pilasters, rustications, cornices, fascia, rosace and balusters.

Figure 4. Reconstruction of the building.

Figure 5. Night illumination.

7. Resume

The results of energy audit of 5-store building social educational services “Hydrotechnical building-2” have been described and analyzed in this article. There have been performed termotechnical calculations. The class of energy efficiency has been defined. And possible ways to improve the class of energy efficiency of the object have been proposed.

If we compare the values obtained with the normative values for determining the energy efficiency class of the building occupied by the Ministry of Regional Development of the Russian Federation, we can see that the building “Hydrotechnical building-2’ doesn’t meet the standards in many respects. Thus the value calculated for specific drain of energy for heating of building based on standard requirements is - 9%. So, it is a building of the “E” class («Very low») in terms of energy efficiency. Thus the building does not meet the standards required. The results of the inspection and analysis are necessary for further research. One of possible solutions of this problem is the reconstruction of facades with the application of thermal insulation material with the thickness of 100 mm.

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Causes of hotel renovation delays in Egypt

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Abstract

Hospitality is one of the major industries in Egypt due to the country's touristic and business significance in the Middle East. Hotels have to undergo renovation process every seven to ten years to uphold the success of their operations, increase revenues and recognition, maintain and enhance the overall efficiency, and be updated with latest hospitality systems. Renovation requires delicate coordination and reliability between all involved parties throughout all the phases of renovation. Many of the renovation projects in Egypt encounter duration overruns; which have significant financial consequences both in the short and long terms. Despite the constant frequent occurrence of delays during hotel renovations, little research is found discussing this matter in Egypt. The purpose of this paper is to investigate and explore the most influential causes of delays in hotel renovations in Egypt and classify their impacts on time and cost. Findings of this research are important as they will allow owners, operators, project managers, consultants, and contractors to incorporate important aspects in the renovation planning scheduling. Moreover, by identifying the causes of delays and their impacts on time and cost, better plans can be made to mitigate or even avoid these causes from early phases to minimize damages. The results of the research reveal that the most frequent causes of delay in hotel renovation are related to deficiencies in coordination between the involved parties in the execution phase as well as inaccuracies in the planning and design phase that lead to significant changes in the execution phase. Other factors such as change orders by operator, unfit choice of tendering method, and political unrest are also found to have great impacts on renovation cost and time.

Keywords: causes, delays, Egypt, hotel, renovation.

1. Introduction

1.1. Definition and Importance of Renovation

Hotel Renovation is defined by Hassanien & Baum (2001) as "The process of retaining or improving the hotel image by modifying the tangible product, due to a variety of reasons, through any changes in the hotel layout (e.g., property structure-new extension) and/or any additions or replacement of materials and furniture, fixture & equipment". Renovation is a process that encompasses a wide range of activities that can be categorized under replacement, restoration, redesign, re-decor, reinstatement, etc. Since renovation is concerned with hotel image, it can be classified as a very powerful marketing tool.

Hotel renovation is a very essential and unavoidable process for the success of hotel operations. The renovation process have to underwent every five to ten years to uphold the success of hotel operations, increase revenues and recognition, maintain and enhance the overall efficiency, and sustain the up-to-date status with the advances hospitality systems. To upgrade existing hotels, the broad options are either to renovate or re-construct. Usually in this case renovation is the commonly selected option. This can be tracked to many reasons such as the lack of prime and spacious sites for demolition and reconstruction, and time saving and continuing appreciation of historic architecture (Ruttes et al., 2001). Furthermore, finding funds to renovate hotels is much easier than finding funds to build new hotels (Jurgens, 1992; MacDonald, 1995; Ruttes et al., 2001). The American Hotel & Motel Association conducted a survey that revealed that 97 per cent of its members are more likely to renovate their properties than to build new hotels (Paneri and Wolff, 1994). Accordingly, renovation is a very important aspect in any hotel's lifetime that has to be well-studied and well-planned. Renovation leads to better performance through achieving both profitability and guest satisfaction (Hassanien, 2006). It is for these reasons that Hassanien and Baum (2002) claim that at any point in time almost every hotel has recently undergone renovation, is currently in the process of renovation, or is waiting to be renovated.

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1.2. Types of Renovation

Renovation can be classified into several types according to the time intervals taken between renovations and the amount of work involved with each type. Stipanuk and Roffmann (1996) and Hassanien (2002) classify renovation types as minor, major, and master renovations. Minor renovation denotes to replacing or renewing furnishings that are mainly non-durable such as carpeting. So basically minor renovation is concerned with relatively minor changes without affecting or changing the hotel image. Major renovation denotes to replacing or renewing all furnishings, equipment and finishes in a certain area in the hotel. This is made to partially improve the hotel image. An example of this type of renovation is shutting down five floors for an amount of time to totally remove all of their furnishing, equipment, and accessories and replace them with newly designed alternatives with installation of up-to-date entertainment capabilities. Master renovation involves changing the hotel image partially or fully. This type of renovation is more comprehensive than major renovation and it involves the entire property. An example of this renovation type is closing the whole hotel for a period of time for full renovation and replacement. Major and master renovations are the types that are considered in this research because their durations, amount of work, and criticality are more significant that those of the minor renovation.

1.3. Previous Research

It is observed that previous research on hotel renovation problems and obstacles in Egypt is almost non-existent. The actual research found was discussing the obstacles prior to renovation such as lack of funds; however, an Egypt-oriented investigation of the causes of delays and their impacts throughout the process of renovation has not been focused upon in research papers prior to this research in hand. Even generally, previous research on hotel renovation from an engineering point of view is very limited.

A case study conducted by Hassanien (2006) on six five-stars hotels revealed that most Egyptian five star hotels use renovation as a reactive rather than proactive tool for property management. It also showed that the economic recession that took place in the 1990s affected renovation plans of the majority of the cases. Owners were found to be greatly involved in the execution of renovation in most hotels. The cases showed also that the aims and goals of performing renovation by Egyptian five star hotels are different. Organizations with clearly stated renovation strategies have more successful renovations with minimal interruptions and over-runs. Such organizations do always have a sound relationship between the managing and owning companies, sufficient funds, and greater customer involvement. Although this study is oriented to hotel renovation in Egypt, it was focused on the methods of renovation rather than the factors causing duration over-runs.

An earlier research reported by Hassanien (2005) revealed that owners are the main barriers to renovation in mid-scale hotels. Further, the research also showed that among the barriers to renovation in Egypt, general managers ranked lack of money, lack of appropriate in-house experience and lack of suitable manpower as the main deterrent to renovations in that order.

Hassanien and Baum (2002) conducted a questionnaire for hotel representatives in Egypt using the non-probability (judgmental) sampling method with the objective of sampling the hotels of Egypt. One of the outcomes of the survey was to investigate the obstacles to initiate renovation to hotels in Egypt. That research is the closest topic to the topic of this paper in hand. Hassanien and Buam’s research revealed that many of the obstacles facing hotel renovation in Egypt are that the owners; where they do not really value renovation as a marketing tool. Even lacking money for renovation is seen as the owners’ fault.

It can be assumed with confidence that the previously mentioned research subjects are almost the sole research work that has been conducted in hotel renovation in Egypt. So, the topic of studying delays in hotel renovation in Egypt during the renovation process itself is still a fresh topic that has not been tackled as a subject of a published research before.

1.4. Objective

The aim of this research is to investigate and explore the main factors causing duration over-runs –referred to as delays in this paper - in hotel renovation in Egypt for the past ten years. The paper presents also the impacts of the obtained causes on both duration and cost of renovation. The paper discusses as well the best methods to respond to the causes of delays throughout the different techniques of mitigation, transference, and even avoidance.

2. Methodology

The research process was made on two steps. The first step was to interview a representable number of experts in the hospitality field in Egypt for the purpose of identifying and categorizing the common problems and obstacles causing delays to the hotel renovations in Egypt. The interviewed experts were selected based on the following criteria: 1) they must have more than 20 years of experience in the hospitality field in Egypt, 2) each of the experts must have been involved personally in at least one major hotel renovation. The experts were selected from different specialties – owners, operators, consultants, and contractors - equally to ensure the final output is not bias.

After finishing the first step and identifying and categorizing the causes of delays, a questionnaire was made using these outcomes and distributed to a larger number of experts using direct contacting and emails. The distributed questionnaire listed all the causes that were obtained from the first step in a tabulated format and requested the experts to mark the suitable option according to their opinion and experience in front of each cause. The causes were judged according to the following its three classifications:

- The occurrence (probability); this answers the question of: How often does this cause occur?
- The impact on duration; this answers the question of: Shall this cause occur, what will be its impact on the duration of the renovation process?
- The impact on cost; this is to answer the question of: Shall this cause occur, what will be its impact on the cost of the renovation process?

The questionnaire was qualitative and its results are presented in this paper.

3. Step 1: Identification of Causes of Delay

After conducting interviews with experts in the hotel industry in Egypt, the main causes of delays were identified and categorized into five categories: 1) delays caused by design and estimation factors, 2) delays caused by financial factors, 3) delays caused by construction-related factors, 4) delays caused by mis-coordination among parties, and 5) delays caused by external factors; where these categories are further broken down listing all the main causes of delay that are discusses in this research. For the purpose of this research, delay refers to the duration over-runs in the renovation process.

3.1. Delays Caused by Design and Estimation Factors:

Design mistakes contribute to hotel renovation delays in Egypt. In many cases, due to the fast-track nature of the design process and the constant requests by operators to the designers to finish earlier than planned, the designers produce un-coordinated drawings where the design drawings do not exactly match the existing conditions. When contractors start working and find these contradictions, they immediately request design modifications to be able to work properly. This design review and re-coordination efforts expend additional time and cost. Duration over-runs caused by this type of design mistakes can be avoided by good cooperation practices between operators and designers; in other words, operators should grant designers access to existing facilities and to required data to allow them to obtain accurate as-builts and hence design accurately accordingly. Operators shall inform designers of the allowed design duration beforehand and designers should abide by the design milestones given by the operators.

Sometimes even if the designs are well coordinated, the quantities might be estimated wrongly due to shortage of time for revision. Although contractors shall revise the quantities before execution, they fail to do so in cases where operators do not give them enough time to revise or where the hired contractors are not experienced enough. Therefore, contractors estimate their prices according to incorrect quantities; which causes many financial troubles during execution, resulting in claims and variations that, although their effect would be more significant on cost, may cause duration over-runs. Such incorrect estimation of quantities is the responsibility of both designers and contractors. To prevent faulty estimation of quantities, designers are recommended to use the BIM - Building Information Modeling - technology in the design process, where quantities from a BIM Model are extracted to a cost database or an excel file directly to eliminate human error in take-off (Hergunsel, 2011). However, good care should be taken while using the BIM technology, the data output is as good as the data input, so it is very important to have the designers and contractors to agree on component definitions (Hergunsel, 2011).

One of the estimation-related mistakes leading to duration over-runs is under-estimation of activities' durations and relationships. Planning and forming the construction schedule accurately is a task that requires experience and good knowledge of the available resources. Under-estimation of available resources during the planning phase definitely causes duration over-runs during execution phase. When contractors assume they have certain amounts of resources, they obtain certain durations for activities. Then if during execution the actual resources are less than those that were planned, activities' durations will increase causing duration over-runs. Important durations that need to be carefully and delicately planned are the durations related to procurement, testing and commissioning. Contractors have to contact suppliers, especially overseas ones, prior to scheduling durations for procurement in order to obtain suitable ranges for procurement and shipment durations with accounting for contingencies. If shipment of a certain machine arrives later than scheduled, it negatively affects the successive activities. If shipment of a certain machine arrives earlier than schedules, it will be a problem as well because it will require additional storage time; which will incur additional costs (Swidler, 1998).

3.2. Delays Caused by Financial Factors:

Financial problems can occur due to under-estimation of renovation costs. The under-estimation can be in either the costs of materials, transportation, labors, equipment, or even the cost of the design itself. Once the renovation process starts with under-estimated costs, options become very limited. The operator will have to choose either to use less costly materials –which will sacrifice the planned quality– or to accept the incurred actual high costs. The option of redesign or value engineering becomes no longer valid after commencement of renovation works. Under-estimation of cost in the planning stage can be avoided by conducting a good market study and by formulating a comprehensive and updated database for the costs of the available materials, equipment, and labor. Sometimes, even if the costs were estimated very accurately in the planning phase, some material prices increase during the execution phase; which is beyond the control of the estimators. In this case, the renovation costs will increase inevitably. Contractors immediately claim the additional costs right after they're incurred, and if these claims were not responded to by the operators within suitable time, contractors may reduce their pace or even stop execution of works; thus causing delays that are contractually excusable. For that reason, operators must have additional funding as contingency to account for the unexpected material price increases.

In stable cities, the market for hotel financing is growing and has opened up compared to prior years. In Egypt, the conditions in the past three years were not stable economically and politically; and reflection of this instability is observed as financing of ongoing renovation has stopped due to these conditions. Another factor is the stability of the asset itself. Alex Samek, principal of Kor Group, claims that if the operator has a stabilized asset that is performing well, many financing doors will open to him (Azevedo, 2013). So in order to find good financing options, the operator have to show the financers a stable performance of the asset prior to the renovation. Additionally in order to keep the financing flowing through the renovation works, the external conditions have to maintain their stability, which is something that is not controlled by any party.

3.3. Delays Caused by Construction-related Factors:

One of the important aspects that should addressed during the planning phase of any renovation is the work plans; this includes planning the maneuvering routes for the contractors and their personnel. Guests should not be able to see the workers or the equipment during their stay so the operators should specify certain areas for workers entrances and circulation, loading and unloading of equipment and materials, and utilities for workers and engineers. Amy Locke, director of interior design in Hatchett Hospitality, states: "your goal for the hotel is to return rooms to service as quickly as possible - while your goal for guests should be to prevent them from feeling as if they're staying in a construction zone". Hence, an important aspect of work plans is the planning of buffer zones. This point is addressed by all of the interviewed experts. Buffer zones are used to ensure that the noises and smells resulting from the renovation activities do not reach the guests causing discomfort to them. Buffer zones are called the "out of revenue" zones because they are zones with idle rooms and facilities. Other aspects in the work plans are the working hours. Experts prefer to limit the working hours to daytime hours as this time is the time that most guests are not physically in the hotels. Operators, along with contractors, should also plan to not expose finished areas to unnecessary construction traffic and dirt from areas that are still being worked on or else they will undo the renovation efforts that have been made and cause duration and cost over-runs.

The purpose in this paper is not address planning problems, but rather to investigate the causes of delays during the execution of renovation. However, planning and execution are closely correlated. If the work plan has been made, changing it during construction would cause delays in most cases. If the operators keep changing work plans such as buffer zones, working hours, or maneuvering areas due to mis-coordination with other hotel operations (restaurants, wedding halls … etc) it would definitely cause delays in the execution of works as it will cause confusion to the contractors and interruption to their planned activities. In Egypt, only five star hotels have decent manuals containing instructions for hotel renovation. Accordingly, operators change their requirements in the middle of the renovation process. These change orders present golden chances for contractors to claim for additional costs and durations, causing delays in the renovation process. Other construction-related problems include the failure of operators to provide suitable locations for material storage at times. Solving such problems require good planning by the operators. Operators should be fully aware of their capabilities and constraints before the execution of works.

The contractor is a very important party to look at while identifying the causes of delays. For any reason contractors may have slow productivity rates leading to duration over-runs. Of course such delays are not excusable, but they can happen. To prevent delays caused by contractors' insufficient productivity, Strict follow up procedures should be taken to alert the contractors and warn them contractually. Delays can also be incurred due to bad quality of work by contractors. Bad quality is rejected by the supervision consultants thus contractors repeat the rejected works until approval. Such delays are also the responsibility of contractors.

During conducting the investigation for this research, a very important point was raised by one of the experts; which is the contractor's involvement in the planning phase of the renovation. If operators made the work plans (maneuvering routes, buffer zones, storage areas, working hours …etc) all by themselves and gave the plans to the contractors, the latter would face problems during execution because operators will be missing out some issues related to the contractors in the work plans. On the other hand, renovation projects where contractors are involved in the planning stage actively from the beginning are less commonly to face duration over-runs because the work plans will cover all aspects and both the contractor and the operators would have the same full understanding of the plan because they both participated in it.

3.4. Delays Caused by mis-coordination among Parties:

According to the interviewed experts, heavy involvement by operators in the renovation process is very essential and it is very much correlated to the success of the renovation to be completed on time and budget. Even problems initiating from contractors or designers can be linked to the weak involvement of operators; thus making the renovation success very sensitive to the operators' involvement. Operators have to follow up extensively with contractors and designers and have to take corrective actions as soon as any signs of over-run-causing incidents appear. Since renovation is a very delicate process where every single day matters, late decisions or approvals by operators or owners –a problem that can be considered problems related to mis-coordination– effectively cause duration over-runs due to the fact that the majority of the "approval" activities are either on the critical path or have very small floats in renovation projects. Avoiding late approvals is achieved by following strong communication pre-agreed plans where every party knows his responsibilities and the cycle of every document is preset and clearly known. In addition to this, operators have to be alert to requests or queries from the contractors.

The interviews also revealed that the presence of more than one main contractor is destructive and is one of the causes of serious delays in renovations. When an operator signs agreements with several contractors to work simultaneously or preceding each other; each of the contractors will try focus his efforts to find mistakes of the other contractors then will claim that work cannot be proceeded without fixing the found mistakes, then the other contractors will defend themselves and will focus on proving that the mistakes were not existing at there presence and so on. This hassle is very destructive and usually even experienced operators do not have the ability to keep the smoothness of work in this situation. So, experts recommend the hiring of only one main contractor with good project management capabilities and let him hire as much sub-contractors as he requires; this is beneficial for two main reasons. The first reason is that experienced contractors have the ability to control sub-contractors and ensure their timely submissions. The second reason is that the contractual responsible party for any delay can be recognized easily; even if one or more sub-contractors caused delays or damages, the main contractor will be the one to contractually question.

3.5. Delays Caused By External Factors:

Some factors causing delays in renovation projects originate from external influences beyond the control of the contractual parties. Examples of external factors are difficulties of getting the required permits –especially occupation and operation permits and Civil Defense Authority requirements, unavailability of some materials in the local markets, non-availability of skilled labor for similar kinds of finishing works, guest complaints leading to holding the renovation for a period of time or to increasing the buffer zones, and political unrest. It should be noted that since 2011, Egypt faced political unrest that was the main reason for suspension of hotel renovations and even operations. However, before that date Egypt enjoyed political stability and this was reflected in the outcomes of Step 2 in this research.

4. Step 2: Analysis and Discussion of the Causes of Delay

The compiled factors causing duration and cost over-runs in hotel renovation projects in Egypt are compiled and shown in Table 1. These factors were obtained from the interviews –from step 1– and they were used in the questionnaire –Step 2.

Table 1. Factors causing increase in time and/or cost of hotel renovation in Egypt

Design and Estimation	1	Design Mistakes (contradictions between design and existing conditions)
	2	Wrong estimation of quantities as well as wrong / incomplete specifications
	3	Underestimation of renovation required logical duration for completion
	4	Under-estimation of testing and commissioning duration as well as soft opining and grand opining durations
	5	Under-estimation of the required labor resources for the renovation
	6	Wrong choice of contractual procurement methodology
Financial	7	Under-estimation of renovation costs by operator
	8	Difficulties in financing (insufficient funds)
	9	Unexpected increase in material prices
	10	Delay in payments to contractors
Construction-related	11	New requirements by operator
	12	Operator constantly changing working hours due to mis-coordination with other hotel operations (restaurants, wedding halls …)
	13	Operator constantly changing work plans (maneuvering routes, buffer zones ...) due to mis-communication with other hotel operations
	14	Lack of possibility of maneuvering and access on site
	15	Low contractor productivity leading to delays
	16	Losses in operation due to large buffer zones
	17	Poor workmanship leading to rejection and repetition of work
	18	Limited spaces on site for material storage and the like
	19	Non-Involvement of Main Contractor in the Main Planning Phase
	20	Late Delivery of materials
	21	Variation orders by owner
Mis-coordination	22	Delay in taking decisions and permissions by operator
	23	Delay in taking decisions by owner
	24	Delay in taking decisions by consultant
	25	Lack of coordination between procurement team and contractor
	26	Large number of different discipline contractors and miss-coordination between them
	27	Demanding requests of interior designer and late decision making
	28	Lack of experience of the interior designer or lack of cooperation
External	29	Guest complaints leading to holding the renovation for a period of time or to increasing the buffer zones
	30	Difficulties of getting the required permits , especially occupation and operation permits and Civil Defense Authority Requirements
	31	Unavailability of some materials in the local markets
	32	Non-availability of skilled labor for similar kinds of finishing works
	33	Political Unrest (before 2011)

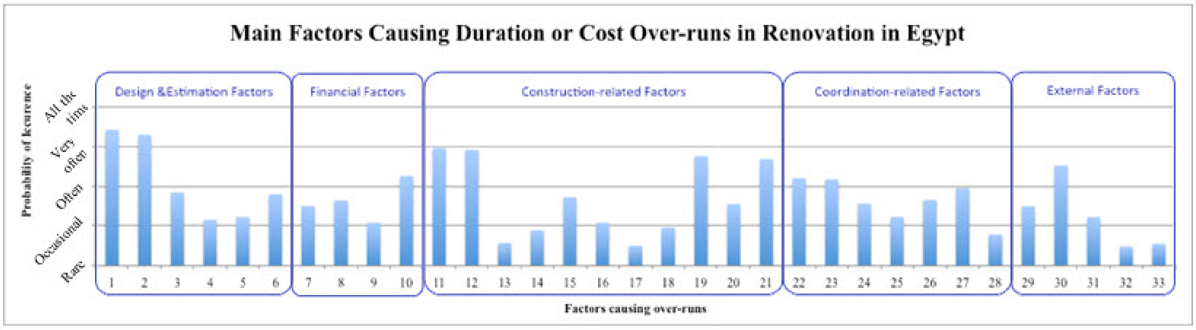

Figure 1. Main factors causing duration or cost over-runs in hotel renovation projects in Egypt

It is noticeable in Fig. 1 that design mistakes and inaccurate quantity estimation occur very often in renovation projects. Further discussion with the experts have shown that all parties blame one another for these two factors; meaning that operators and contractors hold the designers liable for such mistakes in designs and estimations produced by the designers. On the other hand, designers hold the operators accountable for such mistakes because operators usually don't have correct as-built drawings so designers start their designs based on improper data. Another problem that seems to occur very frequently is that operators make changes while the renovation process is ongoing by either adding new requirements or by changing working hours. This is usually can be tracked to the weak planning of operators in Egypt and mis-coordination between the different hotel operation such as restaurants and wedding halls. One problem that is almost non-existent in the western countries but occurs frequently in Egypt is the difficulties obtaining renovation-related permits on time. Even if the permits are obtained on time there is a big chance of the authorities to cancel the permits or demand additional requirements in the middle of the renovation process. According to the interviewed experts, in order to ensure smooth renovation the operators have to be well experienced in the permits issues; if not they would have to hire personnel specialized in obtaining permits. Finally, a problem that is seen by most of the experts to high occurrence rate is the non-involvement of the main contractors in the planning phase of the renovation; this problem has impact on the renovation duration and cost.

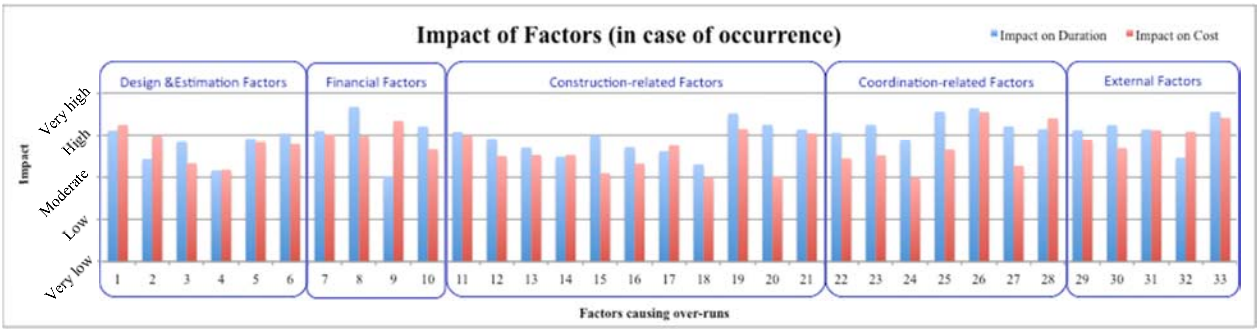

Figure 2. Impacts of the factors causing duration or cost over-runs in hotel renovation projects in Egypt on duration and cost

Although a certain pattern of agreement is observable in the occurrence of causes of delays (Fig. 1), the experts have shown a high variety of opinion ranges in the impacts on duration and cost (Fig. 2) thus showing no clear pattern in the impacts. The only observable pattern in Fig. 2 is that all factors fall within the critical range where they all have high impacts on durations and costs. Even factors with low probabilities of occurrence have high impacts on renovation duration and cost. An example of this is the political unrest; which is very unlikely to happen according to Fig. 1 –before 2011– however in case of its occurrence it would have a very high impact because during any political unrest investors and financiers tend to hold back their investments, in addition to the security conditions that forces the operators to shut down hotel operations. Another example is the involvement of many main contractors in the renovation process. Although it doesn't occur much often (Fig. 1), but in case of its occurrence (Fig. 2) it causes high implication on the duration and cost. A more detailed explanation of this problem is stated earlier in the paper.

Usually the impacts on duration of factors causing delays are larger than the impacts on cost as shown in Fig. 2. According to the conducted study, this is due to the fact that time cannot be compensated with time, however both cost and time can be compensated with money by delay damages and contractual penalties. However there is small number of cases where the impacts on cost is higher than the impact on duration such as the wrong estimation of quantities and the unexpected increase in material prices. Significance of impacts of such factors is more concentrated towards cost rather than time.

5. Conclusion and Further Development

Hotel renovation in Egypt faces many problems that cause duration and cost over-runs. A series of interviews were made with experts in the hospitality field in Egypt that resulted in identifying the most important 33 causes of over-runs in Egypt. After identification of factors, a questionnaire was made to determine the probability of occurrence and impact of these causes on duration and cost. It was found that factors causing over-runs can be categorizes into five categories: design and estimation factors, financial factors, construction-related factors, mis-coordination among parties, and external factors. Some factors are the sole responsibility of operators, such as change orders. Some factors are the sole responsibility of the designers, such as incorrect estimation of quantities and late reply to queries. Some factors are the sole responsibility of the contractors such as slow productivities. Some factors have joint liability such as difficulties in coordination between several main contractors on site. Other factors occur without any contractual party liable to them such as political unrest. It was concluded that hotel renovations require very strong communication between parties as well as robust management and follow up by the operators to ensure meeting the planned duration and budget. In fact, the operator is the key player in the success of renovation process due to the fact that the strength of the operator's involvement is strongly correlated to the success of renovation on schedule and budget. Most of the delays can be traced back to the operator's poor involvement. Experienced operators try to prevent themselves and even other parties from causing any delay-causing problems. This research is very beneficial to hotel owners, operators, designers, and contractors, as it will supply them with key factors that should be taken into consideration while preparing the risk management plan for any upcoming renovation project. Of course each hotel has its own circumstances; not all factors will have the same impact on duration and cost in all hotels, but they will all revolve around the values obtained in this research. For further development in this topic, it is recommended to perform a quantitative questionnaire and analysis to explore more details about the causes of delays and their impacts. After conducting such study it would be recommended to validate the outcomes by comparing them to an ongoing renovation project.

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Environmentally friendly construction products selection based on building model data

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Abstract

This paper presents the conceptual framework for the decision making support system which would allow to optimize building's environmental performance by supporting the environmentally friendly construction products selection process. Moreover, it identifies the elements of the proposed system that could be realized with currently available technologies and resources, and reveals the areas in which there is still a need for development.
In order to develop the scheme of the construction products selection support system several issues were analyzed, namely: European standards for the assessment of the environmental performance of buildings, selected building rating systems, Building Information Modeling (BIM) concept; BIM data exchange schemata (IFC, gbXML).
The main components of the system are: the source of the functional requirements for the construction products (i.e. building model compliant with IFC data schema); the source of the product data (i.e. database of the construction products available on the local market); selection optimizing methodology (for this purpose the paper proposes utilizing the construction products property data scope based on EN 15804 standard criteria weighting factors based on the OPEN HOUSE methodology).
There are also identified areas that still need further development in order to fully exploit the potential of BIM-based decision support tools for the environmentally friendly products selection.

Keywords: BIM; construction products; decision support; specification; sustainability;

1. Introduction

Construction, as most of the industry branches, is constantly facing new challenges as consumers expectations and legal obligations are becoming more and more demanding. Nowadays, buildings are expected to be consistent with the sustainable development rules, which means that they have to excel in the three essential areas: social performance, economic performance and environmental performance. The first two issues have existed in the construction industry for a long time. Construction experts are familiar with them and they have at least basic knowledge how to assess potential solutions in their context, whether using calculations or intuition, and how to act to achieve the desired results. Environmental performance however is definitely less understood. There is no global formula that would allow to conclude that one solution is better than the other in the context of environmental impact (Ding, 2008). Furthermore, it is unclear what range of environmental characteristics of buildings and their constituent elements should be taken into consideration, but it is undeniable that many of them. Thanks to the worldwide efforts, numerous tools facilitating sustainable construction have been developed up to this day, e.g.:

- various building sustainability assessment systems, such as commercial systems, of which two are considered to be most common (Schwartz & Raslan, 2013): BREEAM and LEED, or Open House methodology, developed within the EU's Seventh Framework Programme for Research (FP7) (Open House Project, 2013);
- guidelines for the qualitative assessment of buildings environmental performance, such as LCA methodology and the European standards set "Sustainability of construction works" (EN 15643-2 "Assessment of buildings - Part 2: Framework for the assessment of environmental performance" , EN 15798 "Assessment of environmental performance of buildings - Calculation method", EN 15804 "Environmental product declarations - Core rules for the product category of construction products"), which specify the system boundaries and calculation rules (Piasecki, 2012);
- simulation tools that allow to assess some environmental characteristics of building design, and therefore give possibility to compare different building design variants (Schlueter & Thesseling, 2009) (Adamus, 2013).

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One of the crucial goals that have to be achieved in order to meet sustainability expectations towards buildings is addressing the potential of the innovative data management technologies, improving accessibility of the environmentally relevant data, intensifying its sharing and reuse during all the building lifecycle stages, and supporting its processing (Watson, 2011). At the same time the construction industry experiences rapid development and increasingly wide adoption of BIM (Building information Modeling) concept (Fox et al. 2014). One of its most significant advantages is the automation of building data transfer and reuse. Digital model of building can also be utilized as a source of data for decision support systems.

One of the essential parts of the construction process which greatly affects the buildings environmental performance is the selection of the construction products to be used (Akadiri et al., 2013)(Franzoni, 2011). Due to the specificity of the construction industry and the issue considered, many multi-criteria decisions that require considering a huge number of possible solutions which are characterized with many parameters have been involved (Czarnecki & Kaproń, 2010) (Emmitt & Yeomans, 2008). Because of that, it is particularly important to provide building design process participants with software tools which would allow to efficiently perform environmentally friendly construction products selection based on a wide range of precise data.

This paper presents the conceptual framework for the environmentally friendly construction products selection decision support system. Moreover, it identifies the elements of the proposed system that could be realized with currently available technologies, methodologies, standards etc., and reveals the areas in which there is still a need for development.

2. Environmentally friendly products and materials selection as a decision problem

Every construction process aims to meet the needs of the investor related to the functionality and sustainability in the most effective manner. This also applies to all individual stages of the process, including the two phases of construction products and materials selection (Franzoni, 2011):

- on the general design level, when the major assumptions are made (e.g. if the building will be wooden or concrete) and building elements dimensions and functional requirements towards them are defined;
- when specific construction products and materials available on the market are selected.

In the former phase the designer makes his decisions taking into consideration many parameters, such as functionality, visual features, environmental performance, etc. These decisions can be based on his professional knowledge and experience or external guidelines. They can also be supported by decision support systems (Basbagill et al., 2013). In this phase only statistical data about materials and products is available, which causes uncertainities in building assessments (Hoxha et al., 2013).

The latter phase could be performed by one of the designers (specifier) or by the contractor (Emmitt & Yeomans, 2008), depending on the adopted workflow model. Selected products and materials have to comply with the requirements set by the designer in the most effective manner, i.e. having the lowest cost and the least environmental impact. Because of a growing pressure on reducing costs and achieving higher environmental performance this kind of decision problems is becoming more and more difficult.

The conceptual framework for decision support systems presented in this paper relates only to the second phase of the selection process. It is assumed that before the decision process certain information about building (i.e. location and estimated service life) and its elements (i.e. type, shape and minimal performance requirements) is determined and provided to the decision maker. Therefore, the role of the decision maker in the last phase of the selection of the products and materials is to choose adequate products from the local market which will meet the functional requirements while minimizing cost and environmental impact.

In the above context, this phase of materials and products selection can be considered as a multi-criteria decision problem, where the cost and the environmental performance are the selection criteria, and products accessible on the market that meet the functional requirements are the feasible solutions. In this approach the environmental quality is a complex criterion which encloses many internal criteria adequate to the various environmental impacts. The value of the specific solution can be calculated as follows:

$$V = a_C C + a_E E \qquad (1)$$

where C is the solution value in terms of cost, E is the solution value in terms of environmental performance, a_C and a_E are the respective weighting factors. Analogically, environmental performance can be calculated as follows:

$$E = \sum_{i=1}^{n} b_i E_i \tag{2}$$

where n is the number of environmental assessment criteria, E_i is the value of the solution in context of the i criterion, b_i is its respective weight.

Both cost and environmental performance of product or material considered as a potential solution have to be assessed taking into account the cost of transport from the distribution point to the construction site and its environmental impact, the necessity of replacement, if the reference service life of product is longer than the reference service life of the designed building (Hoxha et al., 2013).

During the second phase of construction products and materials selection, the primary problems for the decision makers are (Emmitt & Yeomans, 2008):

- acquiring information about construction products and materials accessible, especially their environmental properties;
- assessing the environmental performance of products and materials (even if numerical values of their environmental properties are known);
- quantity of building elements types which causes the necessity to perform the selection multiple times;
- processing a large amount of data in order to evaluate all possible solutions against appropriate criteria.

In practice, the most common approach is not to make a decision based on comprehensive knowledge about the problem, but rather to choose well known, previously used solutions. It hinders the diffusion of innovations and sustainability in construction industry(Akadiri et al., 2013)(Emmitt & Yeomans, 2008).

The process of products and materials selection is considered to be difficult and requiring the support of information technologies (Akadiri et al., 2013)(Franzoni, 2011) as buildings are more and more commonly designed in line with BIM concept (information about building design). This paper proposes the conceptual framework for the construction product selection decision support system which would improve the process and eliminate main problems faced by the decision makers, using digital building model as a source of information about the elements needed.

3. Framework for the decision support system

3.1. General schema

Proposed decision support system framework is based on the assumption that during one decision process only one type of construction product is selected (selecting products and materials for the whole building requires a certain amount of repetitions of the process). It consists of 4 main areas (Fig. 1): a source of information about the designed building and the requirements towards its elements, decision maker preferences regarding the relevance of decision criteria, methodology that allows to assess environmental performance of solutions, and information about construction products available on the market. The first two of them are specific for every single decision process (but may be constant for many decisions regarding the same object), another two are immanent components of the system. Important issue which concerns many components of the system is the scope of the parameters characterizing construction products and materials, both functional and environmental, that are taken into consideration. Information about functional performance of products and materials accessible on the market must be sufficient for the purpose of verification if they meet the requirements specified in the building design. Information about their environmental features must be sufficient to the purpose of their evaluation in the context of the assessment methodology used by the system.

3.2. Digital building model as a source of requirements towards construction products and materials

Nowadays, in countries with a highly developed construction sector, the majority of building designs are created in line with the BIM concept using BIM based software (Fox et al., 2014). This means that all the information created on the design stage should be stored in a well-structured, digital form and should be accessible for automated use in following stages of buildings lifecycles.

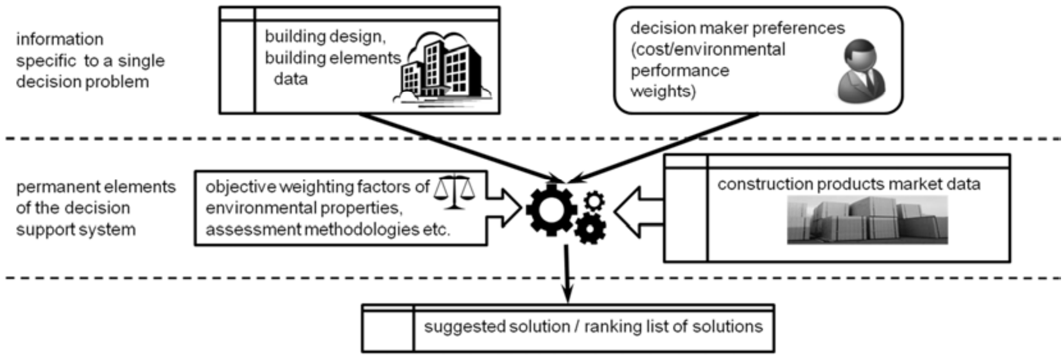

Figure 1. Decision support system components

Digital building model is created by adding subsequent building elements and defining their properties, such as shape, size, purpose, functional performance, etc. The components the designer puts into a model can be generic (abstract, not referring to really existing products) or proprietary (representing really existing products of a particular manufacturer, containing their actual properties) (Jones, 2011). They also can have various origin. They can be created by the designer himself for the current model, copied from one of the previous models (reused) or downloaded from repositories of CAD software vendors, construction products manufacturers or independent organizations (Kusy, 2013). Therefore, besides the shape and the size, they can contain various functional properties that are introduced into the building model. For the purpose of using the building model as a source of the requirements towards construction products and materials, it is crucial to identify the set of functional properties which are considered by the designer as critical for the buildings performance. The values of these properties can be used as the threshold requirements for the products and materials selection process.

Depending on the relation between a building model component and the products or materials required to realize represented element of the real building there can be distinguished several types of situations, when single building model component represents:

- a building element consists of a single construction product (e.g. window);
- a building element consists of many construction products of the same type (e.g. single layer brick wall);
- a building element consists of many layers (e.g. two-layer wall – brick and insulation);
- prefabricated precast concrete building element;
- a building element made of cast-in-situ concrete.

Each of them requires different approach to the calculation of construction products and material quantity procedure.

Since there are many BIM based design computer programs, and many of them use proprietary data models and file formats to store the building models, there is a need for the platform neutral, open data scheme that would allow for transferring data among the software produced by various vendors. There are two most prevalent open data models available nowadays which are used for the purpose of the exchange of information about buildings, including environmental features – gbXML (Green Building XML) and IFC (Industry Foundation Class). The gbXML schema is easier to implement but does not include all building (and its elements) information relevant for an environmental analysis, and in its current version it is rather targeted towards energy simulations only (Dong et al., 2007). IFC gives more possibilities regarding the scope of building elements data (Adamus, 2013), and therefore its use is suggested as the data model for the input data for the decision support system.

IFC 4 (ISO 16739) is an open data schema developed with the purpose of describing all aspects of building in its whole lifecycle within digital building model. Storing information about building elements functional properties can be done by assigning property information explicitly to the single element, by assigning a group of elements to the previously defined type of elements to which properties are assigned, or by assigning material to the single element (or a type of elements) and assigning properties to the material. What is more, IFC allows to define constraints - limiting values or boundary conditions which may be applied to an object or to the value of a property. This functionality can be used to distinguish properties of building elements that are crucial for achieving buildings performance planned by the designer from those that are simply derived from downloaded building model components. IFC also allows to define geographical coordinates and the estimated service life of the building.

Because of some specific requirements towards the building models that would be used as a data source for the system, there is a need to develop guideline documents specific for IFC: MVD (Model View Definition, defining the subset of the IFC data schema designed for specific applications) and IDM (Information Delivery Manual) defining the data exchange requirements (its scope, structure etc.).

3.3. Construction products data source

Construction products and materials accessible on the market are the potential solutions of the considered decision problem. To accurately assess the value of a single construction product or a unit of material it is necessary to take into account its summary cost and environmental impacts, resulting from the manufacturing process, transport to the construction site and possible replacements during the building lifecycle. Therefore, the scope of information about the product has to include several elements with various origins:

- environmental and functional properties, estimated service life determined by the manufacturer;
- accessibility (information if it is possible to purchase requested amount of product or material at the moment), unit price and the distribution point location determined by the distributor.

The scope of the environmental properties should be consistent with the adopted assessment methodology. It also should be well defined and recognizable within the construction products industry. The European standards for the assessment of the environmental performance of buildings (EN 15978, EN 15804) define a certain set of indicators describing environmental properties of products and materials.

The scope of the functional properties should reflect potential possibilities of the requirements that the designer can define, so that it should be developed consistently with the Information Delivery Manual for building models.

It has to be guaranteed that the information stored in construction products and materials database is always up to date, especially regarding their accessibility at particular distribution points. Due to this fact, it is necessary to guarantee cooperation between the database and distribution points of warehouse management systems. Another important issue is data quality and reliability (Kusy, 2013). It is advisable to enforce supervision of an independent organization over the products and materials data provided by their manufacturers.

3.4. Evaluation of solutions

The first step of evaluation construction products and materials as the solutions of the decision problem is checking whether their functional properties meet the requirements set by the designer, obtained from the building model. Those that do not satisfy this condition are immediately rejected. The remaining ones have to be evaluated according to their cost and environmental performance.

In order to acquire comprehensive data, the price of product or material in the distribution point and its environmental properties declared by the manufacturer have to be summed up respectively with cost and environmental impact caused by the transport to the construction site. Assessing real values resulting from transport before it takes place may be very challenging or even impossible.

Every product and material has to be evaluated firstly in the context of environmental criteria and secondly in the context of environmental performance and cost, accordingly to the equations (2) and (1). The environmental performance should be calculated on the basis of a widely adopted, reliable methodology which would provide guidelines for the evaluation of construction products and materials in the context of the environmental criteria (E_i in equation (2)) and their weights– b_i in equation (2). Moreover, it is advisable that the results of the construction products and materials assessment methodology reflect their influence on the whole building assessment result and its possible marketing value. This would allow the decision maker to estimate, at least intuitively, potential market benefits resulting from the environmental advantage of one solution of the decision problem over another. For the purpose of this paper three building assessment systems were analyzed: LEED, BREEAM and Open House. In both LEED and BREEAM systems, the assessment methodology used does not allow to estimate how the differences between environmental properties of products and materials will influence the final grade of the building. The Open House methodology allows, assuming some simplifications, to assess the impact of construction products and materials selection on the final buildings score. However, this score is expressed in points, not with a grade on a scale (as it is in case of LEED and BREEAM), and therefore it is difficult to estimate the market value of improving the assessment score.

Preferences towards the importance of cost and environmental performance of the possible solutions should be obtained directly from the decision maker by letting him set the weights of these criteria (a_C and a_E factors from the equation (1)) in an interactive way.

4. Conclusions

The process of selection of the construction products and materials is a difficult decision problem. At the moment there are no software tools to support it in a comprehensive way. Developing such tool, that would utilize the data from the digital building model, would help to make quick decisions based on knowledge, while taking into consideration the actual products accessible on the market. Providing comprehensive information to the decision makers would also facilitate the uptake of the innovative and environmentally friendly products and materials.

In order to create the support system compliant with proposed framework, several elements have to be developed, namely:

- the guidelines for the building models that would be used as a source of minimal requirements;
- the methodology of construction products and materials environmental assessment criteria, that would allow for their comparison;
- the methodology of estimating cost and environmental impact of transport of the products and materials.

Another issue that has to be addressed is the willingness of the distributors and manufacturers to participate in the system and provide a good quality, reliable data about the construction products and materials.

The framework proposed in the paper not take into consideration potential improvements of the building performance in its use stage, resulting from using construction products and materials with better properties than defined as minimal. To resolve this problem it would be necessary to integrate the decision support system with the building performance simulation tools.

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Finding the shortest paths in construction sites: Complexity vs. precision

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Abstract

Through the course of a construction project, resources such as material, labor, and equipment constantly travel on the site from one point to another to support construction activities. Site topography and other barriers might prevent these resources to travel on a direct path and force them to make detours around obstacles. Accordingly, the actual shortest path between two points is not always the direct or even a rectilinear distance between them. Determining the shortest path between two points is important for path planning and reducing workflow and material handling costs on the site. This paper presents the following three approaches to predict the actual distances that resources travel on the site: direct, grid based, and visibility graph approaches. The direct approach predicts the distance using the X-Y coordinates on the departure and destination points. In the second approach the construction site is divided into an orthogonal grid system. The distance between any two points is then determined on the modes and arcs of this grid based system. Eventually the last approach represents the site layout using a visibility graph which is created by connecting the visible corners of the obstacles together. A path between two points on this graph reflects how resources detour around the corners of obstacles to travel on the site. These approaches are applied to 750 randomly generated layouts to compare their complexity and accuracy.

Keywords: construction site, optimization, path planning, shortest path, Site Layout Planning.

1. Introduction

Construction resources (labor, equipment, and material) travel on construction sites to support different activities (Tommelein et al. 1992, Andayesh and Sadeghpour 2013a). Reducing the traveled distance contributes to less wasted time and energy, and accordingly, more productive projects (Hegazy and Elbeltagi 1999, Andayesh and Sadeghpour 2014). The travel distance can be reduced by first planning the layout of objects and second determining the shortest travelling paths on the site. The first step involves optimizing the layout of different objects on the site, for instance by comparing several scenarios, to minimize the overall distance travelled by resources (El-Rayes and Said 2009). The second step for reducing the traveling distances is finding the shortest path that connects the departure and destination points in the planned layout (e.g. Soltani et al. 2002, Zhou et al. 2009). This path should consider the dimension of the resources and obstacles and should detour around the obstacles to pass them and get to the destination. In both steps, predicting and planning the actual distances between any two points on the site plays a significant role in reducing the travelling distances.

This paper presents three approaches for determining the distance on construction sites: direct, grid based, and visibility graph approaches. Section 2 explains the basic concepts of these approaches and demonstrates how they can be implemented. Section 3 compares the accuracy of the proposed approaches and determines their complexity by comparing the steps they take to find the shortest path on the site. Section 4 observes these approaches in action by applying them on randomly generated layouts. This section provides the running time and the accuracy of each approach in predicting the actual distances in randomly generated layouts. Eventually, the conclusion that is drawn from the generated results is presented in section 5.

2. Approaches for Reflecting Distance

This section explains the basis of three approaches for reflecting the distance between two points on a construction site: direct, grid based, and visibility graph approaches.

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2.1. Direct Approach

The distance between two points can be extracted from their coordinates directly using two different scenarios: Euclidean and rectilinear (Andayesh and Sadeghpour 2013b). In the Euclidean distance (D_e) the points are connected using a straight line and in rectilinear distance (D_r) using a rectilinear line as presented in Figure 1a. These distances can be calculated as follow:

$$D_e = \sqrt{(X_a - X_b)^2 + (Y_a - Y_b)^2} \quad and \quad D_r = |X_a - X_b| + |Y_a - Y_b| \tag{1}$$

where (X_a , Y_a) and (X_b , Y_b) are the coordinates of point A and B. This direct approach is the simplest method for reflecting the distance between two points since it does not need any computational effort. However, this approach does not reflect the reality of how resources travel on the site since it does not consider the detours that need to be made around the obstacles to move from one point to another.

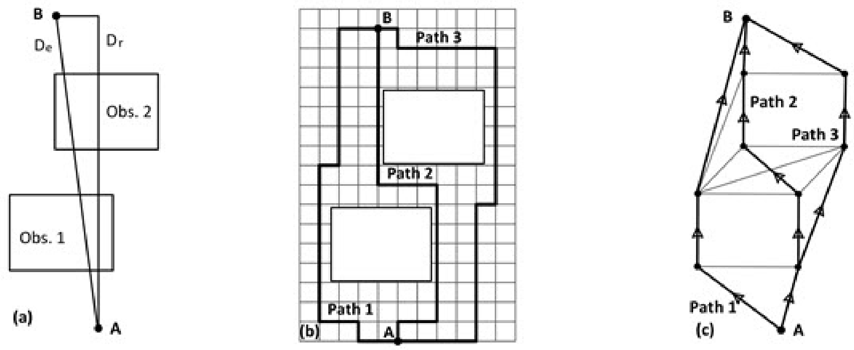


Figure 1. Three approaches for reflecting the distance between points A and B in a construction site: a) direct approach, b) grid based approach, and c) visibility graph approach

2.2. Grid Based Approach

In the grid based approach, the site is divided into an orthogonal grid system (Figure 1b) to present the available space for transporting resources. The grid intersections represent the graph nodes and the graph arcs are created by connecting the adjacent nodes. Nodes that fall inside obstacles are unavailable for travelling and a route will be found using the available nodes only. For instance, Figure 1b shows three possible paths for traveling from point A to B. The grid based approach provides the opportunity to maneuver around the obstacles and pass them. Following steps show how the distance between two points can be determined in grid based approach:

Step 1. Identify potential nodes based on the site shape and grid size

Step 2. For all obstacles, eliminate the nodes that fall inside the obstacle

Step 3. Connect the remaining adjacent nodes with a direct arc to create the grid based graph

Step 4. Search for the minimum distance between the start and end nodes on the graph

These steps are presented in the example of Figure 2a which aims to connect points A and B in a construction site with one obstacle. The first step is generating all the possible nodes on an orthogonal grid system(Figure 2b). The unavailable nodes, that fall inside obstacles, are eliminated in step 2 (Figure 2c). Step 3 adds the arcs of the graph by connecting the adjacent nodes together. In this example each node is connected to maximum of four adjacent nodes (Figure 2d). The last step is determining the shortest path between points A and B on this graph (Figure 2e).

The accuracy of the grid based approach depends on the grid size in step 1 or the number of connection per each node in step 3. Figure 2f presents a more accurate path between A and B by reducing the grid size and increasing the number of connections between adjacent nodes. This accuracy, however, requires more computation effort in compare to the previous scenario (Figure 2e). The accuracy and complexity of different approaches are compared together in more details in section 3.

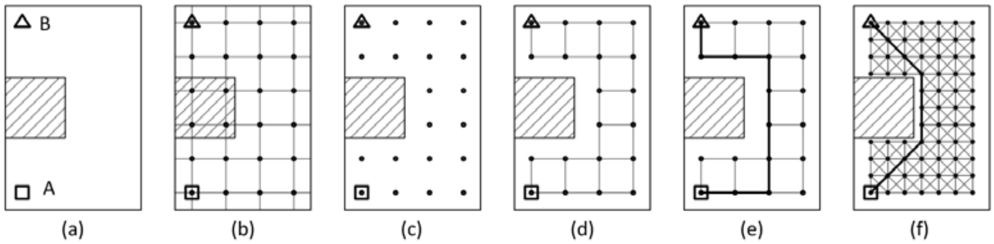


Figure 2. Grid based approach: a) example of a construction site with one obstacle, b-e) steps 1-4 for determining the distance, f) a more accurate presentation of the distance

2.3. Visibility Graph Approach

When traveling on the site, construction resources maneuver around the corners of obstacles to pass them and get to their destination. Visibility graph mimics this behavior by creating a graph of all possible paths to detour around obstacles. The nodes of the visibility graph consist of all the vertices of obstacles in addition to the start and end nodes (De Berg et al. 2000). Each arc of this graph represents a visible connection between two nodes. Figure 1d presents an example of a visibility graph for a site with two obstacles and three different possible paths between points A and B. The steps for creating the visibility graph and determining the distance are as follow:

Step 1. Identify nodes of the visibility graph: start and end nodes and the vertices of obstacles

Step 2. Connect every two nodes together to generate all the possible arcs of the graph

Step 3. Eliminate all the arcs that pass through an obstacle

Step 4. Search for the minimum distance between the start and end nodes on the visibility graph

To explain these steps, consider a site with one obstacle in Figure 3a. The first step identifies all the vertices of obstacles as nodes of the graph (Figure 3b). The arcs of the graph represent a visibility connection between nodes. To identify the arcs, all the nodes are connected together in step 2 to create a pool of all the potential arcs (Figure 3c). Then in step 3 each potential arc are compared to all obstacle to determine the acceptable ones (Figure 3d). The distance between A and B is determined by searching for the shortest path on the visibility graph (Figure 3e).

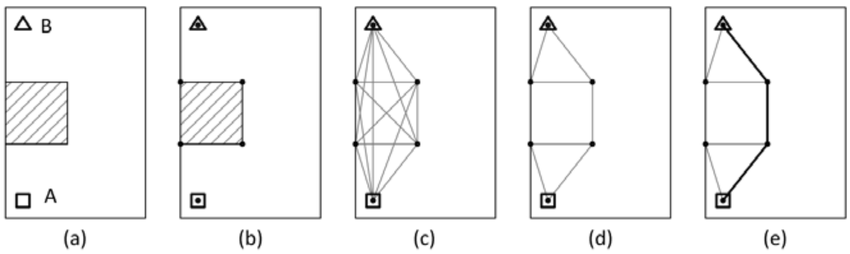


Figure 3. Visibility graph approach: a) example of a construction site, b-e) steps 1-4 for creating the visibility graph and determining the distance

3. Accuracy and Complexity

Without any doubt the direct approach is the less complex approach to predict the distance between two points as it does not involve any extensive calculations. However, this approach does not consider the obstacles on the construction sites and assumes resource can travel on a direct (or rectilinear) line without any interruption. This assumption is not realistic which limits the application of the direct approach for predicting the distances.

The accuracy of the grid based approach depends on the size of the grids and the number of connection between the adjacent nodes. For large sites with few obstacles, a large grid size can reduce the required computation effort without a significant effect on the efficiency of the generated path. However, large grid size for dense sites can lead to inefficient paths, and even in some cases, prevent the grid based approach from finding any path. For such cases small grid size should be selected to allow searching for paths that pass through the narrow available spaces between obstacles. On the other hand, reducing the grid size will increase the required computational effort significantly. The complexity of the grid based approach can be determined by identifying the running time of its steps as a function of its input. The inputs for determining the running time of the grid based approach are as follow:

A_{site}:	Area of the site	A_{Oi}:	Area of obstacle i	A_g:	Area (size) of grids
a:	number of arcs per node	k:	number of obstacles		

The running time of the first step (step 1 in section 2.2) is a linear function of the number of all the potential nodes ($O(n_1)$) which can be calculated as follow:

$$n_1 = A_{Site}/A_g \tag{2}$$

The second step is eliminating the nodes that fall inside obstacles with a running time of O(k). The running time for connecting the nodes together (step 3) is a function of the number of the remaining nodes (n_2) and the number of arcs per nodes ($O(a.n_2)$). The number of the remaining nodes can be calculated as follow:

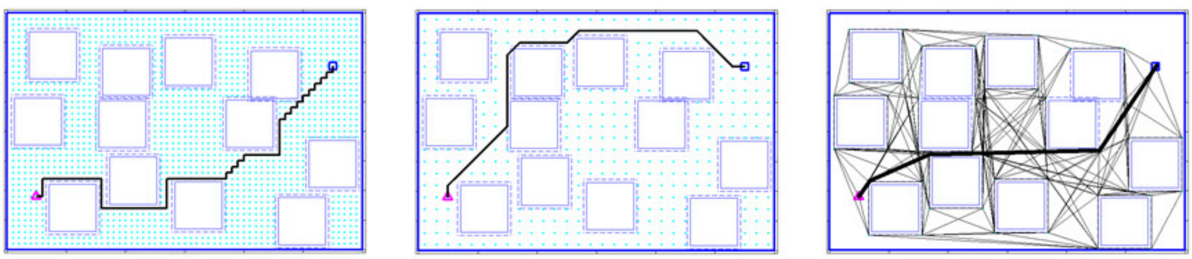
$$n_1 = (A_{Site} - \sum A_{Oi})/A_g \tag{3}$$

The last step is searching for the shortest path on a graph with n_2 nodes. This study uses A^* search method to find the shortest path that connects two nodes on a graph. The run time for this search method, which is one the fastest of its kind, is a quadratic function of the number of nodes $O(n_2^2)$ (Zeng and Church 2009, West 2001). The largest of these numbers dictates the overall running time of the grid based approach which is $O(n_2^2)$. Accordingly, the running time of the grid based approach highly depends on the number of nodes that present the available space on the site (n_2). As Eq. 3 shows, this number decreases as the grid size (A_g) increases. It is interesting to note that the running time of the grid based approach decreases as the space occupied by the obstacles ($\sum A_{Oi}$) increases.

The visibility graph generates the most accurate distance since it mimics the reality of how resources travel on the site. The running time for the visibility graph depends on the speed of implementing its steps. To determine the arcs of the graph, all pair of two nodes are connected together to create a pool of all the potential arcs (4k nodes and $16k^2$ potential arcs). All of these potential arcs are then compared to edges of obstacles to eliminate the ones that pass through an obstacle ($64k^3$ checks). Accordingly, the running time for creating the visibility graph is $O(k^3)$. Searching for the shortest path on this graph takes $O(k^2)$ running time. From comparing these two numbers, the overall running time of the visibility approach will be $O(k^3)$. Unlike the grid based approach, the running time of the visibility graph approach will increase as the number of obstacles increase.

4. Computational Example

This section compares the accuracy and running time of the proposed approaches in determining distances in randomly generated site layouts. In these layouts the site is a 40m x 60m, the obstacles take either a small size of 4mx4m or a large size of 8mx8m with a safety offset of 0.5m around them, and the start and end point are constant. The unavailable space due to each obstacle equals 25 m^2 and 81 m^2 for small and large obstacles respectively. In order to get a wide variety of examples, the random layouts are generated for two cases of small and large obstacles considering a various number of obstacles. For the case of small objects, the layouts are generated for a package of 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 obstacles which respectively represent 5%, 10%, 16%, 26%, 31%, 36%, 42%, 47%, and 52% of unavailable space on the site. For large obstacles, the packages include 3, 6, 9, 12, and 15 obstacles which represent 10%, 20%, 30%, 41%, and 51% of unavailable space. For each package 50 random layouts are generated to get the average running time and average accuracy for comparing different distance approaches.



(b) (c) (d)

Figure 4. Traveling path on the site using different search scenarios: a) Euc. And Rec., b) GB1-4, c) GB2-8, and d) VG

The distance between the start and the end points in the random layouts are determined using seven different searching scenarios presented in Table 1. Figure 4 presents a sample of the generated path in a random layout with 12 large objects (41% unavailable space) using these scenarios. The first two scenarios are using a direct approach which determines the distance using the coordinates of start and end points. Next four scenarios represent different assumption in the grid based approach. Figure 4a and b show the path generated by the grid based approach assuming two different gird sizes (1m x 1m and 2m x 2m) and two different number of arcs per nodes (4 or 8 arcs per node). Eventually the last scenario applies the visibility graph approach in finding the paths on the site (Figure 4c). The results are presented in three sections: *complexity*, *precision*, and *complications*.

Table 1. Scenarios for determining the distance between the start and end points

Approach	Scenario name	Scenario description
Direct	1. Euc., 2.Rec.	Euclidean and Rectilinear distance
Grid based	3. GB1-4, 4. GB2-4 5. GB1-8, 6. GB2-8	Grid size of 1mx1m or 2mx2m 4 arcs per node or 8 arcs per node
Visibility graph	VG	Using visibility graph

Complexity: The running time of all the five scenarios are presented in Figure 5a and b for the case of small and large obstacles respectively. As predicted in section 2, increasing the grid size from 1m to 2m results in less required time to search (compare GB1-4 and GB1-8 to GB2-4 and GB2-8). However, these two graphs show that the number of arcs per node does not have a significant effect on the running time (compare GB1-4 to GB1-8 or GB2-4 to GB2-8). As predicted in section 2, increase in the number of obstacles (increase in the unavailable space) results in less time for grid based scenarios and more time for the visibility approach. Comparing Figure 5a to 5b shows that for less than 15 obstacles the visibility graph approach takes less time to compute compared to all grid based scenarios. However, for more obstacles the grid based approach can generate results faster.

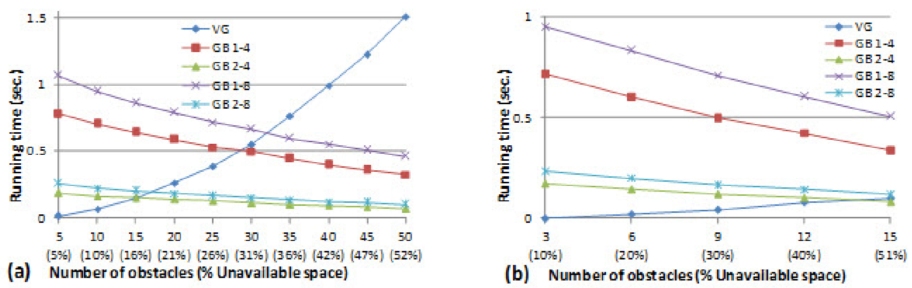


Figure 5. Running time of different scenarios: a) Case I: small obstacles and b) Case II: Large obstacles

Precision: Figure 6a and b show the precision of the proposed scenarios in compare to the visibility graph approach as the most accurate one. These graphs suggest that the accuracy of the grid based approach mostly depends on the number of arcs per node (compareGB1-8 and GB2-8 to GB1-4 and GB2-4) rather than the grid size. These graph also show that the Euc. distance scenario has low error in compare to other scenarios. Considering the low required computational effort, the Euclidean distance scenario is the best choice after the visibility graph.

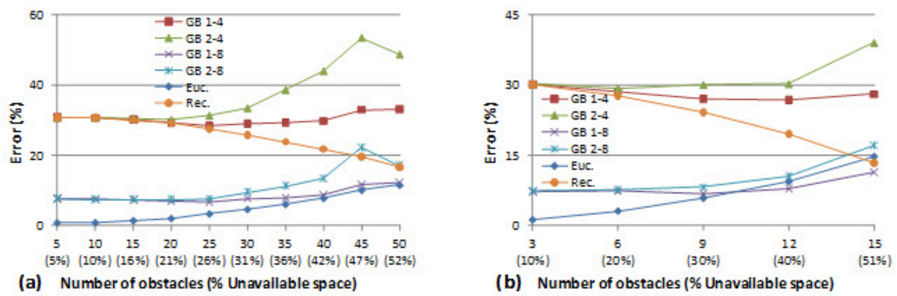


Figure 6. Precision of different scenarios: a) Case I: small obstacles and b) Case II: large obstacles

Complications: The distance approaches may fail to find a path between the start and the end points in crowded layouts for two main reasons. First, the random distribution of objects blocks the start or end points, and accordingly, there is no path to be found. In such conditions, the visibility graph and grid based approaches are unable to find any path. Second, the grid size is too large which makes the grid based approach to lose connection between the available nodes. Figure 7a and b show the percentage of fails to find a path on the site. These two figures show a huge risk of failure for large grid sizes (GB2-4 and GB2-8 scenarios) in sites with more than 40% of unavailable space. Comparing Figure 7a to 7b reveals that the relative size of grids and obstacles also affects the possibility of failure. For small obstacles, large grids result in much more failures but for the case of large obstacles, there is not much difference between grid size of 1m and 2m.

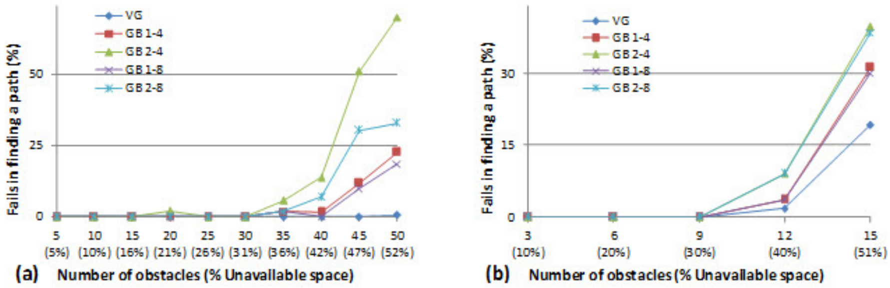


Figure 7. Fails in finding a path: a) Case I: small obstacles and b) Case II: large obstacles

5. Conclusion

This paper presented three following approaches for determining the distance between objects on the construction site: direct, grid based, and visibility graph approaches. In the direct approach the distance between any two points is estimated using their coordinates only. The direct approach is fast and simple but does not consider the obstacles on the site. The grid based approach finds the distance on an orthogonal grid system. The accuracy of this approach depends on the grid size and the number of connection between grid nodes. The last approach creates a visibility graph on the site by connecting the corners of obstacles to mimic how the resources detour around the obstacles to pass them. The shortest distance between points on this graph reflects the actual path that resources travel on the site.

This study compared the required computational effort and the accuracy of all the proposed approaches in randomly generated layouts. The following conclusions are drawn from analyzing 750 randomly generated layouts:

1. The speed of finding the actual distance on the site using the visibility graph approach depends on the number of obstacles rather than the occupied space on the site.
2. The visibility graph is the fastest approach when the obstacles are less than 15 and it takes a fairly reasonable time in compare to other approaches for up to 30 obstacles in the site.
3. The Euclidean distance is more accurate than the grid based approach. Accordingly, for cases when the visibility graph is slow, the Euclidean distance should be used instead.

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Study and comparison of European and Russian technical documentation of building materials

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Abstract

The development process of European Standards and Eurocodes can serve as an incentive for substantial expansion of scientific cooperation with European colleagues, break technical trade barriers down and make it possible to have common-used design rules for buildings and structures. It is essential to start studying entire array of supporting documents. First and foremost the standards for materials and standards for test methods should be analyzed. This article is focused on investigation of the European standard technical documentation in terms of specifications and test methods for concrete mixes and concretes in comparison with the Russian standards. The first stage of the laboratory practicum development meant for students can be a remote learning course in the moodle system.

Keywords: concrete, concrete mixes, Eurocodes, European standards, laboratory workshop

1. Introduction

The major aim of any contemporary government is to ensure high standards of living for its citizens with their prospective improvement. The way the governments use their resources and possibilities to achieve this aim explicates their ability to compete with other countries in global markets (Steinerts, A., Pakrastinsh, L., Gaile L., 2013). The construction industry makes a significant contribution to development of all the economic sectors - both production and non - production. Each country is concerned with its products to be highly competitive and demanded. Having standard documents in harmony is an important part to solve this problem (James Sommerville, Nigel Craig, Sarah Bowden, 2004).

The idea to have construction standards coordinated with the European ones stems from expansion of market relations with the nearest neighbors and Russia's entry into the World Trade Organization (Dzhinchvelashvili G.A, Dzerzhinsky R.I., 2012). It is necessary to harmonize standard documents in order to eliminate disputes between builders and designers as well as to break technical trade barriers down. Provided this harmonization is ensured the Russian specialists will be able to compete with European ones (Vasanthi R Perumal, Abu Hassan Abu Bakar, 2011). In 2012 the State Duma adopted the Federal law "On ratification of the Protocol on the accession of the Russian Federation to the Marrakesh agreement establishing the world trade organization of April 15, 1994." It was signed by the RF President V. V. Putin. Russia became a member of the WTO after it had been notified on ratification by the WTO Secretariat.

Construction materials are fundamental for construction activity. Knowledge of their particular characteristics and of the ways they must be applied ensures that buildings and constructions will be economically efficient and technically reliable. Concrete and reinforced concrete are the main construction materials according to their technical and economic performance indicators, and they take priority places in the structure of global construction industry (Barabanshikov Y.G., Nikolsky S.G, Belyaeva S.V, 2011). Therefore, it is necessary to begin with studying all the supporting documents. First of all, the standards for materials and standards for test methods should be investigated.

1.1. Work objective

The objective of this work is to study and compare European and Russian standards of technical documentation in terms of specifications and test methods for concrete mixes and concretes. An additional

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covering aim is to develop laboratory practicum for students and give sight of the test methods for concrete and concrete mixes in compliance with the European standards.

1.2. History of standardization in the Russian Federation

Industrial standardization in Russia started to develop at an intermediate stage between XVII and XVIII centuries when a number of decrees of the emperor Peter I were declared, which were assigned to ensure endurance testing and interchangeability (Kurochkina A.Y., 2009).

Science, engineering, industry and trade developed rapidly at the beginning of the XIX century in Russia. Metrology and standardization at the same time got completely different development impulse. The formation of the centralized system of standardization in Russia began after revolution in 1920 - 1930 years, and methodological foundations were being actively developed during this period. The category of state standards (GOST) was entered in 1940. The state standards were a must to be used in all the sectors of the national economy of the Soviet Union. Board of Standards, Measures and Measuring Equipment affiliated with the Council of Ministers of the USSR was founded in 1954, and then in 1971 it was transformed into the State Standard of the USSR (Gosstandart of the USSR), and only afterwards to the State Standard of the Russian Federation (Gosstandart of the Russian Federation).

The Federal Law "On technical regulation" adopted in 2002 cancelled provisions of the Law "On Standardization" and revealed a new period of standardization development in our country. An administrative reform was carried out in 2004. Rostechregulirovaniye replaced Gosstandart of the Russian Federation. The current state system of construction standardization in our country includes the State Standards (GOSTs and OSTs), Specifications (TU), Building Codes and Regulations (SNiP), Rules and Regulations (SP), guidelines and instructions.

There are about 500 state standards in construction and building materials industry. The standards on certain building materials specify types and main sizes, specifications, test methods, acceptance rules, marking rules, packing rules, transportation and storages rules. In addition to the general standards the system contains specifications for certain products assigned for building materials production.

1.3. Harmonization problems

Standardization system reform is connected with the requirements assigned for Russia to enter the WTO in respect to have the national standardization system harmonized with the global system implying transition to European standards and Eurocodes and revision of the base of standards (Travush V. I., Almazov V.O., Volkov Y. S., 2011).

Creating a common system of European standards [European Norms (EN)] is one of the elements of the integration process of the developed European countries into the European Union. The European Committee for Standardization CEN was officially established as an international non-commercial organization October 30, 1975. CEN develops standardization and other technical solutions and specifications in respect to European standards development and coordination; it also takes the national features of each country attached to the system of Eurocodes into account (Denton, S.R., 2010). This means that, apart from adopting provisions of international rules in the national standards, it is also necessary to consider climatic, hydrogeological and geological features of each participating country (Steinerts, A., Pakrastinsh, L., Gaile, L., 2011). The amendments to the Federal Law "On technical regulation" adopted by the State Duma have predetermined further integration of Russia into the global, and first of all, European economy. These amendments have obliged technical committees of the Federal Agency on Technical Regulating and Metrology (Rosstandard) to provide recommendations on opportunities to include foreign standards into a list of the documents ensuring requirements of the technical regulations to be met.

The problems of technical regulation in construction are connected with the stage-by-stage introduction of Eurostandards within the territory of the Russian Federation, and also they are related to the production and quality control of building materials and products to a large extent (Yakubson V.M., 2011). At present days uniform criteria for quality assessment in regard to building materials have not been established yet which makes it difficult to harmonize Russian and European construction standards to a full extent. Many provisions of the national standards, such as main requirements for materials, and their classification, various test methods, marking rules and other parameters differ significantly from the European standards which make it difficult to assess compatibility of test results and interchangeability of materials as well. Harmonization of the Russian and European standards for various construction materials has been carried out to eliminate these discrepancies.

The main problems to harmonize the national standards for construction materials with European and international ones are the following:

- There is no sufficient information on whether properties of these materials can be preserved in the Russian climatic conditions and changed while their use.
- Means and methods to test and measure properties of building materials which ensure corresponding results to be accurate.
- There are no harmonized concepts in the field of building materials and construction activities (Blinov V.P., 2011).

The creation of new GOSTs is not based on Eurocodes (Ulybin A.V., Vatin N.I. 2011; Vatin N.I., Ulybin A.V., Ogorodnik V.M. 2011), while regional methodical documents in a great measure based on European standards (Vatin N.I., Kurganov Yu.A., Petrakov G. P., Starkov V. N. 2014; Vatin N.I., Dubov V.V., Petrakov G.P. 2013). A program developed by the Ministry of Regional Development which provides updates on construction standard documents and ensures a stage-by-stage introduction of Eurocodes in the Russian Federation is operating nowadays. There are a number of standard European and Russian documents setting out specifications for concrete and concrete mixes and the methods to test them as well.

1.4. Studying and comparison of standards

EN 206-1 to be developed for concrete was being carried out from 1989 to the end of 1999 by a technical committee. The amendments are being introduced into this standard up to present days. There was a demand for considerable efforts to be made by experts. Therefore 26 editions of the text of the standard were elaborated.

The European standard EN 206-1 is applied to concrete to be used for construction of structures with in-situ concrete, for production of pre-cast constructions, and also for pre-cast building units and engineering constructions. Concrete production in the form of construction areal concrete, commercial concrete or concrete for prefabricated buildings is allowed. It should be used in accordance with the standards on initial materials and test methods. The standard EN 206-1 is referred to a number of dozens of other standards, both completed ones and the ones under development. The practice of their application in Russian practice has not yet been studied. Classification, specifications and test methods to be applied for concrete and concrete mixes according to the standard EN 206-1 are presented in the Table 1.

Table 1. Classification, specifications and test methods for concrete mixes and concretes in accordance with the standard EN 206-1.

Classification	Specifications	Test methods
	Concrete mixes	
Classes in terms of workability (concrete consistency): • consistency (slump cone test); • strength; • level of compaction; • flowability (flow cone test); • maximum filling aggregate size.	Indicators: • workability (consistency and slump cone, strength, level of compaction, flowability); each group is subdivided into classes according to workability; • density; • volume of entrained air; • content of cement and water/cement ratio; • maximum size of aggregate; • temperature.	• selection rules for samples to be tested according to the standard EN 12350-1; • slump cone test (concrete mixes classes related to slump cone: S1…..S5) according to the standard EN 12350-2; • strength testing using the Vebe method (Vebe strength classes: from 3 with (V4) up to ≥ 31 with (V0)) according to the standard EN 12350-3; • level of compaction of concrete mixes (classes related to level of compaction: from >1,45 (C0) up to 1,04 (C3)), according to the standard EN 12350-4; • flowability testing (classes related to flow cone: F1…F6), according to the standard EN 12350-5 and tests for concrete mixes density according to the standard EN 12350-5; • test for volume of entrained air according to the standard EN 12350-7; • water column test; • pressure measurement testing.
	Concretes	
Concretes are classified according to: • Exposure classes related to environmental impacts: no risk of corrosion or any attacks; corrosion induced by carbonation; corrosion induced by chlorides (except for the ones of the sea water); corrosion induced by the sea water chlorides; corrosion induced by alternate freezing and thawing attack;	• The standard EN requirements for concrete are the following ones: component materials; aggregates; volume and quality of mixing water; ultimate admissible content of chlorides in concrete; additions (including minerals and chemicals); compressive strength; bending tension; splitting tension; density; resistance to water permeability; fire safety; chloride	• Monitoring and evaluating concrete strength according to the standards EN 12390-1, EN 12390-2, EN 12390-3, EN 12390-5, EN 12350-1: statistical method based on the characteristics of concrete uniformity by strength; • Controlled parameters: the actual strength of the series of samples; standard deviation.

chemical attack. *Note:* each class is subdivided into indices. • Density classes: normal-weight concrete; heavy-weight concrete; light-weight concrete. • Strength classes: normal-weight concrete and heavy-weight concrete; light-weight concrete.	content class. • There are requirements depending on the environmental impacts for the following indicators: water/cement ratio; strength class; cement content; air entrainment. • There are additional requirements for: prescribed concrete; designed concrete; requirements for manufacturer; requirements for supply of ready-mixed concrete.	The conformity criteria are the values of concrete strength of the specified class. • They are set for: strength of the "n" samples group (criterion 1); strength of each individual sample of any series (criterion 2). • Types of standardized strength to be controlled: strength in primary production; strength in permanent production of concrete.

Today the majority of the Russian enterprises in building industry are crossing over to new intergovernmental standards harmonized with the European standards. The current legislation of Russia does not provide the possibility to apply foreign standard documents directly. The Federal law "On technical regulation" allows full or fractural use of international standards as the basis for development of technical regulations or standards provided such viability is justified. The following Russian standards have been chosen to be compared:

- GOST 7473-10 "Concrete mixes. Specifications."
- GOST 25192-12 "Concretes. Classification and general specifications."
- GOST 26633-2012 " Heavy-weighted and fine-grained concrete. Specifications".

These standards have been developed with due account for the main standard provisions of the regional European standard EN 206-1:2013. Therefore there is a possibility for comparison (Nikolsky S.G, Belyaeva S.V., 2008). Classification, specifications and test methods for concrete and concrete mixes according to the Russian standards are presented in the Table 2.

Table 2. Classification, technical requirements and test methods for shown to concrete and concrete mixes in accordance with Russian standards.

Classification	Specifications	Test methods
Concrete mixes		
GOST 7473-10 "Concrete mixes. Specifications"		
Types of concrete: • heavy weight concrete mixes; • fine aggregate concrete mixes; • light weight concrete mixes. Workability (each group is divided into marks by workability): • hard; • movable; • spreading. Conventional signs of a concrete mix includes: • abbreviation of concrete mixture in accordance with the type of concrete; • class of concrete by strength; • mark of concrete mix by workability. *Note:* If necessary there are other standardized indicators of quality: • mark by freeze-thaw resistance; • marks by water permeability, average density of concrete and others; • standard signs.	Concrete mix is characterized by the following quality specifications: • workability; • density; • ability to delaminate; • void ratio; • temperature; • storage properties over time; • volume of entrained air. Depending on the concrete mix workability concrete mixes are divided into marks: • marks by flow cone; • marks by slump; • marks by density; • marks by compaction.	Tests for concrete mixes to produce heavy, fine aggregate and light concretes are carried out in accordance with the GOST 10181-2000. • The definition of concrete mix workability: determination of concrete mix mobility; determination of concrete hardness (using Vebe type equipment, method of Krasniy, method of Skramataev). • The definition of average density of concrete mix. • The definition of void ratio of concrete mix: volumetric method to determine volume of entrained air; compression method to determine volume of entrained air; calculation method to determine volume of entrained air; determination of volume of intergranular voids in concrete mix. • Delamination ability of concrete mixes: determination of concrete mixes splitting; determination of water segregation; • Determination of temperature of concrete mix. • Determination of storage properties.

Concretes		
GOST 25192-12 "Concrete. Classification and general specifications"		
• According to primary use: construction; special (for instance insulation, decoration). • Resistance to types of corrosion: concrete used in environment without risk of corrosion; concrete used in environment, causing corrosion induced by carbonization; concrete used in environment, causing corrosion induced by chlorides; concrete used in environment, causing corrosion induced by alternate freezing and thawing; concrete used in environment causing chemical corrosion. • According to binding types: cement; lime; slag; plaster; special (for example, polymer concrete). • According to aggregate types: dense aggregates; porous aggregates; special (for example, metal fraction). • According to structure: dense; porous; cellular; coarse-porous. • According to terms of hardening: in natural conditions; in the heated conditions at atmospheric pressure; in the heated conditions at a pressure above atmospheric one (autoclave concrete). • According to strength: average strength; high strength. • According to the velocity rate of strength hardening in normal conditions: high-early concrete; slow-setting concrete. • According to average density: extremely light-weight; light-weight; normal-weight concrete; heavy-weight concrete. • According to freeze-thaw resistance, water permeability, wear capacity: low; average; high.	Specifications are set for quality of concretes in accordance with the standard requirements depending on the purpose of use and work conditions in building constructions and structures: • for standards on concrete of a certain category (type); • for standards and technical conditions on precast and reinforced concrete products; • for working drawings of in-situ concrete and reinforced concrete structures. Standardized quality performance indicators of concrete which are to be monitored while structures production shall be defined in standard or technical documents for specific types of concrete. Standardized quality performance indicatirs should have a standardized method for determining. Materials for preparation of concrete mixes (binders, aggregates, fillers) and the concrete structure are defined in standard, technical and in technological documentation for certain type of concrete. Standardized technological performance indicators of concrete mixes and production technologies on manufacturing of concrete and reinforced concrete structures must be in technical documentation (project execution plan, technological regulations or flow diagram) to produce specific structures in specific enterprises. The values of standardized quality performance indicators of concrete should be determined by testing specially manufactured samples or testing concrete in structures in accordance with standardized methods. The values of quality performance indicators of concrete are allowed to be determined by a number of methods. It is necessary to ensure possibility to compare results by means of comparability conversion coefficients or by other methods. The fact whether quality performance indicators of concrete meet design requirements can be determined by estimating test results with due account for uniformity indicators for controlled quality performance score.	Monitoring and estimating of ready-to-use concrete mixes, in-situ concrete, precast concrete, prefabricated concrete and reinforced concrete structures while production control of concrete strength are carried out in accordance with the GOST 18105-10. • All the kinds of standardized strength are to be controlled: strength during design stage – for ready-to-use, cast-in-place and precast, reinforced concrete constructions; handling and transfer strength - for pre-cast concrete structures; strength at the intermediate stage - for ready-to-use and in-situ concrete constructions (when removing concrete framework and loading construction up to prescribed strength point and etc.). • Determination of concrete strength. • Determination of concrete uniformity properties by strength. • Determination of required strength and actual strength classes of concrete. • Acceptance of concrete strength: according to strength at intermediate and design stages - for ready-to-use and in-situ concrete constructions; according to handling, transfer and design strength - for pre-cast concrete constructions. • Methods for determination of ultimate strength point of concrete: in compression; in axial tension; tension in splitting; tension in bending by means of destructive short-term static tests which are carried out in accordance with the GOST 10180-12 "Concretes. Methods for strength determination using reference specimens". • Determination of strength concrete under static loading with constant increase in velocity of loads, and subsequent calculation of stresses under these efforts: compression testing; tension test for bending; tension test for splitting; axial tensile testing.

When comparing standard and technical documentation in terms of specifications and test methods for concrete mixes and concretes, a number of differences in classification of concrete mixes have been found in European and Russian standard documents as follows:

- GOST 7473-10 gives a classification of concrete mixes and types of concrete;
- EN 206-1 introduces aggressive environment (corrosion caused by exposure to sea water).
- There are differences in terms of concrete as well:
- GOST 25192-12 introduces a separate class of extremely light concretes;
- EN 206-1 uses additional signs for classes of light concrete.

- Also there are a number of differences in specifications for concrete mixes:
- GOST 7473-10 imposes requirements for ability to delaminate and store properties over time;
- EN 206-1 imposes requirements for cement content, water/cement ratio and maximum size of aggregate;
- According to EN 206-1 minimum consumption of cement is determined depending on environmental impacts and concrete class.
- There are differences in terms of concrete as well:
- EN 206-1 introduces classes according to content of chlorides in concrete;
- EN 206-1 imposes requirements depending on environmental impacts according to the following parameters: maximum water/cement ratio; strength classes; cement content; air entrainment;
- EN 206-1 sets additional requirements for: prescribed concrete, designed concrete; requirements for manufacturers; requirements for supply of ready-mixed concrete.

Despite these differences European and Russian technical documentation in terms of specifications and testing methods of concrete mixes and concretes are similar to a large extent.

2. Conclusion

At present days in modern life standardization calls for contributing to a turning point of the national economy to a new innovative way of development leveling up to rapid and sustainable growth based on state-of-the-art technologies. There are great expectations in respect to standardization which may lead to ensuring new standards in scientific sphere, equipment and technologies, work organization and management in general. It is being restructured to secure market-based environment in accordance with the rules and standards of international standardization. Our work is only a starting point to study and compare European and Russian technical documentation in terms of specifications and test methods for concrete mixes and concretes. Our prospective work will be focused on an in-depth study of the test methods for concrete and elaboration of manuals for concrete designing in accordance with the European standards.

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BS EN 12350-4:2009 Testing fresh concrete Degree of compactability.

BS EN 12350-5:2009 Testing fresh concrete Flow table test.

BS EN 12390-1:2012 Testing hardened concrete Shape, dimensions and other requirements for specimens and moulds.

BS EN 12390-2:2009 Testing hardened concrete Making and curing specimens for strength tests.
BS EN 12390-3:2009 Testing hardened concrete Compressive strength of test specimens.
BS EN 12390-5:2009 Testing hardened concrete Flexural strength of test specimens.
GOST 7473–2010 Fresh concrete. Specifications.
GOST 25192-2012 Concretes. Classification and general technical requirements.
GOST 26633-2012 Heavy-weight and sand concretes. Specifications.
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Creative Construction Conference 2014

The role of social media in the construction industry

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Abstract

The construction industry is not widely perceived as innovative and collaborative as many other industries. The construction industry worldwide is trying hard to change this perception using several short and long term strategies. Over the last few years, social media has changed the face of our personal interactions, with an unprecedented rate of adoption that outpaces previous innovations. Social media tools are intuitive to use and allow people to share information, collaborate, discuss common interests and build relationships. This research study focuses on the current and potential usage of social media within the construction industry. To expound, it investigates the social media platforms currently being utilized amongst construction organizations, analyzes the potential rewards and risks, and examines the innovation they provide specifically to make communication and collaboration more effective. To achieve these objectives, quantitative and qualitative data were collected from individuals and organizations within the construction industry. A social media log was developed to track activities on Facebook®, LinkedIn®, and Twitter® platforms for ten construction organizations with social media presence. Additionally, a survey questionnaire was distributed to construction industry professionals. Finally, open-end interviews were conducted with individuals from three construction organizations familiar with social media as a company resource. Results of data analysis reveal that many construction organizations are beginning to take advantage of social media benefits, but in general, the construction industry lags behind most other industries in terms of social media usage. The construction companies are using social medial for the following applications: (1) recruitment; (2) disseminating company's and/or projects' news; (3) client networking; (4) brand awareness; and (5) Showcasing innovations. It is found that most companies have not explored the full potential of social media and only using it as a sporadic one-way communication tool. Construction organizations must invest sufficient time and resources to support daily operations, maintenance, and security of social media resources in order to gain best results.

Keywords: Collaboration; Communcation; Innovation; Information management; Social media.

1. Introduction and Background

Effective communication is one of the pillars of success within the construction industry. Collaborating and effectively connecting people and information in construction projects provides biggest potential for cost savings in the industry today (Pepper, 2013). An ever evolving resource that has recently enhanced this stream of communication is social media. This concept refers to interaction between individuals, groups, and organizations through the use of virtual communities and networks. More specifically, social media enables users to connect by creating personal information profiles, inviting friends and colleagues to have access to those profiles, and sending e-mails and instant messages between each other. These personal profiles can include any type of information, including photos, videos, audios, and text (Kaplan & Haenlein, 2010). Common examples of social media resources include: Twitter®, Facebook®, YouTube®, LinkedIn®, and Instagram® as well as personal and professional web logs (blogs), video web logs (vblogs), and podcasts.

Organizations of all kinds, including the construction industry, are beginning to adopt these new resources to better serve their communication needs. To parallel this concept of value-added communication, social media also allows for potential improvements relative to knowledge management. Using social media, companies are exploring new ways to cultivate and exploit knowledge sharing with their customers, suppliers, and partners both inside the organization and outside strict organizational boundaries (Razmerita, Kirchner, & Nabeth, 2014). Such innovative means of collaboration provide new avenues for construction companies to share and communicate information both internally, with employees in same or different locations, and externally, with potential clients and other companies. As a result, the magnitude of information diffusion within an organization has significantly increased, thus allowing for improved workload efficiency, increased business opportunities, and enriched customer service.

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A recent survey from Experian revealed that Americans spend an average of 16 minutes of every online hour on social media (Thompson, 2013). The same, however, cannot be said for the construction industry. According to a study conducted by infolink.com.au (Australia's Architecture, Building, Construction and Design Directory), one third of businesses in the building and construction industry are still not using social media. The survey of more than 1,126 businesses revealed 36 percent of businesses are not sure how to use social media to engage their market. Furthermore, the survey revealed 72 percent of businesses know having a strategy for social media is important but they are unsure how to create this strategy to engage their followers (Trenchless International, 2014). In response to such uncertainty, groups such as the *Associated General Contractors of America (AGC)* have begun to educate the construction industry concerning the effective utilization of social media platforms within an organization. For example, during the AGC's 92nd Annual Convention, a seminar entitled "The Next Step in Social Media: Rethink Strategies, Reinvest Resources, Reconnect Relationships, and Rebuild Networks" was presented. The key point from the presentation stated that although social media cannot deliver instant success, save a sinking ship, guarantee influence, or replace a marketing strategy; it provides the opportunity to improve multiple aspects of an organization including: marketing, connections, support, education, communication, recruiting, and research (DeVries, 2011). Moreover, a new wave of leaders in the building industry are paving the social media path, showing by example that "tweets" and "posts" have an important place in the world of construction (Basalyga, 2013).

While social media presents potential benefits relative to internal and external communication and collaboration, risks and challenges also exist that cause construction companies to become hesitant when considering implementation within their organization. In general, the risks associated with social media use can be clumped into two groups: *technological threats* and *content-based threats*. The technological threats are the obvious risks such as malware distribution and infection. Content-based risks include inappropriate distribution of intellectual property or offensive content, phishing, retention of business records and revelation of private or confidential information in a public setting (Colley, Sehmbi, & Walls, 2011). Beyond the risks of implementing social media, construction industry firms and individuals also face confusion both about how to use the tools and how to measure success (Schriener, 2009). For many construction firms of all sizes, social media use and presence can be a hit, a miss, or just not part of the mix at all. As a result, construction companies beginning to utilize social media need to understand the time commitment required even though many tools are low cost or free (Joyce, 2011). Even for everyday social media practitioners, training of employees is still needed to deploy social media successfully (Razmerita, Kirchner, & Nabeth, 2014). The construction organizations must be willing to invest ample time, manpower, and dedication when considering the incorporation of social media into their organization.

2. Research Aim, Objectives, and Methodology

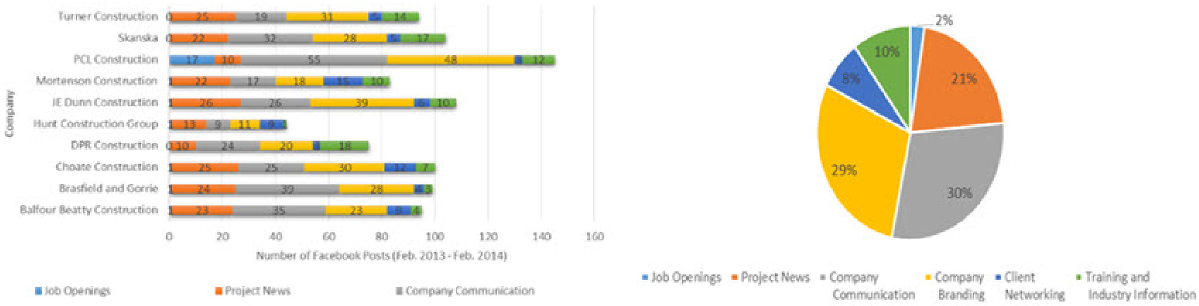
The aim of this research is to explore the current and potential usage of social media within the construction industry, study relative challenges, risks and rewards, and examine the innovation it provides. The objectives of this research include: (1) Investigating the social media resources currently utilized within the construction industry; (2) Analyzing the potential benefits, relative challenges, and associated risks; (3) Comparing and contrasting the utilization of social media amongst construction organizations of varying size and scale; and (4) Determining the innovation that social media provides to the construction industry in terms of improving communication and collaboration.

This study employed a mixed methods research design. Quantitative data is collected by preparing social media usage logs for ten medium-to-large construction companies in the Southeast USA. The timeframe of tracked activities is from February 2013 to February 2014. The qualitative data is collected by conducting a questionnaire survey of key stakeholders (e.g. project managers, human resources managers, communication/marketing officers) to get their perceptions about the benefits, challenges and associated risks of using social media. It is followed by conducting in-depth open end interviews with three selected survey respondents. Once all data are collected, in-depth analysis is performed to compare and contrast the social media usage trends within the construction industry. This paper reports some of the main findings of this research study. The researchers plan to publish full results after performing more rigorous data analysis.

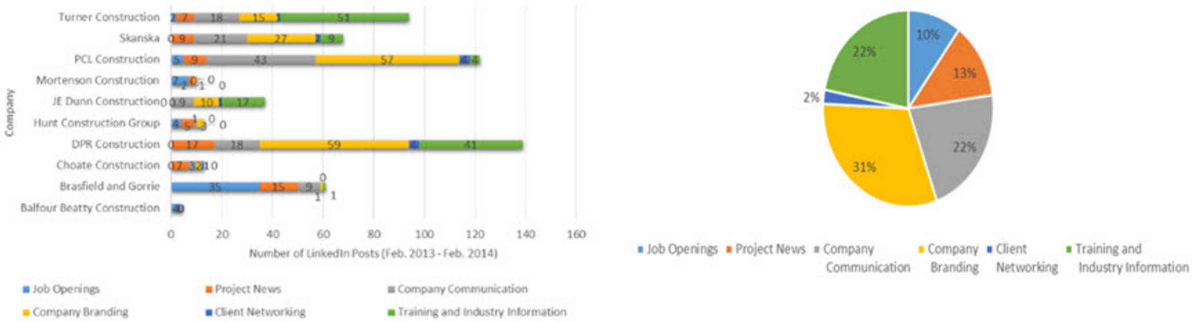
3. Results and Main Findings

3.1. Quantitative Analysis – Social Media Usage Logs

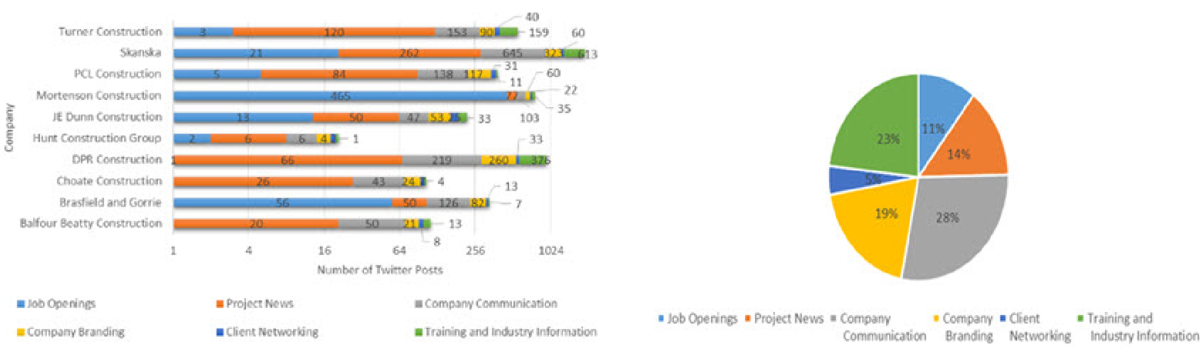
To quantify social media usage within the construction industry, ten construction companies with social media presence were tracked on Facebook®, LinkedIn®, and Twitter®. Each organizations' activities on these social media platforms, from February 2013 to February 2014, were logged relative to category of information as shown in Figure 1. It is found that these companies are using social media for the following purposes: (1) Announcing job openings; (2) Disseminating project news; (3) Company's branding; (4) Client networking; (5) Company's communication; and (6) Training and industry information. Twitter® is found to be the most preferred social media tool. The Twitter® posts count for 8 out of the 10 organizations exceeded the respective combined number of posts on Facebook® and LinkedIn®. On average, the Twitter® posts per month are found to be 45.



(a) Facebook® Posts Log: (Left) Per Company; (Right) Per Category



(b) LinkedIn® Posts Log: (Left) Per Company; (Right) Per Category

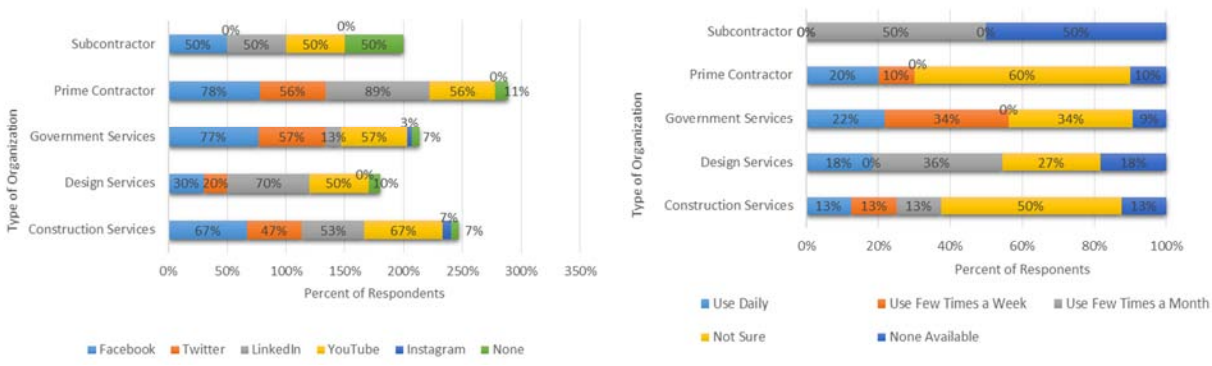


(c) Twitter® Posts Log: (Left) Per Company; (Right) Per Category

Figure 1: Social Media Usage Logs for 10 Medium to Large Size US Construction Firms (Data collected between Feb. 2013 to Feb. 2014)

3.2. Qualitative Analysis – Survey and Interview Results

The questionnaire survey was sent to 105 individual organizations within the US construction industry using purposive sampling. Fifty eight (58) valid responses were received yielding a response rate of 55%. The respondent organizations represents different trades within the construction industry and their usage of social media is at different levels as shown in Figure 2.



(a) Socia Media Platforms used by Organizations (b) Frequency of Social Media Usage by Organization

Figure 2: Social Media Tools and Usage by Surveyed Construction Organizations

After analyzing the survey data, three in-depth open-end interviews were conducted with the selected respondents. The interviewees were: (1) Vice President of communications and marketing of a large general contracting firm; (2) Public affairs specialists of a military construction organization; and (3) Marketing coordinator of an engineering consultant firm. The combined results of the questionnaire survey and interviews are presented in the following sections.

3.2.1. Social Media Impact Recruitment

Nearly sixty percent (60%) of survey respondents consider social media as an effective marketing tool for hiring new employees for their organization. The interviewee #3 said “I think the recognition alone we would get from using social media would allow us to reach potential employees in a different way than we currently do. Depending on the type of employee we're trying to reach, that might be the optimum place to contact them”. Overall, data suggests that social media could significantly aid in hiring new qualified employees.

3.2.2. Social Media Impact on Disseminating Company’s or Projects’ News

Data obtained from the questionnaire revealed 55% of surveyed individuals believe social media is an effective tool for disseminating real time company’s or project’s news to the public. Conversely, when considering impact on communication and collaboration amongst all parties involved on a construction project, almost one-third (34%) of surveyed individuals consider social media to be an effective tool. From these results, it is evident that current social media usage within the construction industry to broadcast company and/or project news is a regular and consistent practice. However, this information focuses more on project metrics such as construction milestones achieved and progress updates rather than communication and collaboration enhancement amongst project specific individuals. Interviewee #2 explained it as follows, “I think having an effective overall communication plan for our construction program, to include social media, is most important. Ultimately, however, social media is just another tool in our communication tool belt to get the word out concerning our construction program”.

3.2.3. Social Media Impact on Company Branding

Information broadcasting relative to company’s branding is found to be prevalent use of social media within the construction industry, with 84% of the surveyed individuals indicated their organizations using or plan to use this practice. Branding communications include information such as company’s recognition within the industry and charitable efforts within the surrounding community. Interviewee #1 explained the significance of social media relative to company’s branding by stating, “One of the things we want to be known for is making a positive difference in our communities. Getting that type of information out there in the social media arena helps support that brand message. It also helps build the pride of our employees. So, for the purpose of brand recognition, people visit our social media platforms to learn about XXX, and we are able to promote the image we want".

3.2.4. Social Media Impact on Client Networking

Nearly 66% of surveyed individuals think social media to be an effective tool for linking with the clients. From the perspective of an organization trying to employ a strong social media program, Interview #3 said, "I think we would better link with the clients if we develop a social media plan, and that would allow us to share information about ourselves with our potential clients they might not learn through other avenues". Survey data further suggests that this category of information sharing shows potential to increase within the construction industry as social media utilization becomes more prevalent.

3.2.5. Social Media Impact on Training and related Information

Seventy-five percent (75%) of surveyed individuals think social media to be an effective tool for providing organizational training opportunities and related information. Additionally, 57% believe employees' participation concerning training would increase if offered through social media avenues. Interviewee # 3 shared her perspective by stating, "Social media might be something we would want to use to share information externally to show that training is important to the company and that our employees are always learning and developing their careers". Twitter® found to be the preferred platform for most executives to share such information.

3.2.6. Risks and Challenges Concerning Social Media

The risks and challenges associated with social media can push construction companies to become hesitant when considering implementation within their organization. In the questionnaire, when queried if social media creates security risks concerning the unauthorized dissemination of information within an organization, 82% of the surveyed individuals responded "yes". Additionally, when asked if social media creates technological risks concerning potential malicious software distribution and computer infection, 60% responded "yes". The survey respondents were also asked if they think the benefits of social media within an organization outweigh the associated risks and challenges. Fifty-five percent (55%) of the participants responded "yes". Interviewee #1 explained it as follows: "To have any type of a voice in the social media arena, there is some tending and nurturing required. Although these resources are free, there is cost associated with necessary upkeep and maintenance of a social media presence. As a result, people and organizations need to be aware, as they enter the social media realm, that time and cost are associated with creating a successful social media plan otherwise it will be very difficult to maintain a presence and connect with other people and organizations".

3.2.7. Innovation and Collaboration Provided by Social Media

Organizing effectively for social media excellence brings the promise of fundamentally transforming organizations by allowing them to harness the power of mass collaboration, to break the "silos," and to reap the benefits of more fluid configurations (Weinberg et al., 2013). The three interviewees were asked to provide their professional opinion concerning innovation social media provides to an organization. Interview #1 said, "I think these social media platforms will continue to develop and offer new advantageous resources for the industry. The spirit of all these sites is building the connectivity, teamwork, and collaboration within the industry." The point of view of interview #2 is as follows; "Social media can provide additional means to communicate everything our company is doing for our clients, our employees, and our community to individuals and organizations all throughout the construction industry". Whereas interview #3 mentioned, "It allows us to communicate much faster than ever before, and to a much wider audience".

To further understand the impact social media has on collaboration, examples from other professional arenas such as the academic community should also be considered. Internet access in homes, schools and communities has become increasingly available which lead to an emergence of a new digital landscape that fundamentally changed both current and future students in colleges and universities across the world. Students today have around the clock access to a wealth of information to invest and discover new knowledge (Ghanem et al., 2014). Moreover, the frequent usage of social networking sites offers a unique new teaching opportunity to instructors. Because many students are familiar with these programs and the technology involved, instructors can utilize the communication tools in these programs to engage students in a manner comfortable and enjoyable to them

(Ghanen, El-Gafy, & Abdelraziq, 2014). In essence, social networking is part of today's life and is being used by people of all ages and for the widest variety of purposes (Ghanen, El-Gafy, & Abdelraziq, 2014). In a nutshell, the innovation social media provides to an organization within the construction industry can be realized through multiple aspects of communication and collaboration. In addition, as these technologies continue to develop, further innovation will continue to advance these resources.

4. Conclusions and Recommendations

From quantitative and qualitative data analysis, it is evident that social media tools such as Facebook®, LinkedIn®, and Twitter® are progressing methods of communication within the construction industry. The social media activities covers a wide realm of information categories such as company branding, disseminating project news, information on job hiring, Client networking, etc. Additionally, this information is being disseminated both internally and externally allowing for a much broader audience. The survey data concerning overall communication capabilities of social media revealed 80 percent of respondents find it beneficial for external purposes while 50 percent think it is beneficial for internal means as well. In essence, social media resources provide additional aide to a construction company's communication program allowing for faster information sharing to a larger network of people and organizations. Despite these observations, however, social media is yet to be mainstream as a communication tool throughout the construction industry. The survey data revealed three factors attributing to this lack of utilization: Security issues, Privacy issues, and Lack of understanding. It is also found that most companies have not explored the full potential of social media and only using it as a sporadic one-way communication tool.

The following items outline recommendations for enhancing utilization of social media within the construction industry: (1) Sufficient time and funding should be allocated to support daily operations, maintenance, and security of social media resources; (2) Information dissemination on social media platforms should be regular and consistent to maintain a social presence among individuals and other organizations; and (3) Proper training should be provided to company employees to better orient them with the resources social media provides and how to use them to best represent their organization.

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Creative Construction Conference 2014

An overview of budget contingency calculation methods in construction industry

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Abstract

Due to risks and uncertainties associated with construction projects, owner agencies usually add a reserve amount to the estimated project cost. This reserve amount, known as contingency, is to absorb the monetary impact of the risks/uncertainties and to prevent cost overrun. Over the past two decades, many contingency calculation methods for construction projects have been introduced by practitioners and researchers. These methods can be ranged from simply considering a percentage of the project base cost to complex mathematical methods. Each of these methods suggests an approach for calculating contingency using different assumptions. The question is which one of these methods should be applied to a certain project at a specific phase. Knowing the advantages and disadvantages of each method can help practitioners in construction industry select the best method based upon their project characteristics, budget, and time. This paper compiles almost all contingency calculations methods and divides them into three main categories of: (1) deterministic methods, (2) probabilistic methods, and (3) modern mathematical methods. Each of these categories are then divided into more subcategories and discussed in detail.

Keywords: Contingency, Budget, Risk, Deterministic, Probabilistic, Monte Carlo Simulation.

1. Introduction

Owners usually need to have an accurate early cost estimate for their projects in order to provide sufficient budget for projects. Risks and uncertainties associated with a project are impediments to reach an accurate cost estimate. For instance, nearly 50% of the large active transportation projects in the United States overran their initial budgets (Sinnette 2004). To overcome the cost overrun issue, identifying project risk factors and cost escalation factors have been the subject of much research (Shane *et al* 2009). To absorb the cost impact of these risk factors, a contingency budget is added to the total project budget. This means that a total cost of project is broken down to: (1) base cost, and (2) contingency cost. Base cost is the cost of project which is not including contingency (Touran 2006). These are certain cost items of a project with a given scope necessary to physically deliver the project. Contingency is defined as a reserve budget for coping with risks and uncertainties and to help keep the projects on budget. Contingency is traditionally estimated as a predetermined percentage of project base cost depending on the project phase. In recent years, some agencies have started conducting formal probabilistic risk assessment to estimate contingency budget rather than deterministic approach (Touran 2010). However, to establish the contingency budget, an agency must make all efforts to set aside a budget which is optimized. This becomes more important when an agency is dealing with a portfolio of projects. Allocation of an excess budget for a project will use up the money that can be spent on other projects. For instance the current approach used by the U.S. Federal Transit Administration (FTA) to estimate the contingency budget in transit projects called Top-down Model is based upon a probabilistic method using lognormal distributions for different cost categories in the project. However, the way that cost categories are ranged is very conservative resulting in a contingency budget far larger than what might be indeed needed (Bakhshi and Touran 2009). In this paper, first several contingency definitions given by different agencies are presented. Then an exhaustive list of available methods for estimating contingency budget in construction industry is compiled and discussed.

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2. Contingency Calculation Methods

In this paper, as it is depicted in Figure 1, the common methods for establishing contingency budget are divided into three main groups: (1) Deterministic methods; (2) Probabilistic methods, and (3) Modern mathematical methods. All other common methods will be explained as the subcategories of these three in the following sections.

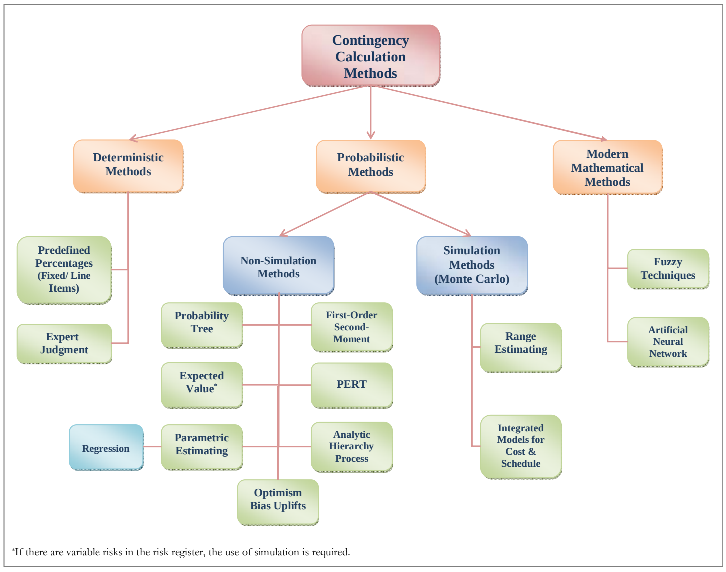

Figure 1. Contingency Calculation Methods

2.1. Deterministic Methods

Deterministic methods are considered to be the simplest and most common methods used to establish contingency budget (AACE 2008a; Baccarini 2006). These methods can be summarized in two main categories as follows:

Predefined Percentages (Fixed/Line Items): This approach is the simplest method of contingency allocation. In this method, either an across-the-board predetermined (fixed) percentage of total project base cost or various percentages of line items will be added to the project budget as contingency. When contingency is added separately for each line item (allocated contingency), it can be an overall contingency as unallocated contingency added to the project budget on top of the allocated contingency. Each agency has its own set of guideline for contingency percentages. The suggested percentages are given for different key phases of a certain type of project and may be a single value or a range of values.

Expert Judgment: The only difference of this method and predetermined percentage is that in this method there is not a set of predetermined percentages, but an expert or a group of experts with strong experience in risk management and risk analysis define(s) the percentage of contingency for the project under consideration. Even though this method can relatively considers the specific situation of each project by adding unique percentage for each project but it does not go through a formal and comprehensive risk assessment. Therefore, the contingency budget cannot be estimated adequately. Furthermore, similar to predefined percentage method, it does not provide the confidence level for the sufficiency of the estimated contingency.

2.2. Probabilistic Methods

The main difference between probabilistic methods and deterministic methods is that in probabilistic methods, uncertainties are explicitly modeled using appropriate statistical distributions (Touran 2006). Probabilistic models are divided into two main categories: (1) Non-simulation methods, and (2) Simulation methods.

2.2.1. Non-simulation Methods

This category includes the analytical methods in which risk assessment and contingency calculation are conducted without the use of simulation software packages. This is an advantage when an agency is not willing to invest on such software packages. However, these approaches are not suitable for large infrastructure projects where complex models are required. These models can be effective tools for the risk assessment of early phases of project developments such as conceptual or planning when project definition is not complete. With the advent of the low-cost, personal computer-based, and powerful simulation software, the justification for the use of non-simulation approaches is reduced. However, the main weaknesses of simulation approaches, such as lack of a closed-form solution and the possibility of non-convergence of results remain. Following are some examples of non-simulation methods.

Probability Tree: Probability trees provide a systematic method to transform individual risks each with a conditional expected value impact and probability of occurrence into an overall probability and expected value. This method is a diagrammatic representation of possible outcomes of consequence events. This model is not practical when the number of risks become large as the number of outcomes increases exponentially with the number of risks (Parsons *et al* 2004).

First-Order Second-Moment (FOSM): FOSM methods are approximate methods to calculate the mean and standard deviation of complex functions. They usually linearize the function first using methods such as Taylor series about an appropriate point (usually mean) and then its first and second moments are obtained.

Expected Value: In this method first all significant risks in the risk register are identified. Risk register is a list of all risks/opportunities along with their impacts on cost/schedule of the project which is the important product of risk identification process (Touran 2006). Then the risks need to be quantified by estimating the probability (likelihood) of risks' occurrence and impact of risks. The expected value of each risk is calculated by multiplying the probability of occurrence and its impact. If the all impacts are deterministic, the analysis can be done without simulation. However, most of the times it is not the case and the impact is uncertain and has a distribution. AACE (2009a) groups the risks that have deterministic impact as fixed (or deterministic) and those with uncertain impact as variable (or continuous). When the risks are variable or at least there is one, the use of Monte Carlo is required and this method should be considered as a simulation method. The correlation among the risks can be addressed while using Monte Carlo simulation. The contingency is considered to be the sum of all expected values and has a cumulative distribution function (CDF) when the impacts are uncertain. AACE (2009a) recommends that those risks that are being accepted by agency should be input to expected value analysis.

Program Evaluation and Review Technique (PERT): Program Evaluation and Review Technique (PERT) is a project management method developed in 1957 which works for both schedule and cost of projects using central limit theorem (CLM). This method assumes a Beta distribution for the cost of each item which is approximated with a three point estimate: optimistic cost (lowest), most likely (target), and pessimistic (highest). These three points can be either estimated quantitatively using data from previous projects or qualitatively using expert knowledge and experience (Moselhi 1997). Having the three-point estimate of each cost item, mean and variance of cost item distribution can be calculated based on some assumptions in the PERT method. However, Yeo (1990) modifies the original variance equation according to a 5-95th percentile. PERT assumes that the cost items are independent of each other which is a drawback of this method. Moselhi and Dimitrov (1993) suggested a probabilistic method similar to PERT which can accommodate the correlation among the project cost items.

Parametric Estimating: This method creates a relationship between an output which can be the cost overrun and inputs which can be a set of risk factors. This relationship is developed using historical data and methods such as multivariate regression analysis, artificial neural network, or even trial and error. Even though this method is simple and quick to apply, precaution is needed to select the risk factors that have predictable relationship with the outcome. First, parameters of the model which are risk factors such as scope definition, level of complexity, and size of project must be identified (AACE 2009b). It is recommended by AACE (2009b) that outcome is set as cost growth percentage relative to the base estimate excluding contingency. Data must be controlled to be free of any obvious and significant errors. After establishing all input and output parameters and collecting the necessary data, the relationship model can be constructed using either traditional multivariate regression analysis or more recent neural network methods. The neural network methods are classified as Modern Mathematical Methods and will be explained in Section 3.3.

Regression: This type of parametric estimating has been used since 1970s. This model is more effective for the early cost estimate when there is not enough detail about the project. Using a sophisticated model at the early stages of project requires adding assumptions that add more uncertainty to the analysis and runs against the parsimony principle of regression analysis. Ideally, the regression model must be simple and without using unnecessary parameters, it should provide the best fit for the data at hand (Baccarini 2006). Regression method is recommended where there is a linear relationship between dependent (*e.g.* cost growth) and independent variables (risk factors). While the assumption of linearity is not necessarily true, it is commonly made. As an instance of the regression method, Kim and Ellis (2006) formed a model to estimate and predict cost contingency of transportation projects based on two factors: original contract amount, and estimated contingency amounts set by maximum funding limits.

Analytical Hierarchy Process (AHP): To assess the effect of risks on the projects, different methods have been proposed that utilize probability analysis and Monte Carlo simulation. However, there is not always quantitative detailed information available to us for developing such models. Therefore, the use of a subjective approach for project risk assessment sometimes becomes indispensable. The analytical Hierarchy Process (AHP) developed by Saaty (1980) presents a flexible and simple way of project risks analysis. The linguistic terms used in AHP allows risk analyst to include subjectivity, experience, and knowledge in an intuitive and natural way. This was first applied in the risk analysis by Mustafa and Al-Bahar in 1991 for the risk assessment of a construction project (Dey *et al* 1994). In a method suggested by Dey *et al* (1994), first the whole project is classified according to the work breakdown structure (WBS). Risk analysis is performed separately for various work packages (WP). In each WP, risk factors and subfactors are identified and the overall risk of WP is calculated using the AHP. To allocate contingency budget they use two tiers. First, they implement the PERT approach suggested by Yeo (1990) for each WP to estimate the total cost distribution. Then using the overall risk of WP estimated from AHP, they find the appropriate targeted cost from the total cost distribution. The required contingency is the difference of the targeted cost and base cost.

Optimism Bias Uplifts: Optimism Bias Uplifts method (also known as Reference Class Forecasting) is a non-simulation probabilistic method developed by Flyvbjerg and COWI (2004) for the British Department for Transport (DfT) in effort to deal with optimism bias in capital project cost estimates. In this method, transportation projects have been divided into a number of distinct groups. These groups include road, rail, fixed links (such as tunnel or bridge), buildings, and IT projects and have been selected in order to have statistically similar risk of cost overrun based on the study of an international database of 260 transportation projects. For each category, the probability distribution for cost overrun as the share of projects with a given maximum cost overrun was created. Having established the empirical cumulative probability distribution, uplifts are set up as a function of the level of risk that the DfT is willing to accept regarding cost overrun. "Uplift" is the term used to show the amount that the original estimate needs to be increased to arrive at the project budget for a given level of certainty with respect to cost adequacy. In this approach, it is assumed that the projects in future will behave similar to the past projects from a budgeting point of view. Also, because the uplift values are based on a relatively small number of projects (for example, the database is comprised of only 46 rail projects), serious error can potentially occur in the calculated uplifts. In Bakhshi and Touran (2009), the Optimism Bias Uplifts method using by the DfT in the U.K. is compared with a method practiced by the United States FTA for transit projects in the U.S.

2.2.2. Simulation Methods (Monte Carlo)

In this method usually expert judgment and an analytical method come together to reach a probabilistic output using a simulation routine (AACE 2008a). In many cases where the closed form equations are not available or due to several mathematical operations of distributions, analytical models become more complicated, simulation can help analyst find the probabilistic output. Monte Carlo is one of the most common simulation methods in the construction industry which is widely applied in risk analysis and contingency calculation.

Range Estimating: In this method, first critical cost items are identified and the deterministic estimate of each critical cost item is considered as the most likely value. Next, the minimum and maximum values of the critical items are defined by a project group. At the end, with the help of Monte Carlo simulation the total cost cumulative distribution function (CDF) is calculated. This CDF is used to estimate the required contingency to reach the desired confidence level that budget will not fall short. To identify the critical items, the Pareto's Law, the law of the significant few and the insignificant many, or what is known as 80/20 rule is employed (Moselhi 1997). AACE (2008b) explains the critical item as an item that its deviation from target can cause ±0.5% change (called critical variance) in the bottom line cost at the conceptual estimate or ±0.2% at the detailed estimate. Just those cost items identified as critical are ranged by a project team based on their knowledge and experience. An example of this method is the technique used by the Federal Transit Administration (FTA 2007) published in Project Guidance (PG)# 40 called Top-down model. This method is explained in more detail and compared with the method used by British Department for Transport in Bakhshi and Touran (2009).

Integrated Models for Cost and Schedule: Even though it is obvious that cost estimate and schedule of construction projects are somehow related, cost estimating and probabilistic scheduling are often separately and independently applied (Isidore and Edward Back 2002). When there is no such a direct link between schedule and cost estimate of a project, the developed model cannot completely capture uncertainty and risk impacts associated with the project. Therefore, the calculated contingency budget may not be sufficient. A model called ABC-Sim (Activity Based Costing Simulation) was developed by Isidore and Edward Back (2002) in which range estimating and probabilistic scheduling are applied simultaneously on an appropriately modeled construction project at the work breakdown structure (WBS) level. Roberds and McGrath (2006) suggested an integrated cost and schedule risk assessment approach for infrastructure projects. They discussed that most commercial software packages developed for conducting risk analysis using Monte Carlo simulation are not capable of conducting true probabilistic, risk based, integrated cost and schedule modeling. They suggested the use of general-purpose Monte Carlo simulation software such as @Risk for developing tailor-made spreadsheet-based models. Touran and Bakhshi (2010) introduced an integrated cost and schedule model for multi-year programs which considers uncertainties in cost, schedule, and escalation. This model uses Monte Carlo Simulation and considers Martingale series for modeling of escalation uncertainties.

2.3. Modern Mathematical Methods

Fuzzy Techniques: Fuzzy set theory is a branch of modern mathematics that was first introduced by Zadeh in 1965 for modeling vagueness intrinsic in human cognitive process (Chan *et al* 2009). This is a method for capturing vagueness, uncertainty, imprecision, embedded human knowledge, human behavior, and intuition, and fuzzy logic enables computing with words where words are used instead of numbers (Sachs and Tiong 2009). In the risk assessment process when there is no statistical data available, opinions of experts with years of experience become very important. Experts can provide qualitative assessment of the risks. The conversion of these qualitative statements to numbers for estimating the uncertainty is not always easy. Fuzzy set theory is a mathematical tool that can help analyst quantify these linguistic terms (Choi *et al* 2004). Due to conceptual differences between fuzzy logic and probabilistic logic, Fuzzy technique has not been categorized into probabilistic methods. Sachs and Tiong (2009) develop a method for quantifying qualitative information on risk called Quantitative Qualitative Information on Risks (QQIR). In this method, fuzzy sets are used for capturing expert opinions and fuzzy weighted average method is employed for aggregating that information. The outcome of their model is a probability density function.

Artificial Neural Network: Artificial Neural Network (ANN) is an information processing technique that simulates human brain and its biological process (Chen and Hartman 2000). ANN uses a mechanism to learn from training examples and detect hidden relationships among data for generalizing solutions to future problems (Baccarini 2006). ANN is a better solution for modeling complex nonlinear relationships than conventional method such as nonlinear regression analysis (Chen and Hartman 2000).

3. Conclusion

According to the presented contingency definitions, there is consensus that cost contingency is a reserve budget for coping with monetary impacts of risks and uncertainties associated with a project. It should be noted that contingency budget is not intended to absorb the impacts of escalation, major scope changes, and extraordinary. Therefore, to keep a project within budget, calculation of adequate contingency is essential. To this end, it is imperative that an agency/owner be aware of different contingency calculation methods and select the most appropriate one based on the project characteristics. In this paper, the common cost contingency calculation methods were collected and classified into three main categories of: (1) deterministic, (2) probabilistic, and (3) modern mathematical methods. Then, probabilistic methods were further divided into two main categories: (1) non-simulation methods, and (2) simulation methods. Overall fourteen different methods were identified and discussed under these categories. This paper is a good resource for agencies/owners who are in budget development phase and want to allocate contingency budget for their projects.

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Project management control tools derived from the quality Risk based management systems

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Abstract

The Quality management and the Risk management in Civil engineering processes are frequently discussed topics on the construction market. Synergy effect of combining the Project management tools with Quality/Risk based management systems is most desirable solution of complex Civil engineering tasks in construction projects. Process oriented management is a key to successful (continuous) improvement. Unfortunately Civil engineering stays behind other industrial branches in correct applying and integration of the management supporting tools. The certification process in Quality/Risk based management systems is unavailing; certification of the Project management is not even existing or not required by the Construction market. Application of international standards such as ISO, TQM or others is often very difficult in construction processes or projects. Integration of common requirements into the management system of Construction Company is ineffective. The Management System is not bringing the added value, comparing to paid price for the certification or to internal costs spent. Effectively working management system in the construction company can be really cheap. Project management could take the advantage and utilize well known (inexpensive but effective and verified) tools from Quality/Risk based management systems.

Keywords: Quality management, Project management, Quality assurance tools, 5S, Lean, Construction Engineering.

1. Introduction

Modern project management as a methodology implemented in construction engineering is well described and widely known for almost a century. We had many opportunities to gain the knowledge from documented phenomenal projects, successful constructions, large- or micro-scale projects during last decades. Unfortunately we could also learn from many disasters in the history. Principal questions when something unexpected happens are: "What could have been done better (more resistant, built faster, cheaper or bigger)?" and "How we will do it next time?"

This we define as the "Continuous Improvement" – cyclical approach of the Management System helping many managers to find and implement the best measures. Continuous improvement is well described e.g. by the Quality Management, Risk management, Safety management or Environmental protection management systems.

Table 1. Reference of shortcuts used in this paper

A shortcut or a term	Explanation
5S	Five S method (derived from LEAN management methods, originally came from Japan, the shortcut stands for: Seiso, Seiri, Seiton, Seiketsu and Shitsuke, which is being translated as: Sort, Set in Order, Shine, Standardize and Sustain)
FTE	Full Time Equivalent (used frequently as the KPI for "Human Resources Optimization" processes – usually shows the number of employees to be reduced from the line organizational structure)
MS	Management system (QMS, EMS, SMS, IMS stands for the Quality, Environment, Safety or Integrated management systems, e.g. based on ISO standards)

1.1. Quality management and Risk management principles

The 'ISO based' management systems usually define the "continuous improvement" as a consolidated set of requirements, behaviors or internal culture based on the Plan-Do-Check-Act (PDCA) Cycle. PDCA is used to build-up a resilient Management system.

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The Quality Management System standards define eight following principles as the fundamentals (ISO 9001, ISO 9004, ISO 1006):

- Customer focus
- Leadership
- Involvement of people
- Process approach
- System approach to management
- Continual improvement
- Factual approach to decision making
- Mutually beneficial supplier relationships

Project management applies knowledge, skills tools and techniques for project activities to reach the project requirements. Primary objective of the project management is to deliver the product (service, change, improvement) in time, in full functionality within the assigned costs (budget). Project is a unique (not repeating) set of activities, an intention developed in order to create the added value, to find the solution (or construct a building). Project has a beginning and the end, it has unique characteristics (it's exact opposite of a batch production).

Although it might not be clear the Project management and the Quality management do have tense relations. For instance processes in the Quality (or other) management system can be used to define the project. Repeating and (in a long term scale) improving activities of a Process management are used within the management of a project by involved people in the organization and also by the management.

Following figure shows the internal relations of Process activities and management of a project:

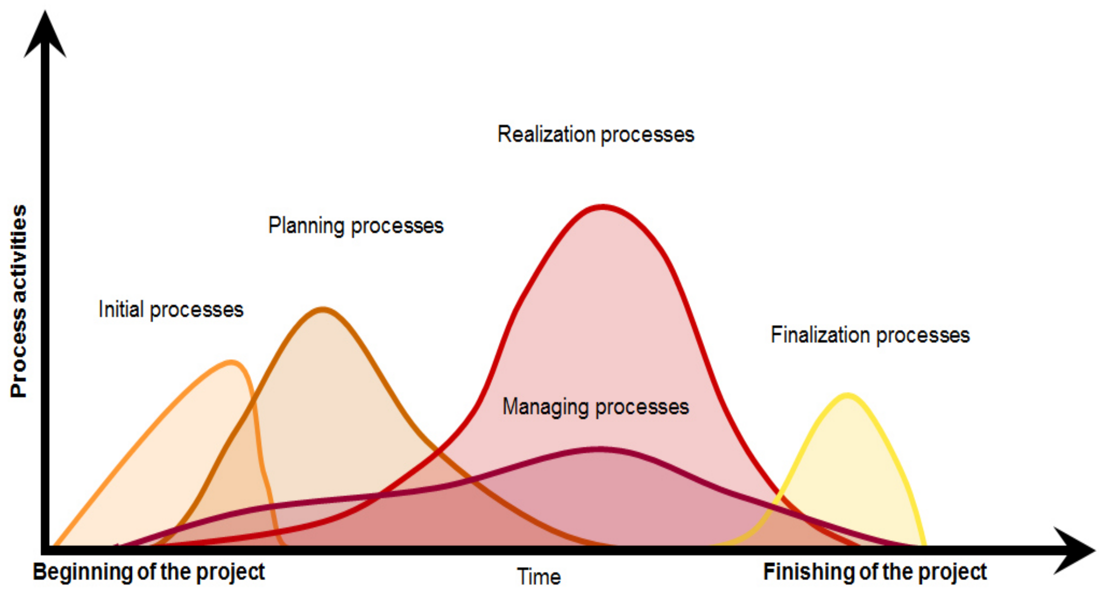

Figure 1. Relations between the Project management and Process activities within the timeframe of a project

1.2. Process oriented management – a key to successful improvement

The process oriented management is the most effective way of bringing the added value (Process improvement through Six Sigma with Beta correction: a case study of manufacturing company, 2014). Process based management systems have shown as the most effective managerial approach already in sixties of the last century. The process based management (PDCA – Plan-Do-Check-Act) and its fundamentals were defined and documented by one of the "Fathers of the Quality" - W. E. Deming. He promoted the PDCA after the World War II. The PDCA fundamentals were widely implemented into the industry management for the reengineering and reconstruction of the damaged economy in Japan.

Modern management systems are still based on the PDCA cycle up to these days. The following figure shows the definition by the ISO 9001 standard:

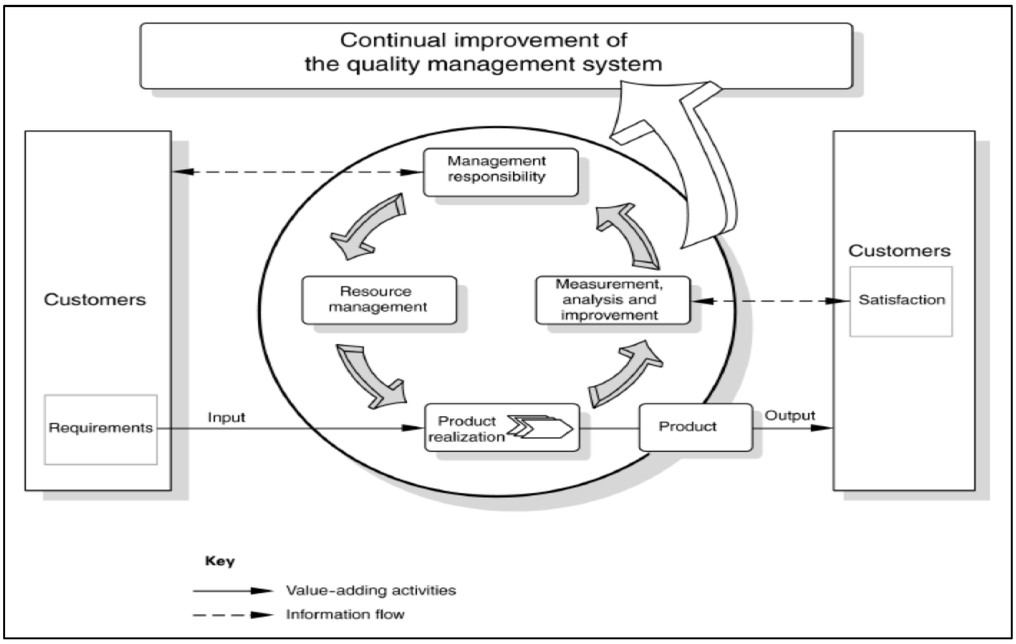

Figure 2. PDCA (continuous improvement) process based management system - ISO 9001

The economic effects of management systems are difficult to be seen immediately after the MS implementation. The managers' expectations (shown on the following figure) should not be overestimated.

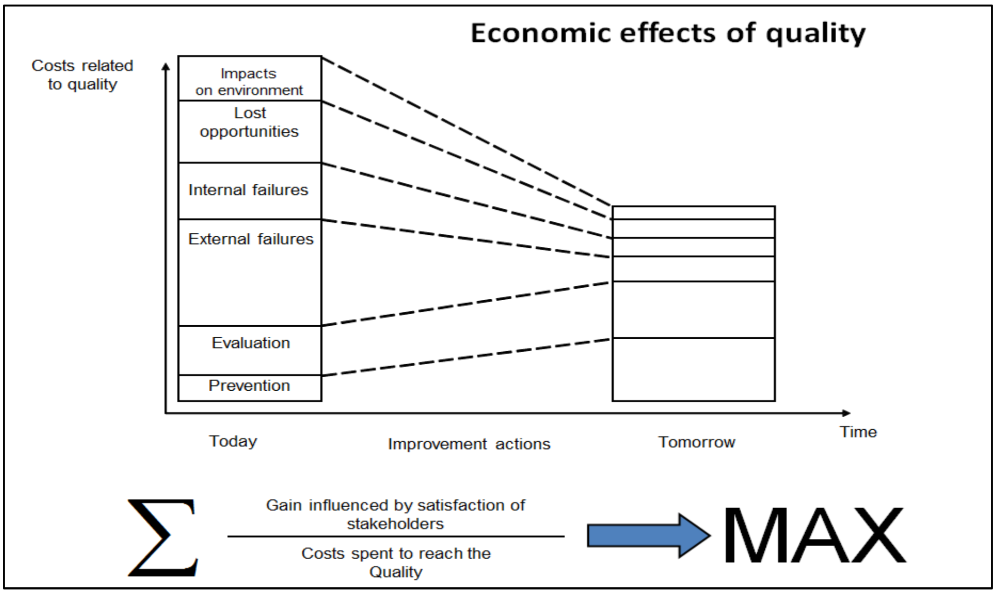

Figure 3. Economic effects of quality – Managers expectations on continuous improvement

2. Difficulties in Civil engineering management systems application in practice

Civil engineering stays behind other industrial branches in correct applying and integration of the management supporting tools. There is a significant lack of time and insufficient management effort to use sophisticated management system tools. The quality management system is usually implemented very quickly, with a high pressure to receive immediate results (Planning for Quality, Productivity, and Competitive Position, 1990). But the potential outputs from well implemented management system are not understood correctly (and/or not even expected in many cases) by the organizations management. Managers' expectations are often limited to fast delivery (budget savings, process administration improvement, Full Time Equivalent (FTE) reduction, or even a "certificate on the wall" as the required input for prepared competitions) (Understanding Statistical Process Control, 2010).

Therefore the integration of consolidated requirements into the management system of a construction company is ineffective or not bringing the desired value. The application of international standards such as ISO, TQM or others is very difficult in such construction processes or projects The certification process in Quality management systems is unavailing - frequently used argument of such managers' decisions is low effects received comparing to the paid price for the certification or compared to the additional internal costs brought into the management system.

However the 'cost-saving' or 'immediate results seen' attitudes of the organizations' management might be identified as very logical, they are not helping to keep the sustainability of the organization from the long-term view.

Concerning the Project management certification the situation is even worse. The certification of the Project management systems according to the international standards in fact does not even exist on the Construction market. The possible cause is that the knowledge of Project management system certification is very low. Even that there are existing standards for the Project management certification; their implementation is struggling with the similar issues as were identified with the Quality management systems. The certification of the Project management is often not required by the market. This leads to spontaneous misguiding of Project management requirements and to their incorrect understanding.

3. Inexpensive tips and tools for easy implementation

On the other hand - well implemented, effectively working management system in the construction company might bring many positive effects and doesn't have to be expensive. There are many managerial tools, cockpits and methods on the market and we do have positive experiences with their implementation into the practice (Six Sigma: hints from practice to overcome difficulties, 2014). The common aspects of successful tools are *Simplicity of understanding* and *Easiness of use*.

3.1. SIPOC

As an example of such simple-easy tool is SIPOC (The Six Sigma Way, 2000). SIPOC is a high level view of a process. It stands for Suppliers, Inputs, Outputs, and Customers as shown on the following figure:

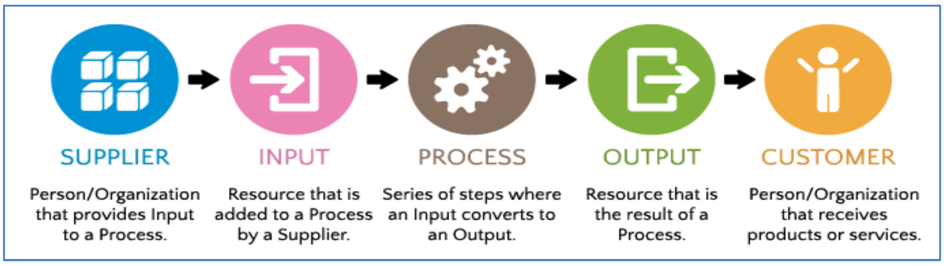

Figure 4. What is a SIPOC? (GoLeanSixSigma.com, 2013)

It is commonly used for fast process mapping and effective process map drawings to design the process structure, resources needed, process owners and users, inputs received from suppliers and outputs given to customers. SIPOC brings a clear and timely understanding of what is really essential for a sustainable organization (and also helps to show what is not) (Six Sigma for IT Management, 2006).

Following figure shows the example of a SIPOC analysis result in a construction company – a process definition chart. Provided as the output of a student semestral thesis – Czech company "Swietelsky s.r.o." was analyzed in 2012, fiction employee names are used:

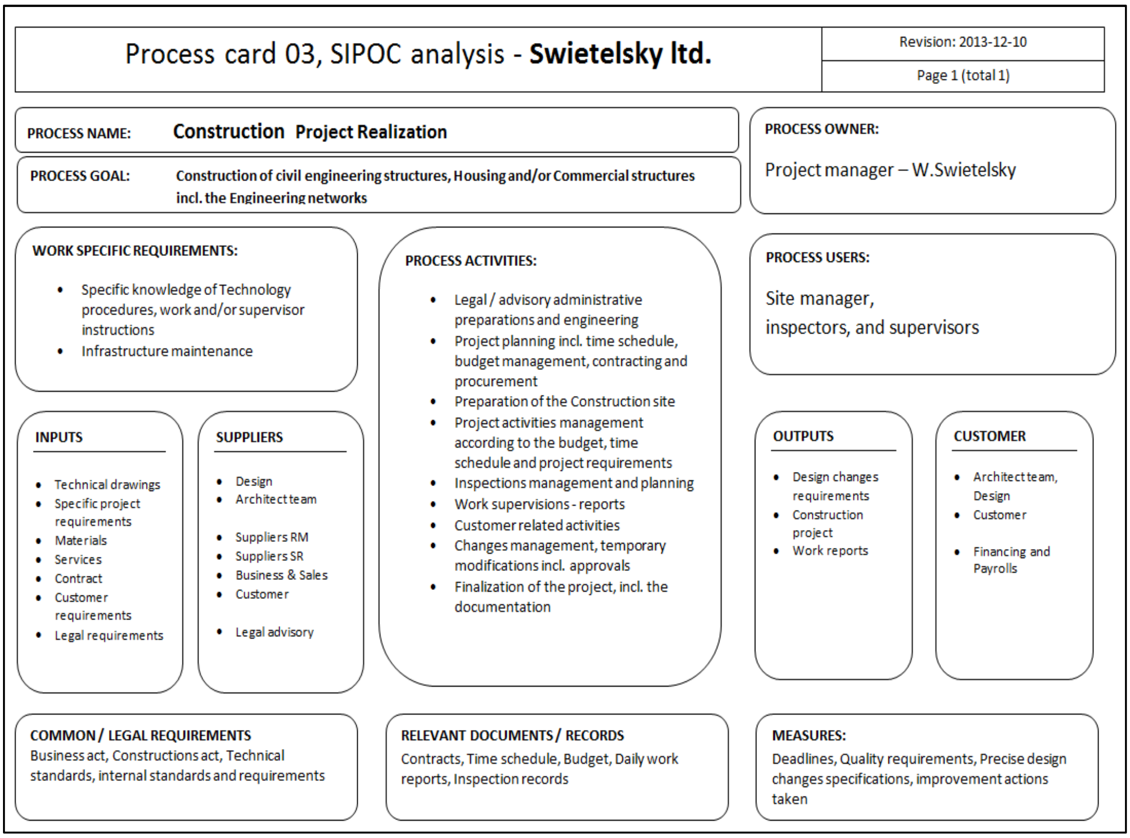

Figure 5. SIPOC process chart - example of the process definition

3.2. 5S Methodology

Five S method (derived from LEAN management methods), originally came from Japan, the shortcut stands for: Seiso, Seiri, Seiton, Seiketsu and Shitsuke, which is being translated as: Sort, Set in Order, Shine, Standardize and Sustain. Methodology of the 5S is typically associated with a higher topics management system tools such as, Kaizen, Lean Production or Continuous Improvement programs. (The Six Sigma Handbook, 2003)

The philosophy is based on a way of organizing and managing the workplace, especially a shared workplace (like an office area, shop floor or a warehouse). The aim is to have the place organized to see the main flows, inputs and outputs transparently and to identify easily the potential sources of “waste-losses” concerning the LEAN approach.

Its application became very popular in last decades because of its immediate result seen effect. As an addition the managers receive the immediate picture of their own working area (as it is quickly obvious when e.g. something is missing from its designated location, helping them to decide what should be kept, where it should be kept or how it should be stored). Fast effectiveness increase by applying the 5S into the managing processes can be demonstrated from many implementation examples.

The 5S diagram consists of a cyclic loop of continuous improvement and fostering the discipline, following figure shows the overview of the 5S methodology:

Figure 6. Fostering the discipline - 5S Diagram (Lean4Success.net, 2014)

4. Conclusion

Project management in the Construction market might take the advantage of these Simple-Easy (well known, verified, not expensive but effective) managerial tools of Quality/Risk based management systems and utilize them in a non-destructive way. 5S, SIPOC or PDCA as managerial tools are powerful, cheap and fast to implement and use. Project management certification is also plausible. Reengineering of the management system is needed when "Certificate on the wall" is the only effect of the management system. The visible results and improvement of the management system must be seen in medium-term operation period.

Acknowledgement

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Ontology evaluation: An example of delay analysis

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Abstract

Ontologies have a place in knowledge sharing with their ability to capture real world information in a machine readable environment. Their application varies from any approach structured on ontological commitment to meta-level ontologies serving for variety of purposes. This variety continues also in methodologies for constructing the ontologies. There are wide range of ontologies differing in size and complexity that are created with different design criteria. The main point with the ontologies is their structure and ability to serve for the intended purpose. This is only granted with the continuous evaluation of ontologies in the construction process, and also before release or reuse of the ontology. Ontology evaluation methods cluster around two concepts such as verification methods that ensure the structure of the ontology, and validation methods that examine their applicability in real world. In light of these, different approaches as quantitative and qualitative methods are depicted in literature from tools to evaluations by experts all of which investigate different characteristics.
Objectives of this study are to underline the importance of ontology evaluation and to present an employed validation method used during ontology development for delay analysis. In this context, first; literature review on ontology evaluation is presented. Second, a delay analysis ontology is introduced with its basics to lay the foundations of the study. Cases taken from the Turkish construction industry are exemplified to explain the utilized ontology validation process. Comparison of the concepts in the constructed ontology and expert reports written for each case is used to evaluate the ontology. Furthermore, alternative validation techniques are discussed as well as possible attempts to keep it responsive and up-to-date.

Keywords: construction sector; delay analysis; ontology; ontology evaluation; ontology validation.

1. Introduction

Ontologies occupy a prominent place in knowledge sharing. The ontology concept is flexible and its adaptability leads variety and prevents a common ontology development or evaluation method to be accepted. Their usage area is wide and they are developed to respond many need in the area. The soundness of an ontology between all the created ones is manifested only by its evaluation. So, evaluation is highly recommended during whole life cycle of an ontology. In this context, many evaluation methods are available that are responsive for different evaluation aims.

An ontology of delay analysis in construction sector underlies this study. This inevitable problem of construction sector is tried to be handled in this way to increase knowledge in the issue and to form a base for any attempt that would be held in machines environment. Possible use of the ontology by construction companies in project, risk and/or claim management and as a database for the companies is expected by this ontology. Accordingly, validation by real expert reports on delay analysis is selected to ensure the soundness of the literature based ontology.

In this paper, literature review on ontology evaluation methods is handled and the followed validation method is presented to show the variety and importance of ontology evaluation methods.

2. Research background

In this section, firstly ontology is defined and following that literature review on its evaluation is presented to reveal its extent.

2.1. Ontology

Ontologies have been widely used in knowledge engineering since 1990s to meet the need of unified forms for information sharing to provide common understanding and reuse (Corcho, Fernandez-Lopez, & Gomez-Perez, 2003; Noy & McGuinness, 2001). With its widely known definition, an ontology is "an explicit

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specification of a conceptualization" (Gruber, 1993a; 1993b). Corcho et al. (2003) present a unified definition as "ontologies aim to capture consensual knowledge in a generic and formal way, and that they may be reused and shared across applications (software) and by groups of people". Additionally, Gangemi et al. (2006) structurally define an ontology as "a graph whose nodes and arcs represent conceptualizations". Basically it is the graph of meta-data ranging from thesauri, taxonomies and axiomatized theories. The taxonomic (sub-class of / is-a) relationships of an ontology constitute the depth and breadth of an ontology, whereas non-taxonomic relations constitute the density of the ontology. It is the dexterity of its developer to keep the conceptualization in a semantically formalized form, namely in the graph (Gangemi et al., 2006). Ontologies are basically taxonomic tree of conceptualizations from general objects at the top level to the specific ones at the bottom level (Chandrasekaran, Josephson, & Benjamins, 1999). When taxonomies are improved with more information through relations and rules for modeling a domain, they become ontology (Neches et al., 1991). Accordingly, one is free to construct any lightweight (generally including concepts, concept taxonomies, relationships between concepts and properties of concepts) or heavyweight (additionally including axioms and constraints) ontology that would be structured to be responsive to any need (Corcho et al., 2003). There are various ontology construction methods ranging from construction from scratch to merging existing ontologies and generating ontologies with automatic generation principles (ontology learning) (Alfonseca & Manandhar, 2002). In response to this, there are wide range of evaluation metrics available presented to evaluate the intended structure and functionality of the ontology. Moreover, researchers that propose development strategies also mention some design and evaluation criteria for ontologies like the ones presented by Fox and Gruninger (1997); Gomez-Perez (1996); and Gruber (1993b).

2.2. Ontology evaluation

With wide-spread usage of ontologies in knowledge representation, development and re-use of ontologies bring up question of evaluation of ontologies. There are various evaluation methods that search for different measures with qualitative or quantitative metrics for different ontologies, however no global approach has been adopted (Gangemi et al., 2006). As it is previously stated; ontologies vary in their domain, size, purpose, language, and may be hand-carved, may be constructed by scholars or domain experts or may be obtained by an automatic or semi-automatic process. This situation leads evaluation of ontologies to be complicated and prevents release of a standard evaluation procedure (Netzer et al., 2009). Additionally evaluation is required during whole life-cycle of an ontology; namely during pre-modelling, during modelling, before release and after release (Bolotnikova, Gavrilova, & Gorovoy, 2011; Hartmann et al., 2004). Many study held by different researchers in the ontology evaluation area address the problem and point up importance of the issue. There are methods that are either manual or automatic, either dealing with taxonomy or evaluating the content, and either dependent to some specific tool/language or independent (Lovrencic & Cubrilo, 2008). This double variety of ontology development and evaluation increases the complexity in the area and keeps the evaluation problem unsolved (Bolotnikova, Gavrilova, & Gorovoy, 2011; Fernandez-Breis, Aranguren, & Stevens, 2009). Accordingly; to obtain a reliable ontology, complementary use of different evaluation methods is appreciated (Lovrencic & Cubrilo, 2008).

2.2.1. Classification of ontology evaluation methods

There are various classification attempts on evaluation methods and tools. The details are given below however what is common between them is at the outer set they are either *verification methods* that ensure the ontology is constructed correctly, or *validation methods* that ensure the ontology represents the real world (Gomez-Perez, Fernandez-Lopez, & Corcho, 2004).

Hartmann et al. (2004) classify ontology evaluation for the methods as (1)*OntoMetric* – Analytic Hierarchy Process based method that presents set of measures to select the best ontology for a particular need; (2)*Natural Language Application Metrics* – mainly associating mentions in the text with the concepts in that ontology (precision and recall metrics, cost-based evaluation metric, ontology fit – the tennis measure, and lexical comparison level measure); (3)*OntoClean* – evaluation of formal structure of the taxonomy by the ontological notions of rigidity, unity, identity, and dependence; (4)*EvaLexon* – mainly creating ontologies from text, comparison of the vocabulary with text calculation of coverage, accuracy, precision, recall. Additionally, they present the applications and tools as (1)*ODEval* – tool that detects possible problems in concept taxonomies, (2)*OntoManager* – tool that evaluates the truthfulness of an ontology with respect to the domain.

Gangemi et al. (2006) identify three categories as *structural measures* – evaluation of formal structure of the ontology, the graph; *functional measures* – evaluation of the relation between the ontology and the intended meaning, how it serves for the purpose, its cognitive semantics, mainly precision/recall-based measures; and *usability-profiling measures* – evaluation of the ontology profile, communication context of the ontology, its pragmatics. *Structural measures* are depth, breadth, tangledness, fan-outness, specific difference, density, modularity, logical adequacy, meta-logical adequacy, degree distribution. *Functional measures* are precision, recall and accuracy which are measured against experts' judgment or a data set assumed as a qualified expression of experts'.. Finally, *usability-profiling measures* are handled as recognition, efficiency, and interfacing.

Netzer et al. (2009) group the ontology evaluation purpose as *assessing the quality* by its developers, or *ranking the ontologies* to choose for some particular use. Additionally they group the evaluation methods as *intrinsic* and *extrinsic* methods. *Intrinsic methods* focus evaluation of the structural properties; whereas *extrinsic methods* require some external information such as a corpus that represents the domain knowledge (data-driven evaluation), expert opinion, or a particular task.

Zouaq and Nkambou (2009) mention *structural evaluations* and other approaches as *gold standards* – comparing the ontology with a "gold standard", *application-based* – using the ontology with an application and evaluating the results, *data-driven* – comparing the ontology with a source of data from the domain to be covered, and *assessment by domain experts*.

Bolotnikova et al. (2011) classify the methods of ontology evaluation according to *the goal of evaluation*, *the stage of evaluation*, *the degree of automation*, *the object of the analysis*, and *the tools applied for analysis* and depicts the taxonomy within a schema.

2.2.2. Data-driven evaluation and NLP

Brewster et al. (2004) state that ontologies are simply set of concepts and relations that are either explicitly defined or following from set of axioms, and accordingly they are abstractions from a set of natural language texts that are describing the domain. So they propose reversing the procedure for evaluation as finding concepts in the texts that are related with the ones in the ontology, and name this process as corpus or data-driven evaluation. Additionally, Gangemi et al. (2006) state that functional measurement is based on "matching" between two structures, basically the search of correspondence between the ontology and something else. They additionally refer Natural Language Processing (NLP) based methods, methods based on matching between a corpus of documents and the ontology, as generally used methods for functional assessment. They refer to Daelemans and Reinberger (2004) that NLP based methods provide to show the ontologies are "consensual conceptualizations" rather than just its developers' ideas. Through a corpus-based analysis, empirical estimation of the *accuracy* and *coverage* of the ontology can be made. (Gangemi et al., 2006). In parallel with these, Hartmann et al. (2004) point out two metrics as "one that shows how well a 'sample ontology' built as the result of a certain methodology (human modelling or automated mining) 'represents' a commonly accepted reference corpus, and one that details how the ontology actually ordered 'corresponds' with the input text(s) of the customer's application domain".

3. Evaluation of delay analysis ontology

In this section, the delay analysis ontology is introduced and the established evaluation procedure is presented.

3.1. Delay analysis ontology

As it is previously stated a delay analysis ontology may act as a vocabulary of the delay analysis domain and provide the easy understanding of the debate. Additionally, with its ability of easy adaptation to the machines world, ontology may be used in a software program or form the basis of a company database or decision support system. Methontology procedure (Gomez-Perez, Fernandez-Lopez, & de Vicente, 1996) is followed step by step for the establishment of ontological structure and Protege is used for its implementation. For the design of the ontology, principle of Noy and McGuinness (2001) as; *nouns* in sentences that describe domain constitute *objects/concepts* in an ontology whereas, *verbs* in sentences correspond to *relations* of the concepts in the ontology constitutes the foundation of the conceptual background of the ontology. The main concepts in the issue are extracted from literature review on delay analysis as "*causes of delay*", "*types of delay*", "*responsibility of delay*", "*claim for impact of delay*", "*analysis of delay*" and "*prevention of delay*"; accordingly the delay analysis ontology is defined in few sentences that are able to be read through ways formed by passages from the surrounding classes to the core class "delay". The following Unified Modelling Language (UML) diagram constitutes the graph of the generated ontology (Figure 1). There are relations at concept level depicted in black and blue, and also relations at instances level depicted in red. For the full taxonomy of concepts behind the graph of the ontology, the details of the ontology can be investigated in the study of Bilgin (2011).

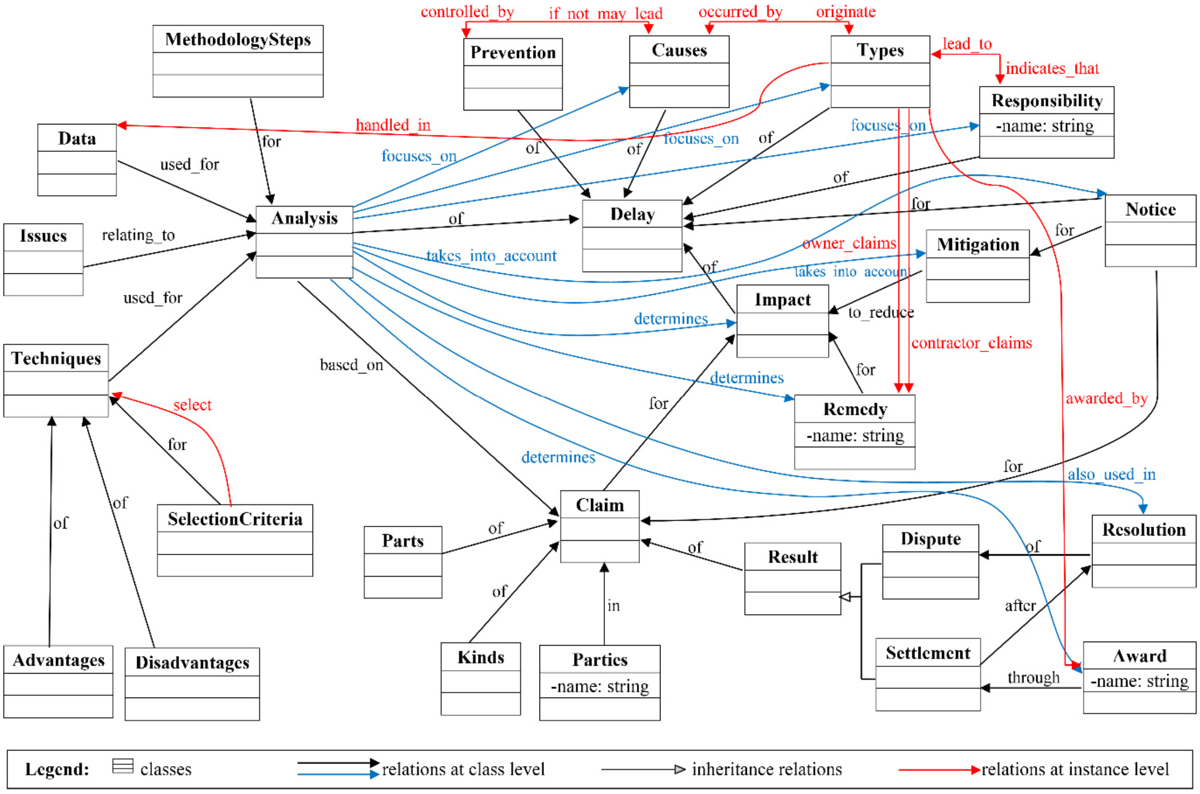

Figure 1. Complete model of delay analysis ontology (Bilgin, 2011).

3.2. Evaluation procedure

As it is presented, there are many methods available for almost any kind of evaluation, and new ones can be added according to the specific features of the created ontology. Within the variety of evaluation methods, it is important to use complementary methods that will respond to both evaluation aspects as *verification* and *validation*. Multiple use of methods leads a consistent and usable ontology (Lovrencic & Cubrilo, 2008). For example, El-Diraby and Wang (2005) use competency questions, expert evaluations and tests on sample documents to evaluate their ontology in terms of ease of navigation, abstraction consensus, representation, and consistency. Evaluation can be done for the search of various measures; however when its specific use is thought, criteria relevant for that use should be taken into consideration (Gangemi et al., 2006). Gangemi et al. (2006) refer to Noy (2004) as it is stated that knowing the ontology is accurate to some formal criteria, namely its structural quality, only implies that the ontology is usable but it does not give any idea about its suitability for the case in hand. In light of these, regarding the evaluation of delay analysis ontology; first of all since it is constructed with a methodology (Methontology) that indicates evaluation step as a continuous step during the construction of the ontology, verification of the ontology is considered from the beginning to the end of the ontology construction process. Competency questions are used in the specification step of the methodology which is a method proposed by Gruninger and Fox (1995) as the queries helping the construction and also evaluation of the ontology. The following *competency questions* are used to structure the ontology: "Why this ontology is being built?", "Who are its users?", "What is delay?", "What is delay analysis?", "What does happen in case of a delay?", "What are the causes of delay?", "Who are responsible from delay?", "What should be done in case of a delay?", "What should be done for the prevention of delay?". Additionally various design criteria presented by different researchers (Fox and Gruninger, 1997; Gomez-Perez, 1996; Gruber, 1993b) have a control over the construction of the ontology, and are taken into consideration as far as possible. Objectivity is tried to be provided to prevent ambiguity, and inconsistent definitions are not included in the ontology. Also, the created ontology is easy to update due to its common representation system and has only the common definitions of the subject, so does not limit its users when its usage is in question. Moreover; for the implementation of the ontology, a reliable tool (Protege) is used that would form an anticipated ontology skeleton. So, it can be said that verification of the ontology is made at considerable level and what is crucial at this point is the search of matching of the constructed ontology to real world. Besides, Lovrencic and Cubrilo (2008) state that small ontologies can be created with only few mistakes however incompleteness problem always exists. Accordingly for a lightweight and this type of ontology, search for completeness is also important. Between available options for validation (expert interviews, case studies, comparative analysis of industry documents and competency questions), the validation of the ontology through case studies is selected (El-Diraby & Wang, 2005; El-Diraby & Zhang, 2006; Gruninger & Fox, 1995; Tserng et al., 2009). Real *expert reports* for claim analysis are selected since they are the primary documents for delay analysis. For the technique handled it can be said that in a way it is parallel with NLP based methods. In total it searches for the *completeness* and *suitability for the use* of the ontology. According to classification presented by Bolotnikova et al. (2011); the method handled can be deemed as a "manual" (automation degree) and "data-driven" (analysis tool) method, applied for "testing before release" (application stage), with the goal of "completeness and precision of the dictionary of the subject domain", and with the analysis object as the "dictionary".

4. Summary of case studies

Three case studies from claim analysis are selected between five available due to their detail handled in. Phrases in the reports are separated into concepts (underlined) and they are matched with the related concepts in the ontology as in the example provided in following table (Table 1). Phrases of the report are totally kept in quotation marks, whereas only concepts in the ontology are presented in quotation marks. To specify the place of the concept in the ontology, upper concepts defined are also included. For the inclusion of information of relations in the ontology; the word "under" is used to refer taxonomic relations between concepts, whereas the demonstration "-association_name-" is used for the non-taxonomic relations. So, "phrases in ontology" are indicated in path forms such as: "concept" under "concept" -association- "concept". The following table (Table 1) exemplifies the process held during evaluation.

Table 1. Example for comparison of concepts.

Phrase in the Report	Phrase in the Ontology
"Obtaining building permits: Contractor informs the Engineer about the delay due to obtaining building permits is not in their (contractor's) responsibility and claims the required extension of time. Engineer approves the contractor's claim and with the consent of owner 17 days of extension is awarded to contractor and the new contract completion date is determined."	"Notice" -for- "Claim"-for- "Impact" -of- "Delay"
	"Building permits approval process" under "Rules and Regulations Related Causes" under "External Causes" under "Causes" -of- "Delay"
	"Owner (or his agents) responsible" under "Responsibility" -of- "Delay"
	"Neither contractual party responsible" under "Responsibility" -of- "Delay"
	"Claim" -for- "Impact" -of- "Delay"
	"Extension of time claim" under "Time Related Claims" under "Kinds" -of- "Claim" -for- "Impact" -of- "Delay"
	"Settlement" -is-a- "Result" -of- "Claim" -for- "Impact" -of- "Delay"
	"Extension of time" under "Award" -through- "Settlement" -is-a- "Result" -of- "Claim" -for- "Impact" -of- "Delay"
	"Award" -through- "Settlement" -is-a- "Result" -of- "Claim" -for- "Impact" -of- "Delay"
	"Current completion date" under "Details of Claim" under "Parts" -of- "Claim" -for- "Impact" -of- "Delay"
	"Practical completion/Substantial completion and initial certificate" under "Contract Clauses" under "Main Contract Documents" under "Contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"
	"Update and reanalyze the network: specify the project is ahead or behind the schedule at delay date." under "Apply Analysis Technique" under "Event Analysis" under "Methodology Steps" for "Analysis" -of- "Delay"
	"Adjusted/Updated schedule: schedule depicting impacts by changes on as-planned schedule" under "Major Schedules" under "Post-contract Documents" under "Data" -used_for- "Analysis" -of- "Delay"

5. Discussion and conclusion

The concepts within the reports and the ontology are matched, only several additions are made as a result of this evaluation. As a summary of the study (Bilgin, 2011), totally 365 concepts are matched; and after elimination of repetitive concepts, 221 distinct concepts are identified. Only 5 concepts are added so this leads to 97.74% matching between the reports and the ontology. The relations are not investigated separately since they complement the existence of the stated concepts. When the matching between concepts in the ontology and reports is considered; it is seen that the ontology has enough concepts to represent real world knowledge for these cases, and it has the potential to ease claim management process like the ones in the case studies. Additionally; as it can be seen, changes can easily be made to meet some specific requirement for its use. This evaluation process constitutes a final evaluation of the constructed ontology before its release. More expert reports can be handled and expert opinions on ontology can be taken for further evaluation. However, evaluation of the ontology is limited to some level with the mentioned methods. Actual evaluation of the ontology can be done by active usage of the ontology in a company database and by the possible updates that would be required during its usage.

Ontologies and their evaluation methods is introduced in this study and exemplified with a delay analysis ontology and its evaluation process. It is believed that, ontology and its evaluation are always welcomed as long as they are supported with some formal processes, and ontologies can be actually validated as long as they are actively used.

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The contractor selection criteria in open and restricted procedures in public sector in selected EU countries

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Abstract

This article presents a comparative analysis of the criteria used in the awarding of the contracts and appointing a contractor in the public sector in selected EU countries. For the purpose of conducting the analysis thirteen EU countries were chosen, e.g. Poland, Germany, United Kingdom, France, Italy etc.

The regulations in all analysed countries are based on and comply with the EU Directive 2004/18/EC which states that the Public Procurement process can be carried out by using two basic procedures: standard and special. In this paper two criteria used in standard procedures have been compared. The results of the comparison showed that the choice of procedures vary remarkably between the countries, and similarly the proportion of criteria used in the award process, where price and price with other non-price criteria are used. The results are illustrated on the diagrammatic maps.

Keywords: contractor selection, public procurement process.

1. Introduction

The appointment(X. Huang, 2011) of a contractor for the building works is a complicated and complex process(Russell, Skibniewski, & Cozier, 1990)(Russell & Skibniewski, 1988), and depends in its major aspect on the correct preparation of the procurement tender specification(Chou, Pham, & Wang, 2013), where all the needs and requirements of the contracting authorities are precisely defined. Insufficient information in a specification increases the risk that the chosen contractor might become unable to meet the requirements of the contracting authorities, and that it may, in a great number of cases, lead to a major failure. The contract awards based on the lowest price criterion may contribute to the imperfect competition on the market by means of artificially depressing the prices. As a result of this process some additional unforeseen cost of the investment may occur(Russell, 1991). Good example is a contractor's walk off site due to a bankruptcy, which incurs some additional cost in the form of necessary inventory of the works, including the inventory of the updated version of specification, possible changes to the project and repeated process of appointing a new contractor. The choice of the most economic offer minimises higher risk and increases certainty of the project completion on time and on budget.

It is needless to say that the preparation of tender specification and technical documentation requires an involvement of sufficiently qualified and experienced writers; consequently it also requires higher cost allocation. However, such cost does not exceed the necessary expenditure in case of a potential failure. Moreover, even if we take into account the other cost incurred during the lifetime of a project, e.g. heating and maintenance cost, equipment fixing and servicing cost, it often becomes apparent that the most economic offer is in fact still the cheapest one.

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2. The legislation in the European Union

The Public Procurement Law in the EU countries has changed several times. In 2004 two EU Directives were implemented, enabling a codification of rules and procedures across EU countries. They are:

- Directive 2004/18/EC of the European Parliament and of the Council of 31st March 2004 on the coordination of procedures for the award of public works contracts, public supply contracts and public service contracts
- Directive 2004/17/EC of the European Parliament and of the Council of 31st March 2004 coordinating the procurement procedures of entities operating in the water, energy, transport and postal services sectors

The national legislations in force had to be amended in order to comply with the Directives. All EU member states have implemented the Directives in their national legal systems.

According to the Directives public procurement should be awarded on the basis of disinterested criteria(W.-H. Huang et al., 2013) which ensure compliance with transparency, non-discrimination, equal treatment, and with guarantee that tenders are evaluated in circumstances of effective competition. Therefore, it is allowed to use only two criteria of contract award: “the lowest price” and “the most economically advantageous tender” (MEAT).

In the case where the contract is awarded (Sönmez, Holt, Yang, & Graham, 2002) on the basis of the most economically advantageous tender, from the Contracting Authority point of view, the criteria which are related to the particular public procurement might be:

- According to article 53 of 2004/18/EC Directive: quality, price, technical merit, aesthetic and functional characteristics, environmental characteristics, running costs, cost-effectiveness, after-sales service and technical assistance, delivery date and delivery period or period of completion,
- According to article 55 of 2004/17/EC Directive: delivery or completion date, running costs, cost-effectiveness, quality, aesthetic and functional characteristics, environmental characteristics, technical merit, after-sales service and technical assistance, commitments with regard to parts, security of supply, and price.

All criteria, as stated in the Directives, are exemplary and there are no obstacles to apply other than those indicated, but with the provision that by applying the criteria the contracting authorities will be able to compare and evaluate offers in the way to guarantee equal treatment.

3. The appointment of the contractors in selected EU countries

Table 1 presents an analysis of the public advertisements published by the Official Journal of the European Union between 2010 and 2013, and relate to the works for the completion or part construction and civil engineering work (CPV 45200000-9). Two types of standard procedures were taken into consideration: open procedure and restricted procedure. Table 1 shows the proportion of procurement processes in each analysed country by means of identifying the number of appointments based on the ‘price criterion’, and those based on ‘the most economically advantageous tender’ criterion.

Table 1. Proportion of chosen contract award criteria in two types of procedures in selected EU countries (www.ted.europa.eu).

Country	Criteria	Open procedure					Restricted procedure				
	Year	2010	2011	2012	2013	Average	2010	2011	2012	2013	Average
France	MEAT	91.70%	91.00%	90.50%	91.00%	**91.1%**	85.20%	82.30%	83.80%	87.30%	**84.7%**
	Lowest price	2.90%	3.10%	2.90%	2.80%	**2.9%**	6.50%	4.10%	3.80%	2.80%	**4.3%**
	Not specified	5.40%	5.80%	6.70%	6.30%	**6.1%**	8.30%	13.60%	12.40%	9.80%	**11.0%**
UK	MEAT	88.80%	87.50%	84.10%	88.70%	**87.3%**	90.40%	91.10%	91.90%	93.10%	**91.6%**
	Lowest price	8.50%	8.50%	12.20%	9.90%	**9.8%**	8.10%	6.80%	4.90%	6.90%	**6.7%**
	Not specified	2.70%	4.00%	3.70%	1.40%	**3.0%**	1.50%	2.10%	3.30%	0.00%	**1.7%**
Ireland	MEAT	98.20%	89.30%	74.30%	60.50%	**80.6%**	88.30%	91.90%	97.40%	84.20%	**90.5%**
	Lowest price	1.80%	10.70%	25.70%	38.20%	**19.1%**	11.70%	8.10%	2.60%	15.80%	**9.6%**
	Not specified	0.00%	0.00%	0.00%	1.30%	**0.3%**	0.00%	0.00%	0.00%	0.00%	**0.0%**
Spain	MEAT	86.60%	81.90%	81.90%	78.60%	**82.3%**	72.30%	78.60%	91.70%	84.60%	**81.8%**
	Lowest price	4.70%	6.60%	5.70%	7.90%	**6.2%**	21.30%	7.10%	0.00%	7.70%	**9.0%**
	Not specified	8.80%	11.50%	12.40%	13.50%	**11.6%**	6.40%	14.30%	8.30%	7.70%	**9.2%**
Italy	MEAT	59.90%	64.00%	64.80%	61.30%	**62.5%**	70.40%	76.10%	69.40%	59.80%	**68.9%**
	Lowest price	35.50%	32.80%	27.80%	32.50%	**32.2%**	28.00%	22.60%	27.20%	37.50%	**28.8%**
	Not specified	4.60%	3.20%	7.30%	6.20%	**5.3%**	1.60%	1.30%	3.40%	2.70%	**2.3%**
Portugal	MEAT	73.50%	70.10%	56.60%	59.60%	**65.0%**	35.10%	51.50%	39.00%	78.60%	**51.1%**
	Lowest price	6.90%	5.60%	12.50%	11.50%	**9.1%**	61.60%	33.80%	58.50%	7.10%	**40.3%**
	Not specified	19.60%	24.30%	31.00%	28.80%	**25.9%**	3.30%	14.70%	2.40%	14.30%	**8.7%**
Czech Rep.	MEAT	66.90%	56.00%	42.10%	23.60%	**47.2%**	60.60%	36.30%	55.40%	47.40%	**49.9%**
	Lowest price	33.10%	43.90%	57.80%	75.80%	**52.7%**	38.50%	57.50%	41.00%	51.70%	**47.2%**
	Not specified	0.00%	0.20%	0.10%	0.60%	**0.2%**	0.90%	6.10%	3.60%	0.70%	**2.8%**
Poland	MEAT	7.80%	8.90%	11.00%	12.90%	**10.2%**	9.10%	7.10%	16.80%	34.30%	**16.8%**
	Lowest price	91.90%	90.80%	88.30%	86.80%	**89.5%**	89.90%	83.00%	83.20%	64.40%	**80.2%**
	Not specified	0.30%	0.30%	0.70%	0.20%	**0.4%**	0.90%	9.90%	0.00%	1.20%	**3.0%**
Germany	MEAT	45.40%	43.00%	38.80%	35.50%	**40.7%**	52.20%	48.80%	45.40%	47.80%	**48.6%**
	Lowest price	52.00%	54.40%	58.80%	61.90%	**56.8%**	36.70%	26.10%	33.20%	46.90%	**35.7%**
	Not specified	2.60%	2.60%	2.40%	2.60%	**2.6%**	11.10%	25.10%	21.40%	5.40%	**15.8%**
Austria	MEAT	47.00%	27.70%	25.10%	31.00%	**32.7%**	16.70%	53.80%	71.40%	57.90%	**50.0%**
	Lowest price	43.80%	64.00%	68.00%	61.20%	**59.3%**	50.00%	15.40%	28.60%	42.10%	**34.0%**
	Not specified	9.20%	8.30%	6.90%	7.80%	**8.1%**	33.30%	30.80%	0.00%	0.00%	**16.0%**
Belgium	MEAT	18.40%	24.50%	22.20%	19.50%	**21.2%**	57.10%	65.20%	56.80%	62.20%	**60.3%**
	Lowest price	76.60%	74.20%	75.80%	79.80%	**76.6%**	39.30%	23.90%	34.10%	33.30%	**32.7%**
	Not specified	5.00%	1.30%	2.00%	0.70%	**2.3%**	3.60%	10.90%	9.10%	4.40%	**7.0%**
Netherlands	MEAT	26.70%	28.10%	30.40%	55.30%	**35.1%**	66.30%	72.30%	80.20%	89.00%	**77.0%**
	Lowest price	73.30%	71.90%	69.50%	43.70%	**64.6%**	31.90%	27.70%	19.60%	10.30%	**22.4%**
	Not specified	0.00%	0.00%	0.10%	1.00%	**0.3%**	1.80%	0.00%	0.20%	0.70%	**0.7%**
Sweden	MEAT	36.00%	35.30%	25.30%	18.60%	**28.8%**	56.90%	69.80%	51.50%	21.90%	**50.0%**
	Lowest price	41.70%	37.80%	40.40%	41.40%	**40.3%**	11.80%	1.90%	0.00%	3.10%	**4.2%**
	Not specified	22.30%	26.90%	34.30%	40.00%	**30.9%**	31.40%	28.30%	48.50%	75.00%	**45.8%**

Based on Table 1 two maps of Europe have been prepared. The maps indicate a combined data covering the period of four years (2010-2013) in all thirteen analysed countries.

3.1. Open Procedures

Sweden and Portugal are the two countries with a high number of other, non-specified procedures, consequently a comparison is limited, but the available data shows that Portugal, in spite of the experienced the market crisis, chose MEAT criterion on the average level of around 65% (from 73.5% in 2010 to 59.6% in 2013). Sweden, on the other hand, preferred "the lowest price" award criterion, and the frequency of this choice is also stable and situates at around 40.3% (from 41.7% in 2010 to 41.4% in 2013). The Netherlands show the most significant change in the proportion of selected criteria; during the last four years the price criterion changed from the most frequently used (73.3% /26.7% the lowest price/MEAT in 2010 year), and was outnumbered by MEAT (43.7%/55.3% in 2013 year). The countries like France, UK, Spain, Italy have shown steady tendency of selecting MEAT, where only a low number of tenders were selected based on price only criterion. The proportion of MEAT offers range from 91.1% in France to 62.5% in Spain. Ireland, however, shows a significant rise in a frequency of selecting “the lowest price” award criterion within analysed years (from 1.8% in 2010 to 38.2% in 2013).

Figure 1 shows a proportion of the open tendering procedures; those based strictly on the price criterion, and those based on the most economic tender.

3.2. Restricted procedures

Similarly to the trends observed in the case of open procedures, there is a group of countries that chose the most economically advantageous offers the most often and those that show firm tendency of selecting the offers with the lowest price.

France, UK, Ireland and Spain are those countries where the proportion of selected MEAT offers is stable and falls between 81.8% in Spain and 91.6% in UK. Italy, Germany, Austria, Portugal, Belgium and the Netherlands show the proportion of “the lowest price” tenders on the level starting at 22.4% in the Netherlands, and reaching 40.3% in Portugal. Sweden proves to have a high number of bids which are not specified, moreover, the number of MEAT selections fell in the last four years from 56.9% in 2010 to 21.9% in 2013. Czech Republic presents almost even average proportion of chosen types of award criteria – average numbers are 49.9% for MEAT and 47.2% for “the lowest price”. The lowest number of MEAT offers has been selected by Poland, where it only reached on average 16.8% between 2010 and 2013, however, likewise in the case of open procedures, the number of “the lowest price” offers plunged – from 89.9% in 2010 to 64.4% in 2013.

Figure 2 presents a proportion of the restricted tendering procedures, those based strictly on the price criterion, and those based on the most economic tender.

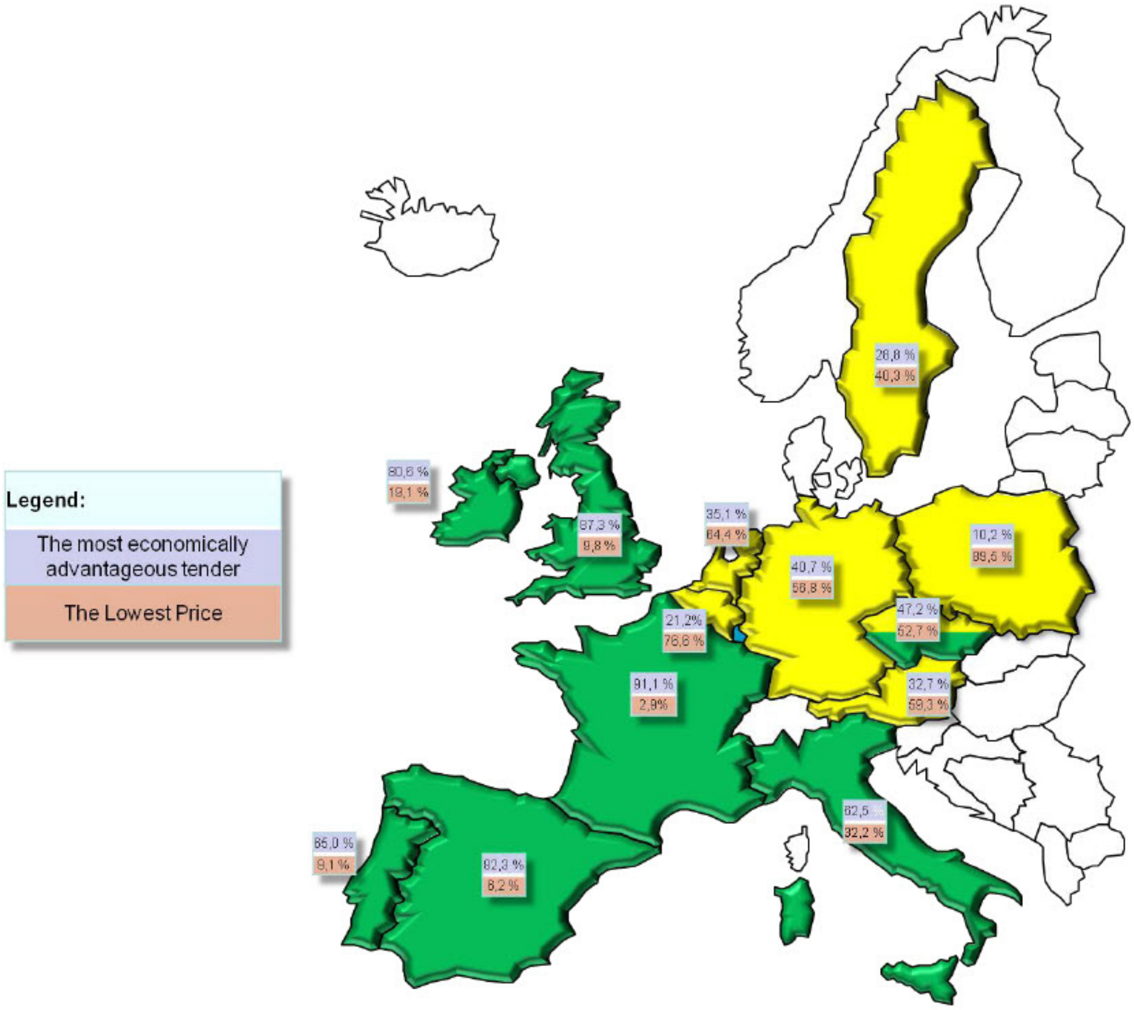

Figure 1. Proportion of the open tendering procedures in selected EU countries

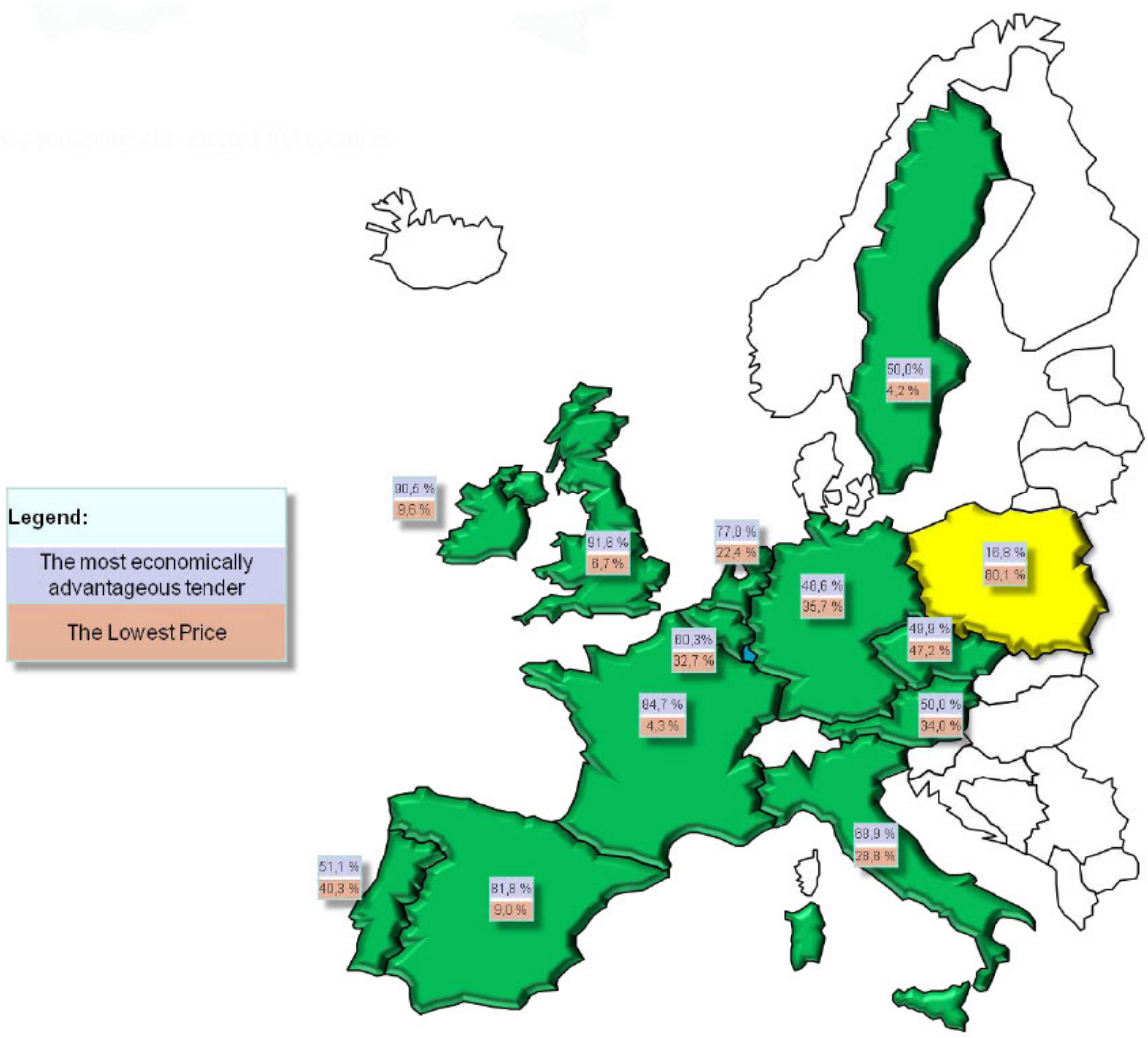

Figure 2. Proportion of the restricted tendering procedures in selected EU countries

4. Conclusions

Selecting the most suitable contractor in a public procurement process plays crucial role in further project realisation and may have an impact on its success. Lowered quality of delivered works, delays in delivering works within set time, or the decision of a contractor to walk off site may all emerge as a result of an incorrect evaluation of the tenders and wrong appointment of a contractor. The procedures used in the process of tenders' evaluation followed by a selection of best bidder vary depending on the country of their application.

The conducted analysis proved that in many countries the selection of a contractor it is not strictly linked with the price and that the applied criteria allow for choosing the most economically advantageous tender. The analysis shows that between 2010 and 2013 in seven out of thirteen EU countries the price criterion prevailed in the open tender procedures, while in six other countries the tenders based on the selection of the most economically advantageous offers predominated. In the restricted tenders in all analysed countries, except for Poland, multicriteria were used. Poland was the only country where most tenders were based on the price criterion.

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Teaching Construction Management Core Subjects with the Help of eLearning

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Abstract

At Szent István University's Ybl Miklós Faculty of Architecture and Civil Engineering construction management subjects are required courses for all students, meaning that Architecture, Civil Engineering and Construction Management BSc student, both full and part-time have to take them in the third year. In Construction Management 1 students get acquainted with the basics of construction projects and cost calculations, while in the next semester the topic is scheduling. The courses are created according to a blended learning model, where face-to-face teaching and elearning are combined. The former is provided in the form of lectures and recitations (integrated with computer lab sessions), while the latter is facilitated by the university's moodle-based elearning system.
In this paper, the blended nature of the construction management courses is discussed. Moreover, the new study materials developed within the framework of the New Széchenyi Plan and co-funded by the European Social Fund provide opportunities for further improvement, which are also presented.

Keywords: blended learning, construction management, elearning, teaching.

1. Introduction

Construction Management 1 and 2 are taught for third-year – both full and part-time – Architecture, Civil Engineering and Construction Management BSc students at Szent István University's Ybl Miklós Faculty of Architecture and Civil Engineering. In an attempt to accommodate 21st century students' need for the use of information technology and following the trends for new ways of teaching, the courses are organized according to a blended learning model. It means that face-to-face instruction is mixed with the use of our university's moodle-based eLearning system.

First, some ideas about blended learning are discussed. Then the subjects are introduced shortly. In the next part of the paper, our current teaching practice is dealt with in detail. Lastly, our newly developed study materials are presented.

2. Blended learning

According to Reiser (2001), IBM's researchers developed CAI (computer-assisted instruction), which was the first program to be used at public schools. In the 60s, computers were used on the university level as well. However, by the end of the 70s, they had made very little impact on education. In the early 80s, when microcomputers became available for the public, the interest in them increased. Still their influence on instructional practice was rather small until the mid-90s. Since then, the use of computers for instructional purposes has significantly increased.

In 1998 the UNESCO's World Declaration on Higher Education for the 21st century stated that "*higher education is being challenged by new opportunities relating to technologies that are improving the ways in which knowledge can be produced, managed, disseminated, accessed and controlled*". It was also noted that new information and communication technologies provide opportunities for improving the contents of courses, altering teaching methods and making education available for more people.

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The EDUCAUSE Center for Analysis and Research has published their study on undergraduate students and information technology every year since 2004. The main goal has been to map the relationship between students and technology. The longitudinal data obtained over the years reflect the changes in technology. Students have been positive about the use of technology in education; however, they are quite slow when it comes to adaptation. The study shows that, while students still need a certain level of face-to-face interaction, they value basic resources the most, for example, course management systems (Figure 1). They prefer to separate their private lives from academics; therefore the use of social media is not welcome by them. Those students who require guidance on how to use technology for academics prefer to acquire the necessary skills in class. (Dahlstrom, Walker and Dziuban, 2013)

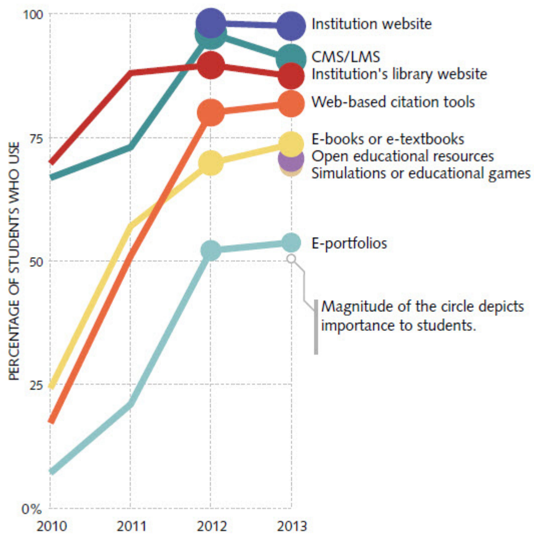

Figure 1. Students prefer basic technology resources (Dahlstrom, Walker and Dziuban, 2013)

The term blended learning has been defined in many ways. The expressions hybrid model and mixed mode are also used as synonyms. Oliver and Trigwell (2005) felt that blended learning is ill-defined. It could mean different approaches based on what modes are actually blended. According to Graham (2006), it is the mix of face-to-face and computer-aided instruction, with an emphasis on the latter. In this paper, this definition is applied when our practice of the blended learning environment is discussed.

Kandies and Stern (1999) stated that in the beginning only study materials were placed on the internet. However, this does not have any added pedagogical value. Therefore the range of applications should be widened. They believed that hybrid learning environment makes the students more active and self-directed learners. Also the fact that students are encouraged to communicate with their teacher via email increases their interaction, and the shier students benefit even more from this opportunity.

For blended learning to be efficient, the digital literacy skills of both parties – students as well as teachers – have to be developed. Kandies and Stern said that teachers should learn how to exploit the opportunities provided by new technologies. Similarly, Kruger and Bester (2014) expressed that teachers have to adapt to the new ways of teaching in the 21st century. Hall, Nix and Baker (2013) stated that digital literacy skills are necessary for students to be able to follow the courses. Their survey also showed that students favor the integration of the development of such skills into the curriculum.

In sync with the ECAR study, Buzzetto-More's research (2008) revealed that students value the presence of lecture notes, discussion boards online. Also they found it convenient to do exams, submit assignments and check grades on the internet.

According to Carman (2005) five key elements of the blended learning environment can be defined. The first is live events, which mean synchronous sessions led by an instructor. The second is online materials to facilitate self-paced (asynchronous) learning. The next one is collaboration of various forms including both peer-to-peer and peer-to-mentor interaction. The fourth ingredient is assessment, while the last one is reference materials.

The web-enhanced part of blended learning can be facilitated by different systems. Watson and Watson (2007) aimed at clarifying the difference between the various types. Course management systems (CMS) are probably the most common ones. While learning management systems (LMS) are more than that, since they are also administrative tools registering the progress of the students.

3. Construction Management subjects

Students are recommended to take Construction Management 1 in the fifth semester. The course offers an insight into construction projects. Students get acquainted with the different phases of the projects and the stakeholders together with their contributions. Various project delivery systems are also discussed. The largest chapter deals with the construction costs, their classification and how the construction budget is made. Different norm databases and the rules associated with their usage are also discussed. Students get acquainted with ProJack, a project management application developed in Hungary, as well. The homework assignment is to make a quotation for the construction of a small holiday house, starting with the calculation of the quantities, and ending with creating the budget in the selected PM software. Students work in pairs on this assignment.

Construction Management 2 is suggested to be taken in the sixth semester. The students learn about modern scheduling techniques, the possible applications of CPM, MPM (Precedence Diagramming Method) and the linear scheduling method. Students can understand how scheduling affects the resource plans taking the economic aspects into consideration, and how financial scheduling of organizations affects the feasibility. The homework assignment is to prepare the schedule for the construction of the same house as for which the budget is assembled in the previous semester.

In case of both subjects, there is a one-hour lecture and a two-hour recitation every week. The attendance to the latter is mandatory.

4. The application of eLearning

Firstly, it has to be noted that eLearning is the name of our university's moodle-based course management system. Therefore, in this paper, it is not used as the term for online courses.

In said system every subject has its own page, which could be filled with content by the instructors teaching the class. Since its introduction in 2008, Construction Management subjects have shown the most activity.

From the very first class of Construction Management 1, students are taught to try to look for answers on the subject's eLearning page. The syllabus and schedule of topics containing the most important information, such as the date and nature of tests, deadlines for assignments and how the final grade is calculated, are always uploaded before the given semester begins.

Lecture notes and recitation slides are also available prior to the classes providing the opportunity of arriving to the classes prepared, maybe even with some questions. Asynchronous, self-paced learning is also facilitated by online quizzes, which give the right solutions, after submitting the answers, and extra reading materials for those who are interested.

All the necessary documentation about the holiday house used for the homework assignment is also uploaded. Then the ready assignments should be submitted online, which is a more convenient than handing it in on paper. Moreover, this way both student and teacher have access to the files, if for some reason it needs to be checked in the future.

Students are also encouraged to use the message board to ask their questions for two reasons. Firstly, because other students may have the same question, and they could also benefit from the reply. Secondly, due to the fact that it helps the interaction not only between students and the teachers, but also among students, as a peer might answer the question as well. Everyone enrolled in the course gets email notifications about the posts in the discussion forum, this way students do not have to be logged in to get the information. Due to this fact, making important announcements on the message board is the fastest way to notify students.

Exams are also written via the eLearning system. These are very much like the tests provided for practice. Test results appear immediately after all answers are submitted. This makes the teachers' job easier. However, it is also good for the students, since they not need to wait for their grades. Figure 2 shows how the corrected test looks like. The questions are listed on the right-hand side. If the number is colored in green, then the answer is correct, while red means that it is not. Also these tests could be accessed anytime, which is good for administrative reasons as well.

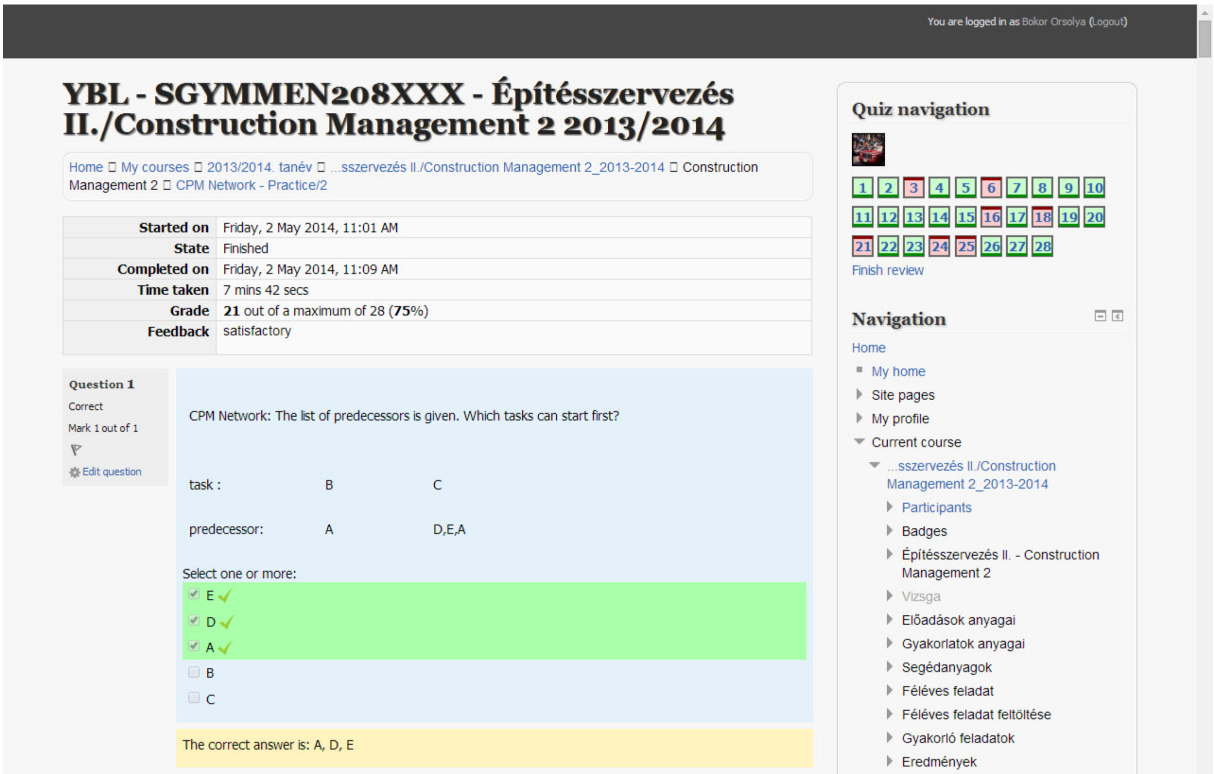

Figure 2. Screenshot of a test

In order to help the students get used to the system, with which they do not get familiar during their previous studies unfortunately, it is used in one form or another in every recitation class. Firstly, the slides with the small assignments solved in the course of the lessons can be seen there. This is also an easy way to cut the use of paper. Secondly, these assignments have to be uploaded at the end of the class. Therefore when they have to submit their homework at the end of the semester, they know exactly how it works. In addition, in a few classes short quizzes have to be solved. Since they work the same way as the exam, the exam is not the first time they see an online test, and this "skill" helps them concentrate on the questions themselves.

Due to the fact that everything is handled in the same system, where all data is stored, every assignment, test result etc. can be accessed anytime in case it is needed. This makes administration easier. Students can also check their progress, because they can see the marks that they receive during the semester.

There are also special sections devoted to part-time students. Since most of them are having full-time jobs, it is even more important for them to be able to access the study materials and all necessary information wherever and whenever they need it, and can find the time for studying.

Owing to the fact that both subjects are offered in English for the Erasmus students as well as for the Hungarian students, all materials can be found and almost every feature is used in English too.

In spite of the fact that the eLearning system is actively used in case of these subjects, it still has a lot more possibilities to offer, which should definitely be considered in the future. Moreover, it is constantly developed to provide even more opportunities for improvement.

5. New study materials

A two-year project of developing new, up-to-date e-learning study materials for 13 subjects – including Construction Management 1 and 2 – has just ended. Our faculty has taken part in a Social Renewal Operative Program within the framework of the New Széchenyi Plan run by the National Development Agency. 95% of the budget is subsidized; it is co-funded by the European Social Fund.

14 lessons has been written for each course corresponding with the number of lectures in a semester. This way the titles of the lessons constitute the curriculum of the given subject for one semester.

Each lesson is divided into chapters, and these are made up of pages. The website-like appearance provides easy navigation between the various parts. See, for example, Figure 3. The three rows of text on the top show you the subject, the lesson and the chapter respectively. The latter one is also indicated on the "timeline" below.

In case of Figure 3, we are looking at Construction Management 2's sixth lesson: MPM: Basics, Time Analysis with Minimal-type Relationships, whose third chapter is MPM/PDM Time Analysis. The little squares in the top right corner represent the pages of the chapter. The orange one indicates the current page.

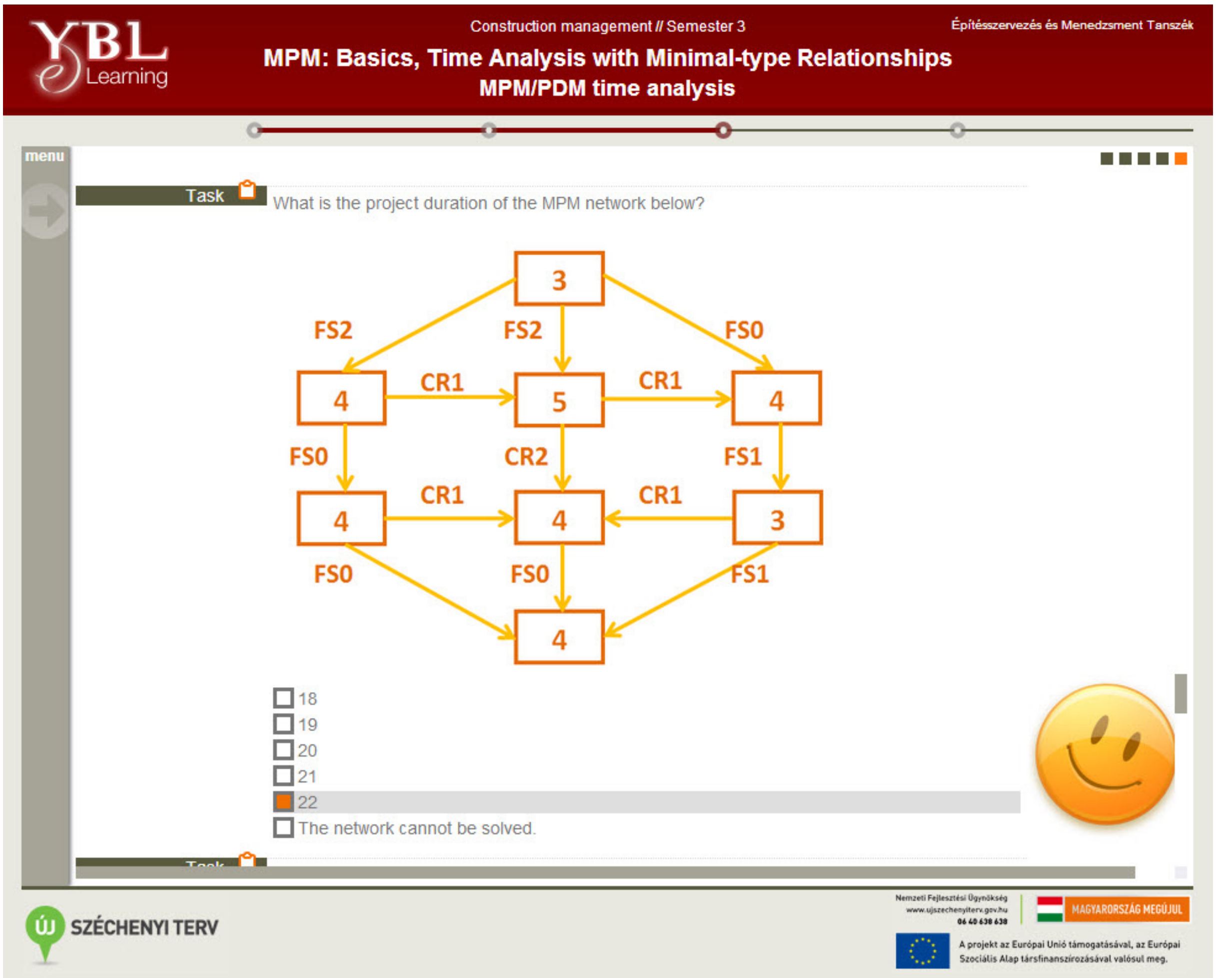

Figure 3. One page from MPM: Basics, Time Analysis with Minimal-type Relationships (sixth lesson of Construction Management 2)

Every lesson is made up of different elements. These are the following: text, figures, interactive videos, non-interactive videos, tasks. The planned amount of each element is given in case of all lessons.

Naturally, the text is the most essential part of the study materials. Being digital means that even the text could be enhanced. The most important definitions appear in pop-up bubbles after clicking on the words. Also links can be added to the text. These can be divided into two groups. To the first one belong those links that point to a certain part of another lesson either of the same or of another subject, thus enabling the connection between the lessons. The other group includes those links that lead to websites, where students can find extra information in the form of texts, figures or videos etc.

Figures can include many different types, as well. There can be tables, photos, sketches created by the authors or obtained from external sources.

Interactive and non-interactive videos can also appear in the materials due to the fact that they are going to be accessed through the internet and not on paper. The difference between the two types is that in case of interactive videos students are more involved; they can choose what they would like to see. Videos can, for example, demonstrate a process, like how to perform the time analysis of a CPM network. Those students who are unsure of their CPM calculation skills can just watch the video. Once they get more confident, they can determine the early and late occurrences of the events on their own, and check their solution. Animations can also summarize the text and figures of the lesson, for instance to sum up all the data a table in a norm database contains, or provide additional information on a topic discussed, for example, display pages from old books on how to calculate the construction costs.

Tasks can be found at various places in the lessons. They are usually at the end of the chapters or lessons. They can be of different types. There are, for example, multiple choice and multiple response questions. If the right answer is ticked, the smiley is going to smile (see Figure 3), if not, it gets sad/angry. In case of multiple response questions, when more than one answer has to be checked for the right solution, the face only appears when all of them are ticked.

Some tasks require calculations. In case of one half of these tasks, the solutions are given, and can be reached by the students when they would like to see them. In case of the other half, the answers are not provided.

No matter what type the exercise belongs to, they all serve the same purpose. They measure the students' level of understanding. This way they would know what parts of the lesson they have to go through again.

Every lesson ends with a bibliography. This, on the one hand, is important, because we do not want to commit plagiarism, so we always properly apply references. On the other hand, we could add extra sources of information, as well, for students who are interested in certain topics.

6. Summary

Due to the fact that students nowadays expect the use of information and communication technology in education, when teaching Construction Management these demands are attempted to be satisfied. With the development of technology, the way of teaching should also be changed, and possibly improved. This situation challenges the traditional methods and with that the teachers as well. Although probably face-to-face interaction can never be completely substituted by computers, in a blended learning environment, ICT gets in the mix, and maybe even becomes dominant.

With the help of our university's eLearning system, all the necessary information can be accessed anytime, anywhere. This makes the job of both students and teachers more convenient. Even though many features of the system are used, there are several possibilities for future improvement. The first step would be to find a way to successfully integrate the new online materials, which have been developed, into our existing system.

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Leadership in Energy and Environmental Design (LEED) and its impact on building operational expenditures

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Abstract

Ever-changing needs in the built environment create new incentives for enhancements in the process of building design. Increasing prices of building operations and utilities have a profound impact on the conceptual design and implementation of sustainable architecture. Green building certifications have been initially implemented as a tool for creating more sustainable buildings. However, the real impact of green certification systems on building operations remains unclear. This article focuses mainly on water and energy consumption assessment of LEED certified buildings and to what degree certification systems achieve cost savings in building operations when implemented during the design and construction process. The method of estimating these effects is based on hard costs and soft costs linked not only to the certification cost itself but also on the economic impact of the construction costs designated for achieving the required certification level. Furthermore, the building projects investigated, have been selected according to a specific paradigm in order to include buildings with a different type of operation. Each selected building has been holistically differentiated and assessed according to its performance in the following categories: water usage and energy efficiency. The aim of this paper is to objectively assess buildings that were certified under the LEED certification system and to determine the financial effectiveness of the invested resources in the construction process in relation to the operational and environmental benefits. Moreover, the research is focused on determining the operational costs at a point in time. Because of this, a relevant discount factor has been determined and applied for the life cycle assessment of each researched project. The outcome of this paper is an objective assessment of six LEED certified buildings based on water and energy consumption compared to a reference buildings.

Keywords: green building certification; LEED; LCC; operational expenditures; sustainability.

1. Introduction

The building industry is continuously facing economical, technological and social challenges. The recent financial crisis caused changes in overall perception of building projects' design and construction. Almost every stakeholder within the construction process is seeking to make savings and reduce costs. Building contractors are being forced to reduce their bidding cost in order to maintain their competiveness, whereas project owners are experiencing difficulties in renting their assets to tenants who are looking for buildings with low operational costs and rent.

However, the financial crisis is not just the only reason for inevitable changes in the traditional conception of property development. Other strong incentives for enhancing the process of building construction are linked with the operational costs such as utilities, cleaning, security and rent. The scarcity of natural resources is placing pressure on the cost of both utilities and construction. Furthermore, it can be predicted that there will not be any decrease to the cost of utilities in the near future (Yudelson, 2008). Buildings must become more energy independent and resilient in the surrounding environment which is very sensitive to political, environmental or economical impulses. Building users are often more interested in the overall performance of the building and increasingly are asking questions such as; "How much do I have to pay for utilities? How effective will my employees be while working inside? How long will the building retain its value?" (EC Harris, 2013).

There is strong pressure on the implementation of sustainable development or the development of green buildings within the built environment. However, there is no official definition of what constitutes a "green building". EPA (U.S. Environmental Protection Agency, 2014) defines green building as: "*a practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort. Green building is also known as a sustainable or high performance building"*. The term "green

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building" places emphasis on creating sustainable buildings and does not give a concrete construction description.

In order to more clearly measure and emphasize building performance in terms of sustainability and green building techniques it is necessary to investigate not only materials and energy performance, but also location, indoor environment quality, management process or innovation enhanced by the development process (Gevorkian, 2007).

Complex assessment tools and certification systems are focusing on measuring buildings from different points of view in order to provide information about a buildings' performance in terms of their location, energy efficiency, usage of potable water, used materials and the quality of the indoor environment. A third party who is delegated for supervising the assessment process verifies the final measurements.

2. Certification Systems

Certification systems have become more popular for complex building assessment and promoting aspects of sustainability and green building all over the word. This article focuses on assessing six real buildings using the same certification system, in this case, LEED (Leadership in Energy and Environmental Design). Nevertheless, it is vital to also mention other main players within the green certification business. Those are:

- BREEAM (Building Research Establishment Environmental Assessment Method). Founded in the United Kingdoms. Used mostly in Europe.
- DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen). Founded in Deutschland.
- LEED was founded in the United States and it has spread over the whole world.

3. Operational Expenditures of Certified Buildings

Certification systems claim that certified buildings are achieving lower operational expenditures and therefore are more attractive for tenants (Halliday, 2008). However, there is a significant difference between the various certification systems (some specifically relate to environment rather than energy efficiency) and there is even a substantial difference in certification levels of the same certification system. In order to investigate the impact of green certification on the building's operational performance there have been six LEED certified buildings chosen and assessed, each built in the Czech Republic. The following buildings have been chosen because of the same certification level (all building have achieved LEED Gold) and because of their structural, construction and type of usage variety.

4. Assessing Criteria

The investigated projects have been assessed according to five main categories, which also serve as the main chapters of the LEED for New Construction and Core and Shell certification system (U.S. Environmental Protection Agency, 2014). Those categories are:

- Project Location,
- Water,
- Energy,
- Materials,
- Indoor Environment.

However, because this research is focusing on the impact of the certification systems on operational costs, only a few key categories have major impact on the wallet of the building users. It is interesting to apply the Pareto principle (also known as the 80-20 rule) to the assessment criteria and confirm that only one criterion has the major effect on operational costs. It is not surprising that the one (20 % of all criteria) mentioned criterion is the Energy consumption (approximately 80 % portion from the operational costs). Nevertheless, because of increasing cost and scarcity of potable water, the research also focusses in detail on the usage of potable water as well.

4.1. Projects

Table 1 defines the projects investigated, all of which are located in the Czech Republic, Central Europe. Each project has used the LEED certification system.

Table 1. Projects details (Arcadis CZ, 2014).

Project Name	Building 1	Building 2	Building 3	Building 4	Building 5	Building 6
Gross Area (sf)	125,365	106,149	114,950	80,4261	207,923	233,318
Gross Area (m2)	11,600	9,800	10,600	74,700	19,300	21,600
Site (sf)	36,800	14,200	15,800	152,300	504,200	29,400
Location	Prague 7	Prague 1	Prague 1	Prague 1	Ceska Lipa	Prague 1
Type of operation	Office Restaurant	Office Retail	Office	Office Retail Restaurant	Industrial Manufacturing	Office Retail Restaurant
Number of building users	528	663	450	3,512	152	1,326
Days of Operation	253	286	286	259	353	253
CAPEX (EUR)	10,454,500	9,373,000	17,015,600	79,310,000	13,554,800	35,112,700
Certification System	LEED 2009 for Core and Shell Development	LEED 2009 for Core and Shell Development	LEED 2009 for Core and Shell Development	LEED 2009 for Core and Shell Development	LEED 2009 for New Construction and Major Renovations	LEED 2009 for Core and Shell Development

4.2. Location

The site conditions and surrounding services of a project can have a profound impact upon the comfort of the building users, but they do not directly influence the operational expenditure. Furthermore, the certification systems influence the interaction of the project with the surrounding ecosystem and stress the need of reducing heat islands and implementing greenery within the project scope.

4.3. Water

The usage of potable water is very often overlooked, since the cost of potable water has always been minor when compared to the other expenditures and investing into the hard, water-saving cost measures is not cost effective. However, the cost of potable water in the Czech Republic has risen significantly since 1999, which is presented in figure 1.

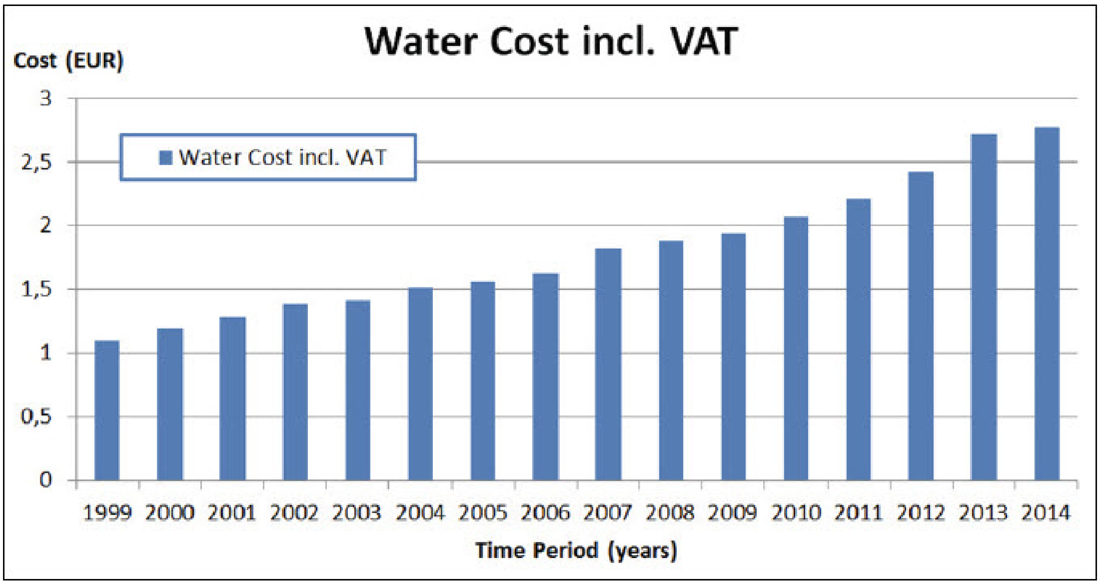

Figure 1. Water Cost Trend in the Czech Republic (Prazske vodovody a kanalizace, 2014).

The chosen projects have been classified according to the water fixtures and fittings used and whether a rainwater collecting system is present in the building or not and how the retained rainwater is used. Subsequently, water usage for each building has been estimated based on number of building users, type of operation and type of lavatories, toilets, urinals (if present), kitchen sinks and showers used. The results are depicted in table 2.

In order to identify reduction of potable water, the designed water appliances are compared to a baseline building. Baseline building for each building presents a reference building with the same type of operation, amount of building users and number of water fixtures and fittings, however the type of fittings is based on standard water flow rates and flushing volumes defined by the LEED standards.

The designed water appliances installed in all investigated buildings are water saving fixtures, which are defined as low flow fixtures with the following flow and flushing volumes:

- water closet with a dual flushing volume of 4.5 litres / 3 litres (full flush / small flush),
- urinal with flushing volume of 1 litre,
- lavatory with water flow of 2 liters/min or metering faucet,
- kitchen sink with water flow of 4 litres/min,
- shower with water flow of 8 liters/min.

Table 2. Water Usage for baselines and performance cases (Arcadis CZ, 2014).

Project Name	Building 1	Building 2	Building 3	Building 4	Building 5	Building 6
Rainwater Storage	YES	NO	YES	YES	YES	YES
Water Saving Fixtures	YES	YES	YES	YES	YES	YES
Rainwater Flushing	YES	NO	NO	YES	NO	YES
Total fixture water use annual volume, baseline case (kGal)	1,146	1,146	641	4,761	338	1,552
Total fixture water use annual volume, performance case (kGal)	640	683	355	2,025	156	752
Percent reduction of water use in all fixtures (%)	44	40	44	57	54	48
Irrigation saving (kGal)	0	0	10	0	0	0
Flushing saving (kGal)	43	0	0	659	0	160

The inputs from table 2 have been processed and the total water costs and savings have been estimated. Inflation was included and determined as 3.3%.

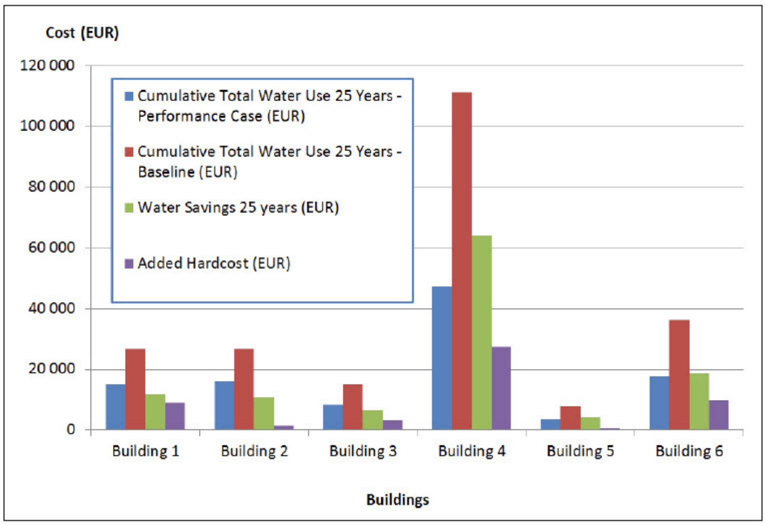

Figure 2. Water Usage of the LEED certified buildings

According to the results presented in figure 2, the certified buildings achieve significant savings due to implementation of low flow fixtures and fittings and due to the reuse of rainwater for flushing or irrigation of greenery. However, it is necessary to include the additional hard costs for procuring and installing the system and compare the water savings with the extra costs. The estimation proves that each building has achieved higher water savings after 25 years than the additional hard costs and therefore the certification system has positive impact of the building user cash flow. Furthermore, it is also essential to mention the contribution to reducing burden on public sewage systems and subsequent waste water treatment which is funded by a public sector.

4.4. Energy

It has been previously said that energy costs constitute a key and major portion of generated operational expenditures. This is mainly due to high-energy loads for heating, cooling and air conditioning (HVAC). LEED determines decrease in energy consumption as a mandatory requirement. To be more specific, it is necessary to prove, through building energy modeling, that the proposed case (building design including all HVAC and electrical equipment) demonstrates a 10% improvement in the building performance rating for new buildings (Green building design and construction, 2009).

As per the mandatory requirement, an energy simulation has been completed for each building. The annual results are depicted in table 3.

Table 3. Total Building Energy Cost Performance (Arcadis CZ, 2014).

Project Name	Building 1	Building 2	Building 3	Building 4	Building 5	Building 6
Process Electricity Cost - Baseline (EUR)	131,276	48,467	65,155	393,972	900,565	171,481
Electricity Cost - Baseline (EUR)	295,011	116,895	142,202	962,949	1,507,700	417,243
Natural Gas Cost - Baseline (EUR)	101,104	22,474	84,815	451,110	170,432	83,105
Electricity Cost - Proposed Case (EUR)	241,646	100,962	124,688	792,624	1,219,985	360,840
Natural Gas Cost - Proposed Case (EUR)	50,545	17,341	32,086	195,268	140,894	44,163
Energy Cost Savings (EUR)	103,924	21,065	70,243	426,167	317,253	95,344
Energy Cost Savings (%)	26	15	31	30	19	19

Particular annual electricity and natural gas costs are more clearly shown in figure 3 and figure 4.

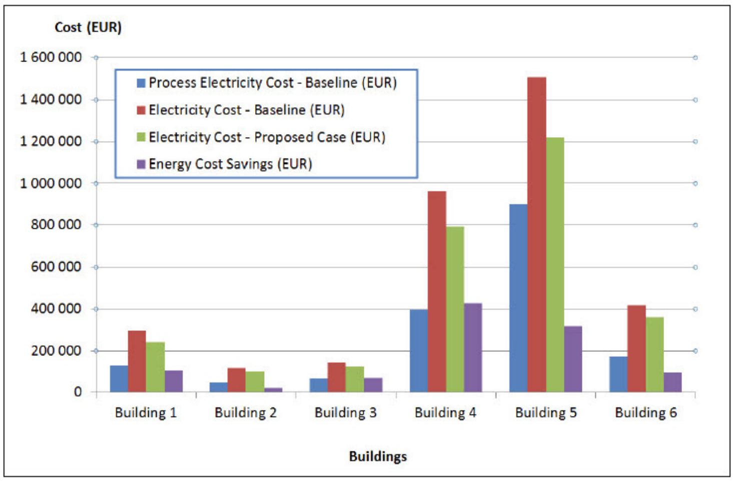

Figure 3. Total Building Electricity Cost Performance

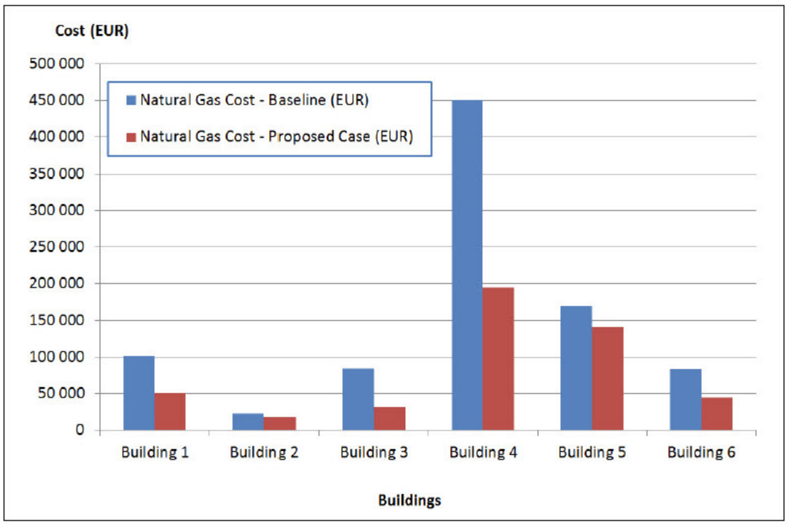

Figure 4. Total Building Natural Gas Cost Performance

4.5. Materials

Certification systems enhance the usage of local and sustainable materials. Furthermore, there is strong pressure favored towards recycling and reusing materials. LEED even compulsorily requires the project team to design and prepare recycling spaces in the building, which will contain recycling storage containers appropriate to building operation. Nevertheless, recycling and reuse has a very low impact on the building operation in regards to degree of other operational expenditures.

4.6. Indoor Environmental Quality

Proactive building designers and owners have realized that creating a healthy indoor environment contributes to the overall working effectiveness of the building users, and since the workforce presents the most significant expense for most companies, the provision of an effective indoor environment must not be underestimated.

A healthy indoor environment is sustained by providing high quality fresh outdoor air, maintaining thermal comfort, using no added VOCs (Volatile Organic Compounds), measuring and verifying performance of all installed HVAC systems and providing building occupants with thermal and lighting user controls. Building operation is tightly linked with the indoor environmental quality, but is shown in the form of capital expenditures for required equipment rather than in operational expenditures itself.

5. Conclusion

Despite the advantages and disadvantages of the various green certification systems, it is crucial to realize that the complex building assessment is only a tool, and must be managed by experienced professionals with the experience and knowhow to implement it. Even a certified building, and thus labeled as a green building, is not required to achieve significant operational expenditures savings.

One of the most challenging obstacles during the green building certification is the lack of knowledge of building practitioners, coincidence or unexpected events that increase the risk of not achieving operational savings and reducing financial effectiveness of a particular building asset. Given that the green certification must deal with prediction of future cash flows and the life cycle cost analysis (LCC), it is vital to include the Black Swan theory that was hypothesized by Taleb (Taleb, 2007). The black swan is an unpredictable event that deviates from the common events based on human knowledge and experiences. Such an event has immense effects. Further, the black swan is even more important during implementation of the new certification process and techniques, where stereotypes or complete ignorance of the newly implemented systems can have serious consequences.

Nevertheless, the comparison of the chosen certified buildings has proved that LEED certified buildings achieve energy and water savings because of the LEED mandatory requirements. In order to certify a building by LEED, the building must achieve as a minimum, 10% reduction of energy cost savings and achieve 20% reduction of the potable water usage. Generally, projects aim for a higher certification score and as a result, must achieve more than the mandatory amount of points. Furthermore, building owners, who decided to have their buildings certified, are more willing to invest their resources for the LEED points that generate operational savings. Examples of this include more efficient air handling units, building façade with higher insulating characteristics (U-values) or technologically advanced cooling systems. Unfortunately, there are very few enlightened building owners who have realized this importance of the operational expenditures and most are not willing to risk the immediate financial effectiveness of the project by increasing the capital cost to allow for more efficient equipment etc.

All six LEED certified buildings researched, performed significantly better than the traditionally designed construction projects. Green certification enhances innovation and motivation for more energy and water efficient equipment. It is a driver for implementing at least a basic sustainable solution, in order to achieve the lowest certification level because of the mandatory certification provisions. Nevertheless, it has been said that green certification is just a tool and if not handled properly, will not deliver a real beneficial outcome.

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New model for construction procurement automation

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Abstract

Many of construction engineers realize an urgent need for bringing construction processes into the information age of the twenty-first century. Most of the innovators in this area feel that the platform of Building Information Modeling is the future of construction. However, BIM approach places great demands on technical skills of all construction project participants. This is the reason why BIM is applied at first on so-called high-end projects (expensive and technologically demanding).However, all other construction projects with all participants are also a part of the 21st century, the age of information technology and they should benefit from it. This paper presents principles and methodology of more effective work in a relationship project owner – construction economist – contractor, with a focus on low-end projects (family houses, etc.). This sector of the construction industry is neglected and not considered as the leader of technological progress. And yet, this work shows, with an example of automation in tender estimates comparison, that the integration of new technologies can start right in this sector. The paper deals with the principles that are necessary for the work of construction economists in their relation to contractors and project owners, with a goal to create an equivalent electronic system for automated use. This is accompanied by a comparison of the costs needed for education and qualification of construction economists for the purpose of the construction cost estimates, with costs needed for the development of new automated system for the same purpose. To confirm correctness of presented principles, a case study is included.

Keywords: Automation, construction economics, tender estimates.

1. Introduction

Paper is focused on using automation in processes within construction industry. A lot of routine especially administrative work is still done manually by human workers. This creates high number of necessary costs and decreases job satisfaction. Automation alternatives are created only by rich companies for complex projects. The underlying idea is that there is a place for automation carried out by information technologies in routine engineering work, and that such automation could be applied in all project sizes. In the beginning, we will analyze the work of engineers and break it down to pieces which could be alternatively done with computing power using information technologies. Then diverse computer replacements will also be presented for workers activities. Then we will put together small pieces of alternative IT approach and create a tool – an application which could be used for automation during the whole process.

A comparison is made between cooperation applications (specifically BIM) and applications with the goal of automation. This paper notes the fact that automation can save costs and save time of engineers so that they can focus on more important tasks.

Goal of this paper in short term is to point out advantages of full individual process automation, collective knowledge, and analysis of construction engineers work responsibilities and workload.

2. BIM

When we talk about using computer science or information technologies in the field of construction industry, we definitely encounter BIM – Building Information Modeling (Eastman, 2011). Building Information Modeling system was designed to create a small revolution in the construction project planning, realization and life cycle.

The idea of BIM is quite simple. Architect creates a 3D design in BIM compatible software. Design is not a simple drawing. It is created with objects (representing e.g. wall, window etc.) which contain a variety of descriptive information. Objects and software are created expertly to help architects. They do so by preventing obvious errors (e.g. the fact that windows cannot be placed in the middle of a room). BIM system also allows cooperation with other professionals. Construction engineers can do their bit in the design regarding building

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equipment and statics without interfering with the work of the architect. When all this work concerning the creation of a design is finished, the appropriate moment for quantity surveying, time planning and bidding comes. This should be made much easier than with the aid of standard design (drawings). Because design created from intelligent objects already contains information about time, price, quantity, material etc.

Professionals agree that BIM is a more efficient way of handling projects than the standard way. However, thanks to its concept BIM has aspects which could be considered as disadvantages. These aspects are noted in this paper, and described to offer comparison and contrast between the traditional method which relies to a high degree on human work, and the proposed method of automation. The most common disadvantages of BIM automation are the following:

- Project is created by the means of one platform so all participants must be familiar with it. It creates a pressure on special education, training and investments for every company involved.
- BIM system is merely a tool. It is created for cooperation and more efficient way of projects design and following work. There is still a need for people to work with it.
- Thanks to complexity of BIM system and to its high cost, only high–end projects are being chosen for BIM implementation so far.

Thanks to these aspects it is very unlikely that BIM platform will spread among all professional in industry during next decade. And even if it does, it may not solve all problems related to construction documentation.

3. Documentation flow and automation

There are at least three main parties in every construction project: architect representing the design, contractor representing a working power to realize the design and the owner representing the capital invested. Construction project itself is a very complex issue which requires cooperation and communication between parties involved. Important communication is realized by documentation flow e.g. blueprints, bills of quantities, bidding documents etc. (Fewings, 2012). Even if the transfer of these documents can be managed by certain cooperation system or their generating can be easier with a sophisticated modelling system (e.g. BIM), there still has to be a human worker to process it. It brings up an opportunity for automation. First of all there is need to analyze engineering work. Such analysis could be automated.

It needs to be said that only routine and non-creative work activities are suitable for automation. It follows from current capabilities of computers (Harel & Feldman, 2004).

4. Specifics of engineering work

The scope of an engineer’s workload is a combination of complex tasks which can be generally divided into two groups: technical engineering work and socially collaborative work (Robinson, 2012). Socially collaborative work includes obvious activities of engineer’s workload: communication, collaboration, meeting, collective decision making, collective problem solving etc. These activities have certain common features. They usually involve colleagues and the outputs of collaborative work have a creative component. This is the place for cooperative information systems or BIM systems which are design for socially collaborative type of work.

On the other hand there is the part of engineer’s work which could be summed up under the heading of technical engineering work activities. This work description includes several general activities: receiving information, offering information, searching for information, locating information source, locating information within source, understanding information, problem solving, decision making, others (Robinson, 2010). According to several sources, we can say that technical engineering activities represent approximately 50% of workers time (Robinson, 2012; McCabe & Wissler, 2010).

Activities including human interaction are very difficult to be managed by automated processes. However, technical engineering work activities are quite suitable for automation, they only need to be divided into subgroups regarding the content of creativity and routine.

According to the definition of creative activities (Parkhurst, 2011), various activities fall within the structure of 3 base categories: strictly routine activities, strictly creative activities and semi-creative activities (activities with mixed nature. For calculation purposes, we assume they are mixed in 50/50 ratio.). Table 1 presents these tree groups with percentages of average time consumption of engineer’s work based on research by Robinson (Robinson, 2010).

Table 1. Activities divided into groups according to the creative aspect including percentage of time consumption of technical engineering workload.

strictly routine activities		semi-creative activities		strictly creative activities	
receiving information	7,22%	searching for information	5,85%	locating information source	5,75%
giving information	9,31%	locating information within source	16,67%	understanding information	16,10%
		decision making	9,46%	problem solving	14,82%
		others	14,81%		

Table 1 offers simple results to our reasoning. Non-creative activities on average represent 20% of total workload and therefore 8 hours of a standard 40-hour work week. These activities are worth an effort for automation.

All of the aforementioned general non-creative and semi-creative activities are composed by basic elements according to WBS - work breakdown structure (Haugan, 2001). There are some examples: physical documents searching (electronic and paper), logical decision making, logical analysis, learning, reporting results, making notes, remembering. Detailed level of basic elements depends on situation. There is an example of WBS decomposition of activity price calculation.

Example: Construction engineer (quantity surveyor) calculates the final price of a pavement with future realization by subcontractors. His activities are: studying blueprints, sending blueprints to subcontractors, receiving bids with quantities, reading and checking bids and quantities, comparing bids, making decision about best subcontractor and sending this information to supervisor.

All of the activities demonstrated in the example can be improved by using a cooperation system which would require participation of all parties (construction engineer, supervisor and subcontractors). Or most of these activities can be handled more efficiently with computer automation which would require participation only from construction engineer and his company.

5. Abilities of computer to replace human work power

As said in section 4, some activities are worth the effort towards automation. This paper presents an option for automation in a construction process of documentation flow. The design of this software and presumably also future trends in software development are based on finding a computer equivalent to WBS activity decomposition as we have seen presented in the previous part. Possible advantages of such computer equivalents are many. Let us bring some of them to attention.

Information related activities (getting, receiving and searching for information) can be managed much faster and more precisely by information technologies (Weizenbaum, 1976). Reading of documents in written form is performed by OCR (Optical Character Recognition) and optical pattern recognition (Govindan, 1990). Decision making and problem solving done by computers can be achieved in situations with predefined boundaries (Greiff et al., 2013). Machine learning is a fast developing research area which focuses on the automated equivalent to learning (Hastie, Tibshirani, & Friedman, 2009). In foreseeable future, this research may bring results which simplify automated problem solving.

6. Economic aspects of computer automation in construction industry

According to previous calculations, there is a 20% span of engineer's time suitable for work automation. It is difficult to state specific numbers concerning the number of construction engineers who are currently employed in construction industry. However, a rough number can be estimated using general statistics of the Czech Republic. There are approximately 433 thousand workers employed in construction industry in the Czech Republic[i] and the percentage of employees with university education is about 15%. Following from these numbers, there are approximately 64 thousand of construction engineers. Construction engineer earns 29000 CZK (Czech crown) per month on average. This salary represents approximately 39 000 CZK[ii] in costs for the employer (including taxes and insurance). To make the calculation more approachable, please note that there are 10.5 millions of inhabitants in the Czech Republic.

[i] Source: http://www.czso.cz/csu/2012edicniplan.nsf/p/3115-12
[ii] Source: private database of salary (http://www.platy.cz/)

Using simple mathematics, automation of routine activities in construction industry represents a window of opportunity of direct costs with value of 570 million Czech crowns (21 million Euros) per year and million inhabitants.

7. Methodology – software design

Case study shows one way of efficient automation in construction process. It is focused on tender estimate comparisons in bids evaluation process. Such process is usually done by construction administrative engineer and it can be decomposed into several partial activities - elements: asking for bids, receiving bids from contractors (written form, pdf etc.), checking validity and calculation of individual bids, checking bid prices and bills of quantities with usual prices, comparing bids, decision making between possible contractors, announcing decision. There is a possibility to create computer equivalent for all these activities. All these equivalent parts will create a full application – software.

In figure 1, there is a diagram explaining document flow through the process described above. Presented algorithm is designed to process tables with a large amount of information like bills of quantities. Bills of quantities are evaluated against database of knowledge which is located at a publicly accessible place (server). Individual documents also enrich the database.

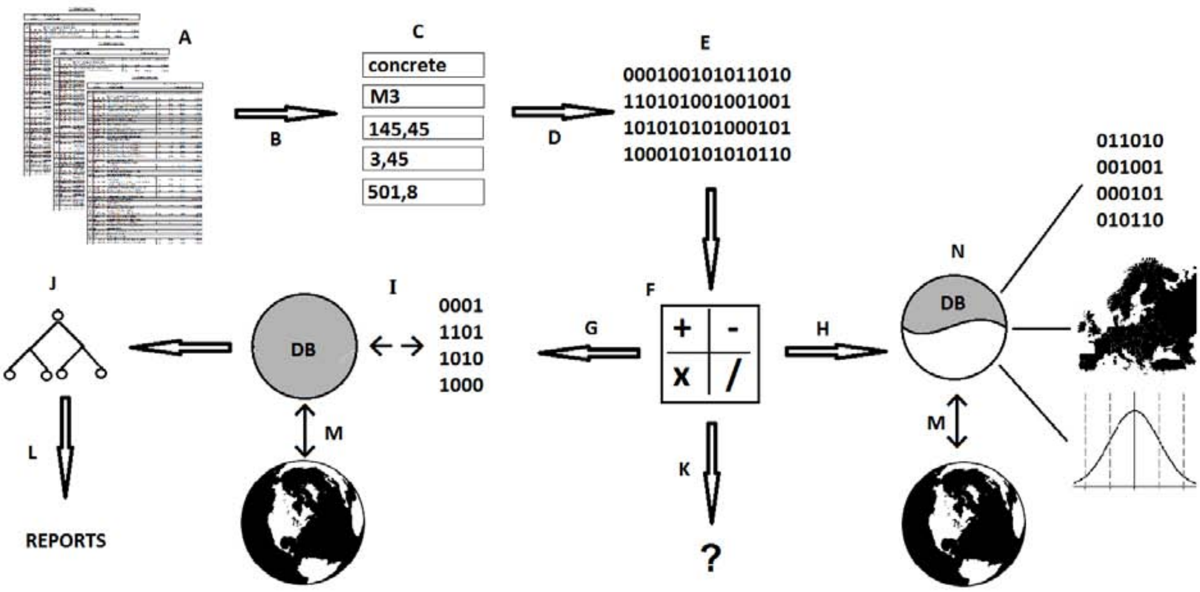

Figure 1. Application for documentation automation design.[A] Receiving bid documents (manually or electronically). [B] Documents are scanned or loaded from memory and decomposed by optical pattern recognition into individual pieces of information (Gatos, Danatsas, Pratikakis, & Perantonis, 2005). [C] Original documents are decomposed into cells with relevant information – in this case, item from bill of quantities: material, unit, number of units, price per unit and price total. [D] Individual pieces of information with coordinates of position in original document are transferred via OCR engine into electronic form. [E] Application detects what the purpose of information is by analyzing its position coordinates and type of information pieces [F] Every piece of information is tested for arithmetical and factual correctness (depends on numerical or text input) [G] After successful checking process individual pieces of information (in this case items from a bill of quantities) are compared with database of previous knowledge. [H] After successful checking process, information enriches database for future purposes. [I] Items are compared with database which implants the information into statistical context (prices, quantities etc.) based on exact match or keywords system (Agrawal, Chaudhuri, & Das, 2002). [J] All information is gathered and supplied into decision making process which can be based on a decision tree (Cha & Tappert, 2009). [K] If an item fails checking process it is pushed into manual sorting. [L] A report is created of decisions made based on documents from point A. [M] Database of previous knowledge is prepared for storage at a distant server for higher availability. [N] Database is enriched by processed information. Information contains not only prices and quantities, but also geographical location of the user etc. Database creates statistical samples of information (e.g. average prices, statistical distributions etc.).

Advantages of described system against solely cooperative systems:

- Database of uses processed information to enrich itself, keeping itself up to date at all times. System is centralized.
- System can be used without the necessity for participation of all parties in construction process.
- With proper settings, the system can work without human interaction and therefore save time and costs.

8. Case study

Presented algorithm was tested with good result. Test subject were bills of quantities for a family house with circa 200 items. Documents were delivered in paper form, scanned and saved in one folder. The algorithm detected tables in documents and decomposed them into individual cells. Optical pattern and character recognition engine (in this case engine Tesseract 3.03) transferred it into binary code with good results in 95% of items. Faulty items were detected in checking process and removed. Recognition and checking process took on average 22 seconds per page with circa 30 items (on Intel Atom 1,6Ghz laptop). Average time needed by a human worker to read and check the same number of items is 8 minutes and 40 seconds. Information database is created on SQL platform. When the algorithm was tested for comparing items with database and enriching database, it brought good results. However, database does not have a sufficient number of entries to create relevant results. In spite of this minor setback, case study shows that most parts of the design work and that it is viable.

9. Conclusion

Let it be noted that there are at least two approaches to use of information technologies in construction industry – cooperation and automation. Much attention is focused on cooperation (e.g. BIM, information systems etc.). However these systems have specific disadvantages. Mainly there is the need for a man to run them and they are only used with complex projects. To bring an element of contrast to the cooperation vs. automation debate, this paper presents the possibility of designing an automation application which can be used across the industry. An estimate is presented which strives to prove that automation is a way of improving work processes in 20% of engineers' time. This time represents a window of opportunity with the approximate value of six billion Czech crowns in Czech construction industry.

Such approach does not, however, suggest replacing a human worker with automation applications. Value of calculated direct cost at stake, could and should be redirected to increasing the quality of the final product, and towards improving work environment.

Application design composed of IT alternatives to engineer's skills has been presented here. Application includes a self-learning algorithm with an information database which could be publicly accessible, and could provide relevant information for anyone. The main goal of the mentioned algorithm is processing documents with high content of information.

Public institutions like universities etc. with proper funding could and should create similar applications and provide them to public on cloud services platform. Participant across industry would benefit from such accomplishment.

Acknowledgement

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A lessons-learned mobile system for construction companies: motivation and design

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Abstract

Construction projects are an important source of expert know-how and organizational knowledge. Though, it is known that construction companies do not make an appropriate transfer of this knowledge for future projects. In fact, it is common to find that most lessons learned in construction projects are lost because most companies never take care of collecting them. To change this situation, construction companies need to have a knowledge management system that allows them to manage the lessons generated on each project. The system should fit their specific needs and take advantage of new technologies available on-site. This paper presents a research that attempts to develop a lessons-learned system to support the construction management process. A research methodology based on case studies has been applied, where semi-structured interviews, direct observation and review of documentation have been conducted on three Chilean construction companies. Based on this, a mobile lesson-learned system application with interface for smartphones and web in a cloud environment is proposed. Currently, a prototype of this system is under development and being tested in a construction company. This article focuses on the design of this prototype and the main characteristics of its architecture. It is concluded that the application of mobile technology on the field would facilitate the use of a lessons-learned system, and that this kind of technology could be an appropriate tool for knowledge management.

Keywords: knowledge management; lessons; lessons-learned; mobile applications.

1. Introduction

As the global economy is ever-changing, it is crucial for construction organizations to adapt with it (Wiegand & Smallwood, 2013). This is a challenging situation for construction companies, who need to improve project performance to survive in the present economic and financial environment (Loforte & Tomásio, 2010). Project performance can be improved when people communicate and share best practices, lessons learned, experiences, insights, as well as common and uncommon sense (Krogh, 2002 cited by Loforte, 2009). Therefore, it is imperative that the construction industry start to pay more attention to knowledge and knowledge management strategies (Zin & Egbu, 2009). Carrillo et al (2013) indicate that a common means of identifying improvements and innovations in project-based environments is through lessons learned (LL) activities. Many organizations in the construction industry have come to recognize the importance of a LL program as a vital asset that plays an essential role in knowledge management (Caldas et al., 2009). These lessons are the knowledge gained from people's successful or failed experience (Lo & Fong, 2010). To manage these lessons, construction companies need a lesson learned system that fit their specific needs and that use the new technological advances to obtain a system really applicable on-site. Currently, mobile technologies present new and interesting opportunities to improve the access to knowledge and information. The use of mobile computing devices can play a vital role to improve data collection and process efficiency in construction processes (Venkatraman & Yoong, 2009; Son et al., 2012), enabling construction managers to input, store, process, and access project information at any location and to communicate that information to any location (Son et al., 2012). Then, mobile technologies can be a very useful tool for a LL system. Through them, people can have access to the information and knowledge very easily. Then, this research considers the development of a lessons-learned system mobile application with interface for smartphone and web, in a cloud environment. It is expected that this system could contributes to improve on-site management in a construction project. This article focuses on the design of this system, presenting a literature

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review on the main topics related to the study, the proposed LL system and the main characteristics of its architecture.

2. Lessons-learned

The Construction Industry Institute (CII) defines a lesson learned as knowledge gained from experience, successful or otherwise, for the purpose of improving future performance (CII, 2007). Lessons learned can be seen as elements of experiential or tacit knowledge that have been rationalized and saved for future use, where the main idea is to encourage good practice to repeat successes and avoid past mistakes (Cheah et al, 2011). Kartam (1996) identify three major components of a lesson learned (1) a set of attributes to sufficiently describe and explain the lesson itself, (2) information regarding the source and context from which the lesson is collected, (3) the means for classifying the lesson in a manner that allows fast, clear retrieval by multiple parameters. Fong and Yip (2006) define LL systems as the activities, people, and products that support the collection, verification, storage, sharing, dissemination and reuse of verified lessons in organizations. Their goal is to capture and provide lessons that can benefit employees who encounter situations that closely resemble a previous experience in a similar situation (Weber at al., 2001). A main problem in the construction industry is that recording good or bad practices at different stages of projects is not common (Fong & Yip, 2006). Generally, lessons learned during the construction phase of a project are not effectively incorporated into the design and construction phases of other projects (Kartam, 1996). Despite this, LL can be a very useful tool for knowledge management in construction companies, because the work they performed is highly intensive in knowledge and experience; therefore, there are many lessons to keep from each project that can be useful for similar future projects. Then, it is clear that construction companies needs to develop better ways to keep and use the knowledge they gain on each project. To accomplish this, information technologies are a very useful tool because of all the capabilities they currently have.

3. Mobile technologies in the construction industry

Construction engineers are interested in improving site information exchange for increasing productivity of the construction project (Kim et al, 2011). The advances in affordable mobile devices, the increase in wireless network transfer speeds and the enhancement in mobile application performance, mean that mobile computing has a great potential to improve on-site construction information management (Chen & Kamara, 2011; Kim et al., 2011). Also, the use of mobile computing devices can reduce the unnecessary cost currently inherent in construction projects by improving opportunities for data collection and thereby the process efficiency (Son et al., 2012). In the last ten years construction companies and academia start to show interest in mobile computing through an increasing number of research related to mobile applications in construction projects, such as Kimoto (2005), Bowden et al (2006), Chen & Kamara (2008), Chen & Kamara (2011), Lee et al (2009), Irizarry & Gill (2009), Kim et al (2011), Ochoa et al (2011), Son et al (2012), Nourbakhsh et al (2012), and Kim et al (2013). Even though construction companies have been slow to adapt to new technologies, this situation is starting to change. In fact, the industry needs to open up to new technologies and make the best use of them for performance improvement. Currently, a new challenge includes the use of cloud computing in construction companies.

4. Cloud computing

A new paradigm related to mobile technologies has appears in the past few years: cloud computing. It can be understood as a new computing model in which resources (e.g., CPU and storage) are provided as general utilities that can be leased and released by users through the Internet in an on-demand fashion (Zhang et al, 2010). Cloud computing services are divided into three classes: 1) Infrastructure as a Service: Refer to the tangible physical devices like virtual computers, servers, storage devices, network transfer, which are physically located in one place but they can be accessed and use over the internet using login authentication systems and passwords from any dumb terminal or device (Gupta et al, 2013); 2) Platform as a Service: A cloud platform offers an environment on which developers create and deploy applications and do not necessarily need to know how many processors or how much memory that applications will be using (Voorsluys et al, 2011); and 3) Software as a Service: Services provided by this layer can be accessed by end users through Web portals (Voorsluys et al, 2011).

Security and privacy concerns are the primary obstacles to wide adoption of cloud computing (Ren et al, 2012). This problem arose because enterprises have total control of their data when they own their physical server, but in the cloud, they must trust in the provider (Hofmann & Woods, 2010). Gartner’s seven security issues which cloud clients should advert include (Sabahi, 2011): privileged user access, regulatory compliance, data location, data segregation, recovery, investigative support, long-term viability. Ryan (2013) indicated that many of these aspects are not unique to the cloud setting, for example, data is vulnerable to attack irrespective of where it is stored. We need to consider that an in-house IT department is not necessarily more secure than a cloud-based offering as it is still connected to the internet and thus susceptible to hacking attacks (Biswas, 2011 cited by Brender & Markov, 2013). Reiterating this affirmation, there are some analysts and cloud users who think that cloud computing can still provide better security and greater reliability than those provided in-house (Sultan, 2011). Among the security benefits imposed by cloud computing we could find centralization of security, data and process segmentation, redundancy and high availability (Zissis & Lekkas, 2012). It is expected that the emergence of powerful players behind this technology in a massive way could help to mitigate this worries (Sultan, 2011). In fact, providers like Amazon and Microsoft, for example, have the capabilities to deflect and survive cyber-attacks that not all providers have (Brender & Markov, 2013). Based on this, it is considered that in smaller organizations with limited resources, data may be safer with a cloud provider (Hofmann & Woods, 2010). Gupta et al (2013), in a study about the usage and adoption of cloud computing by small and medium business, indicated that the ease of use and convenience is the biggest factor cited by these companies to adopt cloud, follow by the improved security and privacy. Then, there is not definitive opinion about the security of the cloud. If a company wants to innovate and include this new framework on their daily work, it must evaluate the cloud features, the provider behavior, the company characteristics and the risk associated with it. Based on this, each company must take his decision.

5. Lessons-learned system proposal

We worked with three Chilean construction companies with more than 20 years of construction experience, using a multiple case study research approach. Then, semi-structured interviews, direct observations, and review of documentation were conducted. The main information of these companies and the number of professionals interviewed is show in Table 1. All the participating companies were medium size construction companies in geographical expansion. The main results obtain on this activities are present next.

Table 1: Information about the case studies

Company	Type	Quality Certifications	Number of Professionals interviewed	Position in the company
A	Construction company	ISO 9000	6	3 Project Manager, 1 Project Supervisor, 1 Quality Chief, 1 Operations Manager
B	Construction company	ISO 9000	5	3 Project Manager, 1 Project Supervisor, 1 Quality Chief
C	Real estate and construction company	None	5	2 Project Manager, 3 Project Supervisor

About knowledge management, interviewees recognize the relevance of knowledge to perform the on-site management process, but they also emphasized knowledge is generally on people's minds and not documented in the organization. Because of this, face to face contact among professionals of the same company is considered a critical activity. The main problem is that communication and cooperation between professionals of the same company is complicated and slow, because the projects are scattered through all the country. Also, people recognized the need for lessons learned about the design and execution of the project, in order to reduce and prevent the occurrence of mistakes. According to respondents, the main constraint to acquire and store knowledge is the lack of time during projects execution. Also, professionals indicated as an important constraint the lack of organizational procedures to manage knowledge. They indicate that they do not store knowledge because it is not clearly defined what information or knowledge they need to save, which is the format or where it must be stored.

About lessons learned, none of the three companies formally documented lessons learned, but all the professionals indicated that a LL system would help them on-site. According to interviewees, among the main characteristics that a LL system must have, we could find: (1) the lessons must be collected during project team meetings or through interviews. The Project Manager should be responsible for the approval of the lessons of their project; (2) the system should be simple, allowing a quick search of the required information. Also, most of the respondents believe that the use of mobile technology on the field would facilitate the use of a LL system, especially to search and retrieve information; (3) to replace or complement face to face interaction among professionals, interviewees indicated that it could be useful to have a place to leave short recommendations on certain issues to be read by colleagues.

It is possible to conclude that construction companies need to focus in the following problems to organize their knowledge and get benefits from it: (1) To document lessons learned, (2) to foster face to face contact among construction professionals, and (3) to define a procedure to manage their information and knowledge. We proposed to face these problems through the development of a lessons learned system with two main components: (1) an organizational database of lessons-learned, and (2) an organizational microblog. The lessons-learned database must allow the storage, reuse and transfer of the knowledge created in the design and construction phases of a project, to avoid the occurrence of mistakes. The organizational microblog will allow a more fluid contact among professionals, being considered as a complementary tool to transfer knowledge inside the company. To benefit from the new technologies, this system considers the development of a mobile application with interface for smartphone and web, in a cloud environment. It is expected that a system like the proposed one would help construction companies to manage their knowledge, fostering the transfer and reuse of knowledge. Also, the use of mobile technologies, specifically cloud computing, would allow a faster and easy access to the relevant knowledge from any location, and the possibility to keep in touch with company colleagues to share experiences through a private social network. Finally, the use of cloud computing will also diminish the investment associated to the IT infrastructure required to host and manage the system, especially for medium sized construction companies, that normally do not have a big IT infrastructure. The next section presents the main characteristics of the design of the prototype system.

6. Prototype System Design

The first step designing the prototype was to develop seventeen use cases and a set of complementary mockups. Together, they represent the proposed functionalities of the system and its requirements. Besides, four types of users were defined: System Manager, Lessons Creator, Approver, and Consultant. The information that a regular user such a Consultant could obtain using the system includes: 1) other users information; 2) company's project information: main data about projects; 3) company's lessons-learned: include information such as main data about the project were the learning took place, a brief explanation of the case, and what was learned, among other items and classifications; and 4) informal knowledge: users could contact their colleagues to share experiences and hints about their jobs through the microblog.

As indicated in the previous section, the prototype includes a mobile application as well as a web application. Then, considering it will be more than one system interacting with the LL database, it is required an API (Application Programming Interface) that defines how different software components should interact, particularly, how the mobile and web applications interacts with the database. Related to the mobile application, the next step was to decide if we are going to do a cross-platform or a native mobile application. Despite the advantages of cross-platform, such as its lower cost and lower fragmentation, we chose a native development because the resulting applications are faster, have better user interfaces and their security features are stronger (Ballve, 2013). Also, considering that the LL system need to be adopted by many users within the company, we decided to work with Android because it has a superior market share and price variety. Finally, as cloud services provider we decided to use the Microsoft's Windows Azure platform because (1) their uptime is 99.9%, (2) they have technical support in Chile and, (3) they offer an academic pass for research. Two natural implications of this decision were to build the web interface and the API using ASP.NET MVC Framework 5.0 and to store the data in a relational database that works on Windows Azure SQL database, being both Microsoft technologies as well.

The mobile application will allow creating, approving, evaluating, and searching lessons inside the database, and use the organizational microblog. We include these functions in the mobile application because they are mostly executed on-site, in different locations. As shown in the conceptual design of the proposed lessons-learned system (Figure 1), the database is not directly modified by the mobile application, but the mobile application sends the information and instruction to the API, which is the only component that has control over the database. Thus, we take advantage of the computing capacity of the cloud and just one agent manages the database, facilitating information integrity.

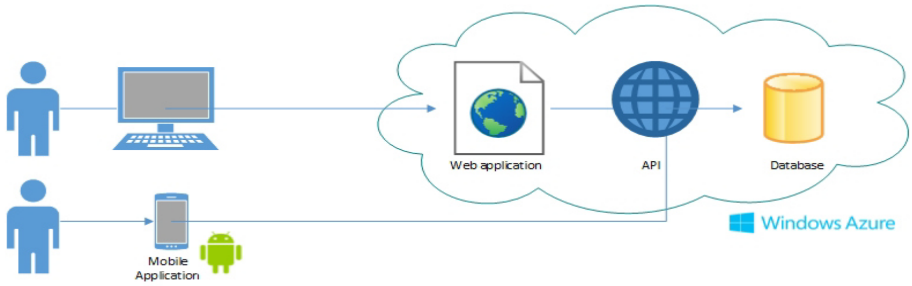

Figure 1: Conceptual design of the lessons-learned system

The web application also interacts with the database through the API. This web application includes all the functions available in the mobile application, but also contains all the administrative tasks required by the system, such as creating users and projects in the database, and managing the microblog. The architecture of each one of the system's components was developed using the software architecture pattern Model-View-Controller (MVC), which separates application data, user interface and business logic into three distinct components. Also, we used design patterns (standard solutions to recurring problems in software development). For example, we used the Memento Pattern to implement a version control system for the lessons' creation, review, and approval process. As discussed previously, a main concern when working on the cloud is security. We faced this problem from two perspectives: security on the cloud and security on the application. To accomplish the first challenge we decided to use Microsoft Azure as our cloud services provider, taking into account their solutions can easily face cyber-attacks. But security on the cloud it is not enough, the application build upon it must be secure itself. To do this, we took advantage of Azure's natural integration with ASP.NET MVC framework, which have built-in functions the programmer can use to robustly solve security and authentication issues. This allowed us to rapidly develop an application that uses the industry's security best practices.

7. Conclusions

Despite the fact that knowledge management is not a new issue, most construction companies still have problems with this process. The interviewed professionals recognize the relevance of a good organizational knowledge management for the success of their projects, and also acknowledge that the use of mobile technologies on the field would facilitate the use of a knowledge management system. We concluded the studied companies have three major needs associated to knowledge management: (1) to document lessons learned, (2) to foster face to face contact among construction professionals, and (3) to define a procedure to manage their information and knowledge. The proposed lesson-learned system was developed based on this requirements and needs, so it is expected that it could help to improve their knowledge management practices once implemented. Given the new trends in mobile technology, the opinion of the construction professionals, and the characteristics of the most probable users of the system (medium size construction companies) we decided that our system must include a mobile application in a cloud environment. For construction companies, the availability of information and knowledge on short notice is an important issue to improve project decisions. Then, mobile cloud computing can be a very useful tool that allow construction professionals an easy access to knowledge and information everywhere and anytime. The main concerns about the design of the system were shown on this article, including how we treat the security on the cloud, a very sensitive issue in this type of development.

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Design and implementation of automated, mobile construction projects monitoring system (MEVMS) based on Earned Value Management as an element of BIM in the execution stage

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Abstract

Polish construction market received huge amount of European Union funds during years 2007-2013 and will receive even more during new budget perspective 2014-2020. Case studies of the most important and valuable Polish construction projects especially in the Design and Build formula (e.g. highways, Warsaw Metro) show that it is very difficult to finish projects on time and within planned cost. New high-efficiency mobile tools for cost and schedule monitoring are needed in order to increase profitability of construction projects. As a response to this requirements the Mobile Earned Value Monitoring System (MEVMS) was developed and implemented in one of the office construction projects in Poland. New tool is an element of BIM and uses mobile computing technologies. Project manager can use mobile devices (smartphones, tablets etc.) to enter cost, schedule and progress data to the EVM monitoring system. The core of the system receives input data and calculates EVM progress indicators e.g. Budget Cost of Work Performed (Earned Value), Actual Cost of Work Performed, Cost Performance Index, Schedule Performance Index, Estimated Cost at Completion and Estimated Time at Completion. Different users have authenticated access to the MEVMS system and can observe project performance reports "online" using mobile devices. The summary of the paper presents effects of the system implementation, other application possibilities (e.i. keeping record for claim management) and further possibilities of system upgrading (Augmented Reality).

Keywords:Building Information Modeling (BIM), claims, Earned Value Management (EVM), mobile computing, project monitoring.

1. Introduction

The dynamic development of the construction industry in the beginning of the twenty-first century, manifesting construction of higher, bigger and more complicated structures in connection with the necessity to minimize cost, time and fulfill the conditions of sustainability require the use of new, more efficient tools in construction project management. A high level of complexity of the project, wide scope of works , high level of specialization, frequent and significant changes in the design documentation and technology make it very difficult to efficiently manage construction projects without modern tools for the design, execution and information exchange. Building Information Modeling seems to be a response to the needs of present and future construction projects. Case studies of the largest construction projects carried out in Poland in recent years show that often construction costs and realization time are exceeded. Due to the reasons listed above there is a need to implement efficient monitoring system of the construction works progress and cost in the execution phase of construction projects. In this paper the Mobile Earned Value Monitoring System (MEVMS) of construction works was introduced which can be an element of Building Information Modeling. Case study with the system implementation was conducted on the office construction site in Poland.

2. Earned Value Management description

The aim of Earned Value Management is the effective monitoring of the project performance and progress with regard to time, cost and scope. This method is a tool that analyses the project performance factors and forecast project future performance. This method can also be applied to the already finished project in order to show analytical and graphical characteristics of its time and cost performance.

Essential features of EVM are listed below:

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- PV (Planned Value) – planned cost according to the financial schedule;
- EV (Earned Value) – project progress measured as a planned cost of work performed until the date of inspection;
- AC (Actual Cost) – real, actual cost of work performed;
- BAC (Budget At Completion) –total planned cost of the project.

PV, AC, and EV are function of time and can be presented in the form of figures on a graph. PV figure is created in the planning phase of the project, while the AC and EV figures are determined on the basis of data collected during the monitoring of the project.

Data from graph figures AC, PV and EV is the basis for the calculation of further indicators. They can be divided into two groups: indicators that are used to monitor project actual progress and indicators that are used to forecast further costs and progress basing on results already achieved.

2.1. EVM monitoring indicators:

Cost Variance

$$CV = EV - AC \tag{1}$$

Schedule Variance

$$SV = EV - PV \tag{2}$$

Cost Performace Index

$$CPI = \frac{EV}{AC} \tag{3}$$

Schedule Performance Index

$$SPI = \frac{EV}{PV} \tag{4}$$

2.2. EVM forecast indicators:

Estimated Cost at Completion

There are optimistic and pessimistic indicators, which depending on the assumed relationship between planned and actual costs have different forms.

If the project cost is lower than planned (CPI> 1):

$$EAC_{OPT} = \frac{BAC}{CPI} \tag{5}$$

$$EAC_{PES} = AC + BAC - EV \tag{6}$$

If the project cost is higher than planned (CPI<1):

$$EAC_{PES} = \frac{BAC}{CPI} \tag{7}$$

$$EAC_{OPT} = AC + BAC - EV \tag{8}$$

Estimated Time at Completion

$$ETTC = ATE + \frac{OD - (ATE \cdot SPI)}{SPI} \tag{9}$$

where:
ATE – time from the beginning of the project until date of inspection
OD – project planned time of realization

3. Mobile EVM monitoring system description

According to the actual Code of Construction Law in Poland there are 4 participants of construction process: Client, Client's Inspector, Design Team and Site Supervisor. For the Client it is very important to receive accurate and reliable information concerning work schedule and cost as quickly as possible. From the Contractor point of view it is not so important and sometimes even undesirable when these information are unfavorable. In conclusion the mobile EVM monitoring system was designed that could be used by Client's Inspector to increase quality and speed of monitoring schedule and cost on a construction site.

Mobile EVM monitoring system framework is presented on figure 1. All the system modules can be divided to 3 key groups:

- system input (green color) – data collection, initial analysis and transfer to the system core;
- system core (red color) – a platform receiving and processing data from the system input;
- system output (yellow color) – data transfer to the Client.

The participants of this structure are: Client, General Contractor (including subcontractors), Design Team and Client's Inspector. Client commisions execution of works that are conducted by General Contractor and the Design Team. In order to supervise the works in terms of schedule, cost and quality Client employs Inspector. EVM mobile monitoring system can be a valuable tool for Client's Inspector.

First part of the system implementation is developing the system core – a platform where the data can be stored, processed and accessed remotely (using mobile cloud computing). The decision should be made which parts of the construction process will be monitored by the system. Design documentation including time schedules, cost plans and drawings should be carefully analyzed and entered to the calculation sheets of the core. It is more convenient to perform this stage with the use of desktop computers or notebooks rather than small mobile devices. Complete system core should have all planned data entered – Budget Cost of Work Scheduled for the whole time of realization. Also cells, formulas and charts of EVM factors for future data entry should be prepared at this stage.

When the construction starts system input is used for real-time data collection from a construction site. Each time the inspection is made Budget Cost of Work Performed data should be entered with the use of mobile devices (smartphones, tablets, notebooks etc.). Mobile devices must have access to the system core via internet. Data entry can be done daily, weekly or monthly depending on the type and scope of monitored works. Data concerning Actual Cost of Work Performed can be put rather after billing period is finished – then regular and additional cost can be assigned to particular works. System core should have built-in error detection that signals obvious data errors for example entering finish time earlier than start time. The system core engine automatically processes data that is entered during inspection. As an effect EVM indicators are calculated and EVM graphs are created in the system core.

System output allows Client to have a real-time access to the mobile EVM monitoring system. Access to the cloud platform with system core is granted through personal login and password. With the use of mobile devices with internet connection Client can see an up-to-date schedule and cost monitoring of the ongoing project. Client could also receive electronic reports of monitoring and alerts when EVM indicators have critical values or significant changes. In that way Client can quickly react to schedule disruptions and cost overruns.

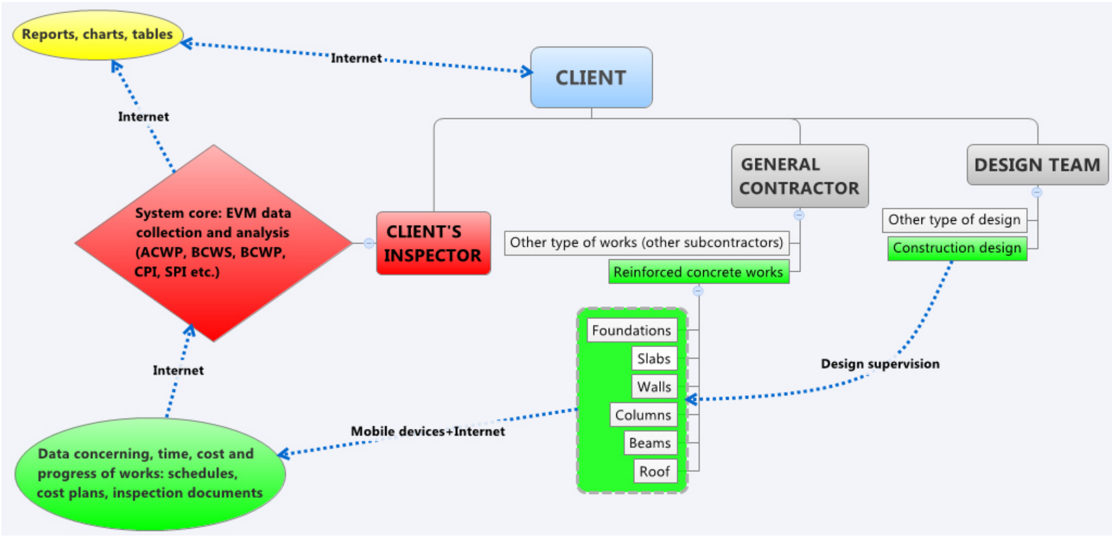
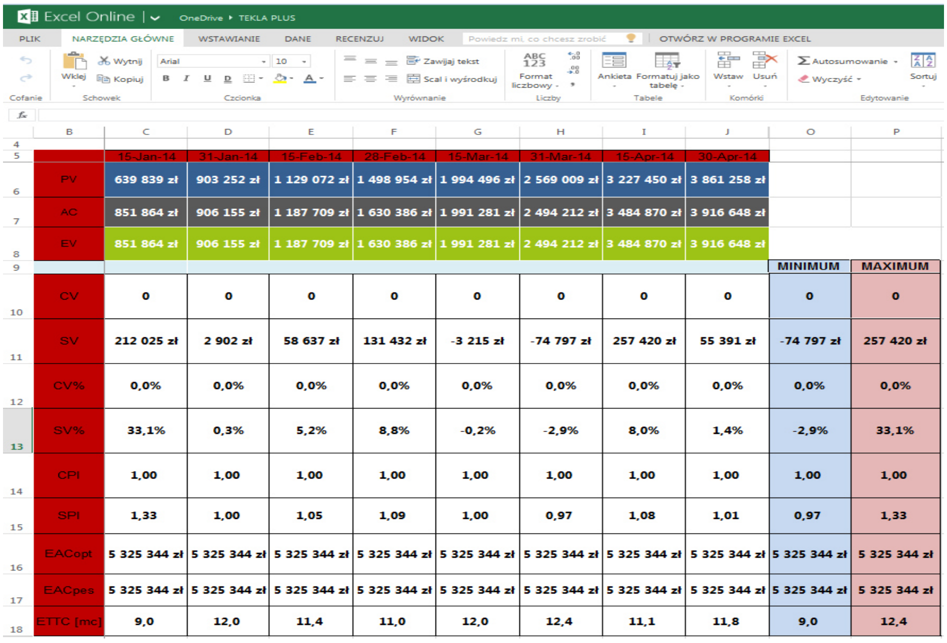


Figure 1. EVM mobile monitoring system framework.

4. Case study

Mobile EVM monitoring system was implemented on a construction of an office building in Warsaw. The building will have 2 underground and 5 overground levels, dimensions in plan 73x33m and the height 20m. Main construction elements will be reinforced concrete and the foundation on diaphragm walls with foundation slab. The monitoring included structural elements (slabs, walls, columns, beams) and has been started on 1st January 2014. The system core was placed on 2 different cloud platforms – Google Drive for smartphone Samsung S3 Mini and Microsoft OneDrive for Nokia Lumia 625. The results of the first 4 months were presented in this paper. Main indicators of EVM was presented in figure 2. MEVMS mobile data entry on a construction site was presented on figure 3.



	15-Jan-14	31-Jan-14	15-Feb-14	28-Feb-14	15-Mar-14	31-Mar-14	15-Apr-14	30-Apr-14	MINIMUM	MAXIMUM
PV	639 839 zł	903 252 zł	1 129 072 zł	1 498 954 zł	1 994 496 zł	2 569 009 zł	3 227 450 zł	3 861 258 zł		
AC	851 864 zł	906 155 zł	1 187 709 zł	1 630 386 zł	1 991 281 zł	2 494 212 zł	3 484 870 zł	3 916 648 zł		
EV	851 864 zł	906 155 zł	1 187 709 zł	1 630 386 zł	1 991 281 zł	2 494 212 zł	3 484 870 zł	3 916 648 zł		
CV	0	0	0	0	0	0	0	0	0	0
SV	212 025 zł	2 902 zł	58 637 zł	131 432 zł	-3 215 zł	-74 797 zł	257 420 zł	55 391 zł	-74 797 zł	257 420 zł
CV%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
SV%	33,1%	0,3%	5,2%	8,8%	-0,2%	-2,9%	8,0%	1,4%	-2,9%	33,1%
CPI	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
SPI	1,33	1,00	1,05	1,09	1,00	0,97	1,08	1,01	0,97	1,33
EACopt	5 325 344 zł	5 325 344 zł	5 325 344 zł	5 325 344 zł	5 325 344 zł	5 325 344 zł	5 325 344 zł	5 325 344 zł	5 325 344 zł	5 325 344 zł
EACpes	5 325 344 zł	5 325 344 zł	5 325 344 zł	5 325 344 zł	5 325 344 zł	5 325 344 zł	5 325 344 zł	5 325 344 zł	5 325 344 zł	5 325 344 zł
ETTC [mc]	9,0	12,0	11,4	11,0	12,0	12,4	11,1	11,8	9,0	12,4

Figure 2. Mobile EVM monitoring system core table with indicators.

MEVMS analysis showed that EV was higher than PV during almost whole time of the monitoring only without the period from 16th March to 3rd April 2014. It showed that during most time the project was ahead of schedule (max. SPI=1,33). AC was equal to EV because there were no cost overruns (CV=0; CPI=1,00; EAC=const.). Unfortunately there were signs of rush observed during inspections and their negative influence to the quality of the elements: concrete cracks, not proper concrete cover and reinforcement arrangement.

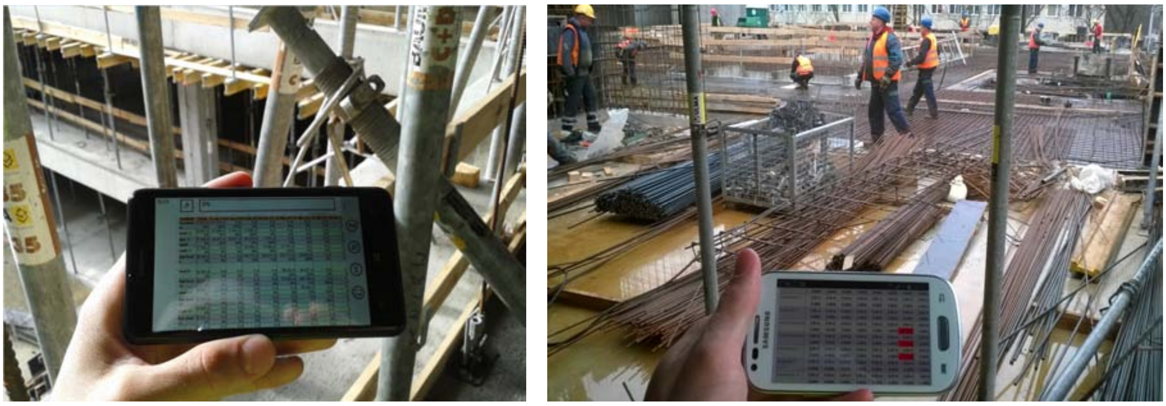


Figure 3. Smartphone application of Mobile Earned Value Monitoring System (MEVMS) on a construction site. Nokia Lumia 625 (left), Samsung S3 Mini (right).

5. Summary

The paper presents innovative way of Earned Value Management application to the construction project. Mobile Earned Value Monitoring System (MEVMS) seems to be a valuable tool for Clients to execute real-time control of time and cost performance. However in the next step the system should be upgraded. Data entry using standard smartphone spreadsheets can be sometimes inconvenient on a construction site. In conclusion the professional mobile application with voice commands should be developed that imports time and cost data from BIM model. The system core communication with the Client could be more effective by sending reports and alerts automatically when EVM indicators values are extreme . Also photos and voice commands from the inspections could be added and Augmented Reality application could be considered. Further works on upgrading MEVMS will be performed on Civil Engineering Faculty at Warsaw University of Technology.

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Comparative analysis of the machine labor ratio for earth excavation in different economies

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Abstract

Earth excavation has the same process flow in all parts of the world. But the choice between excavation technology i.e. manual or machine work, or combination of these vary in different parts of the world as well as costs of manual work and the availability of construction machinery. According to the MGI (2012) there will be potential surplus of 90 to 95 million low-skilled workers in the world by 2020. In advanced economies demand for high-skilled labor is growing faster than supply, while demand for low-skilled labor is weakening. In this paper authors analyze excavation costs in order to determine whether manual work for this kind of job will be possible and cheaper or not. Cost and time analysis is made for the excavation of naturally moist solid soil in a wide shallow pit for building foundations using minimal worker salary and minimal machine costs per hour, related to standards for countries like Germany, Croatia, Pakistan, New Zealand and India. As expected, results have proved that machine work will be the optimal choice in Europe because of insufficient work force to replace a machine in addition to the expensive manual work. However, in developing countries machine work still is not the clear choice.

Keyworks: costs, excavation, human-machine ratio, low-skilled workers.

1. Introduction

Increasing development of the manufacturing technologies in most industries has brought significant economic improvement of the manufacturing process in comparison to 50 years ago or even in some industries 10 years ago. The construction sector has also reported about its technology improvements in recent decades. Manufacturing of building materials and prefabricated components today are almost entirely automated, while construction on site or *in situ* production and installation is still largely dependent on human labor and done mostly manually, specifically in developing countries. The construction industry in most countries has a significant share of employees in the market and a huge potential for employment of a large number of unemployed unskilled or seasonal workers. According to the International Labor Organization ILO (ILO, 2014), approximately 5 million workers in the construction sector were laid off due to the global economic crisis in 2008 and, more interestingly, a nearly equal amount of workers was dispersed in all parts of the world. Orlikowski stated (Orlikowski, 1992): it is crucial to understand how different conditions influence on development, maintenance and use of technologies because it could give us insight into the limits and opportunities of human choice and organizational design. Construction is always considered as a major investment component. Hence expansion in construction activity is closely related to economic growth (Wells, J., 2001). Apart from the provision of growth to other industries through backward and forward linkages, the construction industry generates extensive employment opportunities throughout the globe (Khan, 2008). As per the study conducted by Proverbs (Proverbs D.G., et al, 1999), the construction sector stands among those providing 7.2 % employments to the workforce in Europe. Construction has the ability to “absorb the excluded” (de Souza, 2000). By satisfying the social responsibility, the construction industry provides employment opportunities to the world’s poorest and most vulnerable people. It provides work to low-skilled or entry-level workers and to those migrating from the rural areas (BWI, 2006). Moreover, the construction sector also provides much needed employment in the developed world to those with few academic qualifications (Wells, J., 2001).

As per the survey by the Construction Users Roundtable (CURT) conducted in 2001, 82 % respondents reported shortages on their projects while 78 % indicated that the shortage had worsened in the 3 years prior to

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the study (CURT, 2009). The Construction Labor Research Council (International, 2006) predicts that 185,000 new workers need to be attracted, trained, and retained each year up to 2016 in order for the industry to replace expected turnover and sustain the construction industry's growth expectations. Global Institute's report in 2012 also predicts a potential surplus of up to 95 million low-skilled workers around the world, or approximately 10 percent of the over-supply of such workers is expected by the year 2020 with an expected potential shortage of about 45 million high-skilled workers or 13 percent of extra-demand of such workers. With this future picture, one can easily predict some unevenness in the employment market for the near future. For sure, a long-term and permanent joblessness may be observed by every industry, with no exception for construction sector. Looking into the past, the majority of excavation work for an ordinary moist soil was carried out by manual means, i.e. with low- or unskilled labors. The required number of labors with the help of rudimentary tools performs the operation in order to meet the desired objectives of excavated soil within allotted time. As it appeared that construction would be ever more automated in near future, investments came into picture on more sophisticated equipment in order to compete in this technical industry. In return, the construction industry attains the desired results in quick time with less number of workers. But even now, the idea of using this mechanized technology is not ideal in all parts of the world. Most of the developing countries find it suitable to perform the not-so-large excavation tasks by manual means due to the availability of high number of low and un-skilled labor. In this study, a parametric analysis has been made between the countries chosen from the developed and developing world in order to look at the feasibility of manual and mechanized operation in an excavation activity.

2. Methodology

First part of the paper is focused on the general problem formulation based on the literature review and statistical trends of low-skilled workers on the global labor market, and for countries Germany, Croatia, Pakistan, India and New Zealand. In the second part parametric analysis was made based on the gathered input parameters for each country (average hourly costs and standard times of machine and manual excavation for the same average site conditions for a wide shallow pit and naturally moist soil). Final part of the paper consists of a comparative analysis and discussion with general conclusions.

3. Machine labor ratio for earth excavation

3.1. General problem formulation

Earth excavation has the same process flow in all parts of the world (Figure 1). But the choice between excavation technology, i.e. manual and/or machine work, or any combination of these two varies in different parts of the world. Differences are basically measurable and structured by: objective function (minimal excavating expenses and/or minimal total time) and constraints for decision (availability of resources: excavators and low-skilled workers). While machine excavation technology has significantly improved during the last 30 years, manual earth excavation hasn't improved by any means since the record of history. Still tools and excavation techniques are basically the same and only difference of their usage is by certain earth categories (from humus to solid soil). In time when great historical constructions have been built, engineers didn't have, not by far, technologies as we do today, but still today those constructions are recognized as wonders of the world. Engineer's choice was simple, they didn't have any, but to employ as much of the labor that was available. Nowadays, engineers optimize construction works by all kinds of criteria (mostly by time and costs), and the optimal solution is usually machine usage if possible. Still it's not possible to carry out total automation of construction works. Still construction industry is highly depended on human labor, to be exact on the most numerous group of construction workers: low-skilled workers. The immeasurable or hardly measurable criterion in optimization is the social aspect in terms of employment of those millions of low-skilled workers.

3.2. Survey

In this paper authors have determined parameters by which they conducted parametric analysis of human-machine ratio and option between manual and machine earth excavation by authors' domestic countries. In order to ensure the comparison of results, the input parameters were taken as the same. These parameters include national standards as a reference for required time of manual excavation and required qualifications of workers, statistical numbers and employment trends of low-skilled workers, hourly wage of those workers for excavation, hourly costs of the hydraulic excavator with agreed typical performances (70kW, wheels, mass=14t, bucket=0,86m^3), and standard or calculated time needed for an excavator to excavate one cubic meter, in the same average site conditions and same soil type for all five selected countries.

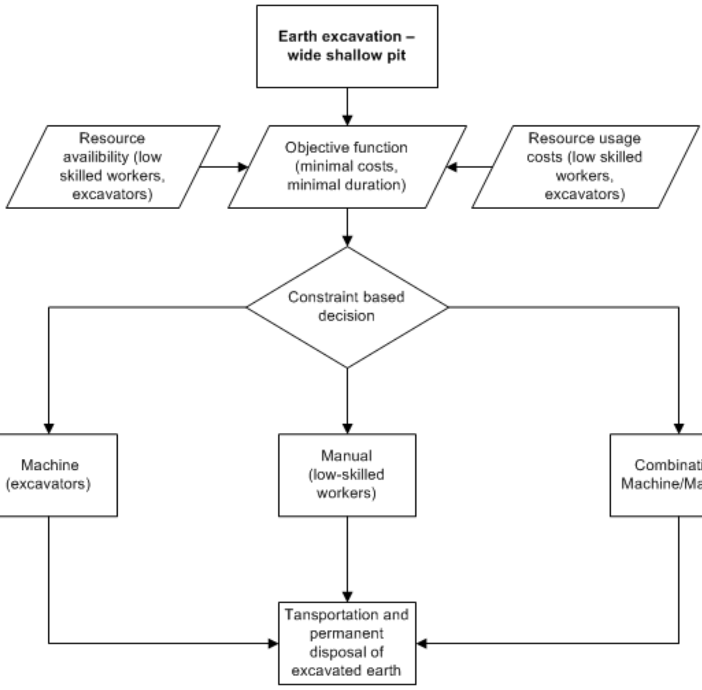

Figure 1. General decision tree for excavation of wide shallow pit

3.2.1. Global trend of low-skilled workers on labor market

As it has been mentioned earlier, according to the MGI (2012) there will be a potential surplus of 90 to 95 million of low-skilled workers in the world by year 2020. Construction industry has always been a great potential source of temporary employment for those workers.

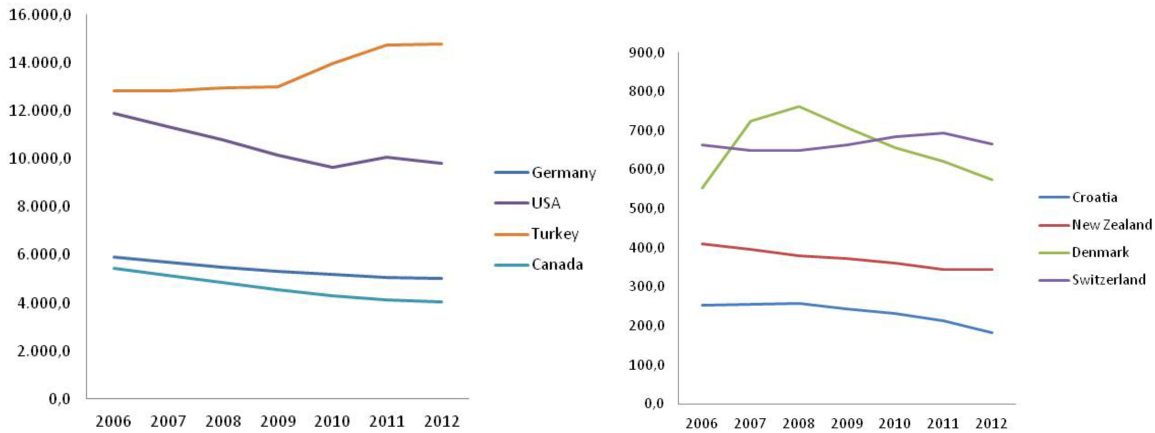

Figure 2. Trend of low-skilled workers employment [number x 1000]

As we are witnessing the global economic transformation happening at a scale and a rate faster than ever in history, the demand and supply on the labor market significantly varies in different parts of the world. While in Europe the number of low-skilled (low and unqualified) workers is decreasing by the decrease of demand, in some developing countries it increases (Figure 2) (Eurostat, Statistic New Zealand, USA Government Data Statistics, Statisticas Canada).

Statistical reports (Eurostat, 2014) showed that there were 42 million of low-skilled workers in 2012 in the EU, and this number is decreasing since 2006 when there were 52 million. In terms of employment of those workers, economically stabile countries (e.g. Luxembourg, Germany, Denmark, Norway and Switzerland) have a high percentage of employed low-skilled workers and those countries are considered to be the most economically developed countries (Table 1). Countries at the bottom of the table are still reporting an increase of low-skilled workers, thereby maintaining the employment opportunities below EU percentage. As a side effect, migration of those workers is logical. Looking into the picture of developing countries from Asia, statistics in India reported around 211 million of low-skilled workers in the year 2011, which by itself is an inconceivable number and cannot easily be compared with other countries. While in Pakistan, by last known statistics from the same source in 2008, there were 8.5 million low-skilled workers (ILO, 2014).

Table 1. Percentage of employed low-skilled workers in Europe (ordered by the 2012 report from highest to lowest) (Eurostat, 2014)

GEO/TIME	**% employed out of total number of low-skill workers**						
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
European Union	**79,42%**	**79,62%**	**79,93%**	**79,90%**	**79,47%**	**80,09%**	**79,89%**
Hungary	92,95%	93,92%	94,56%	94,33%	94,78%	95,15%	95,51%
Estonia	93,53%	92,50%	94,63%	93,42%	94,25%	92,77%	94,44%
Slovakia	93,47%	94,47%	94,57%	92,19%	92,20%	92,79%	94,27%
Luxembourg	94,30%	95,39%	95,41%	94,69%	95,33%	93,81%	94,16%
Germany	93,12%	93,20%	93,74%	94,06%	94,03%	94,03%	93,81%
Norway	91,28%	91,97%	92,48%	92,20%	92,72%	93,17%	92,65%
Denmark	93,90%	92,56%	92,91%	92,22%	93,00%	92,62%	92,29%
Switzerland	91,21%	90,07%	90,82%	91,76%	92,04%	92,29%	92,17%
France	89,90%	90,42%	90,52%	90,76%	90,70%	90,35%	90,60%
Austria	87,97%	88,12%	87,94%	88,37%	88,40%	88,13%	89,05%
Sweden	88,29%	88,09%	88,09%	87,84%	87,00%	88,19%	89,03%
Belgium	86,78%	85,94%	87,71%	86,63%	87,80%	88,14%	88,64%
Czech Republic	91,73%	90,81%	91,81%	91,33%	90,23%	90,34%	88,36%
Iceland	86,67%	88,21%	88,84%	88,40%	86,25%	87,91%	88,12%
Netherlands	89,47%	89,58%	89,54%	89,25%	87,82%	87,81%	87,62%
Latvia	83,93%	86,75%	89,19%	86,82%	88,95%	86,17%	87,06%
Lithuania	69,29%	73,29%	83,93%	81,67%	80,75%	80,51%	84,32%
United Kingdom	86,98%	86,30%	86,09%	85,80%	85,11%	85,29%	83,88%
Malta	83,37%	82,91%	83,66%	83,12%	82,72%	83,18%	83,19%
Finland	83,29%	83,14%	83,71%	83,06%	82,74%	82,43%	83,10%
Bulgaria	79,57%	80,50%	82,10%	81,69%	80,22%	80,31%	81,04%
Spain	78,99%	79,69%	79,38%	79,97%	79,82%	80,14%	78,71%
Ireland	78,34%	77,02%	76,19%	74,88%	76,54%	79,35%	78,39%
Portugal	76,34%	76,43%	76,68%	76,70%	77,29%	78,84%	78,31%
Cyprus	72,04%	72,68%	74,69%	74,06%	77,48%	77,40%	77,48%
Italy	72,43%	72,29%	73,10%	73,50%	73,24%	73,92%	74,48%
Slovenia	74,22%	74,98%	76,46%	75,95%	74,81%	74,87%	74,33%
Poland	54,42%	57,70%	60,81%	62,13%	62,17%	63,34%	64,11%
Croatia	58,38%	60,53%	59,22%	57,80%	54,67%	54,38%	58,40%
Turkey	50,61%	51,79%	51,96%	50,54%	51,64%	52,34%	52,84%
Greece	49,57%	51,11%	52,26%	51,19%	49,41%	49,15%	46,77%
FYROM	46,20%	46,29%	45,69%	44,22%	41,92%	41,37%	42,66%
Romania	27,53%	27,82%	28,44%	28,82%	25,84%	27,46%	27,95%

3.2.2. National standards for excavation

In construction industry it is common that each country has its own set of standards for construction works as a benchmark for tendering and contracting. They are structured by the type of works and each is consisted by generally described operations related to units such as needed material and quantities, workers with required qualifications, number and normative time, and/or machines with normative time. For excavation works, most of standards propose low-skilled (unqualified or less-skilled) workers because some special knowledge or skills for manual excavation are usually not required. It is expected that healthy grown humans can execute the digging technique simply by guiding instructions and then by work repetition. Croatian *Normative and work standards in construction* (1999) in the excavation works propose two hours' time for a cubic meter unit. The standards set by the Croatian construction industry are very similarly structured to German standards (*REFA analysis*) as for example investigated by (Plümecke and Kuhne, 2004) which propose an excavation time of 1.5 hours per unit. As previously discussed, standards from India and Pakistan (*Market Rate System, 2013)* propose the excavation time for a cubic-meter of soil to be 2.0 and 1.6 hours respectively. With a far location from the chosen countries, New Zealand with its standards (*Rawlinsons Construction Handbook*, 2012) adapted a time of 2 hours, thereby assuring the familiarity within the comparable data.

Table 2. Standard time for low-skilled workers to excavate one cubic-meter of naturally moist soil in average conditions

Standard time of low-skilled workers for earth excavation [hours/m³]					
year	Croatia	Germany	Pakistan	New Zealand	India
2013	2.10	1.50	1.06	2.0	2.0

3.2.3. Average costs of resource usage for earth excavation

According to the markets' conditions, significant differences of average hourly labor costs were reported among selected countries. These differences can be explained by the basic rule of economy, i.e. demand and supply. It is truly logical that the cost of the low-skilled workers will decrease with the increasing number of such workers. Surprisingly, New Zealand came on the top of the list with an hourly cost of low-skilled workers to be equivalent to 15.13 Euros per hour. Germany, with different wages among different states came out with an average cost of 11.05 Euros per hour. Croatia stood at an average hourly rate of 2.83 Euros per hour, while Pakistan and India came out with the equivalent of 0.43 Euros as an average rate per hour for a low-skilled worker in the construction sector.

Table 3. Statistical average hourly cost of low-skilled workers in construction sector for the year 2013

Average hourly cost of low-skilled workers in construction sector [€/hour]					
year	Croatia	Germany	Pakistan	New Zealand	India
2013	2.83	11.05	0.43	15.13	0.43

Authors have for this research chosen the most suitable hydraulic excavator for the mentioned excavation and which is globally accessible. It can be defined as semi weight hydraulic excavator on wheels, weight of the machine 14 tons, with the power of 70kW and with bucket's capacity of 0,86m³.

Table 4. Hourly cost of usually type of excavator for excavating a wide shallow pit

Hourly cost of excavator q=0,86m³ [€/hour]					
year	Croatia	Germany	Pakistan	New Zealand	India
2013	70	75	21	93	39

In table 4 hourly costs are average on the market in each analyzed country. Similarly, the study observed a variation among the hourly costs of excavators to be used on construction grounds. This variation is due to several factors which may include fuel costs, rental charges of equipment and hourly costs of the operator required to complete the desired operation. New Zealand was marked on the top of the list with the hourly costs of an excavator to be equivalent to 93.00 Euros. Germany and Croatia stood at the hourly cost of 75.00 and 70.00 Euros, respectively. India was fourth on the list with equivalent costs of 39.00 Euros per hour while Pakistan got the bottom place among the selected countries with equivalent costs of 21.00 Euros per hour for an excavator.

4. Comparative analysis

The expected or planned time of excavation by hydraulic excavator with a bucket capacity of 0.86 m^3 is calculated by formula (1). This is assuming the same excavation and soil type, same average site condition as for the manual excavation. The expected time results in around 0.013 hours per cubic meter, calculated in accordance with the basic production formula for the hydraulic excavators (Peurifoy et al., 2006):

$$\textit{Expected time} = T / (3600 \times Q \times c) \ [\text{hours/m}^3] \qquad (1)$$

T cycle time [seconds]
Q heaped bucket capacity [m^3]
c corrective coefficient which includes external and internal influences on the excavation (taken as 0.6).

Table 5. Comparison of the number of workers needed to match production of 1 excavator and their hourly cost

Description	Croatia	Germany	Pakistan	New Zealand	India
number of workers required to replace 1 excavator	162	115	82	154	154
hourly costs of the needed number of workers [€/hour]	458.46	1,270.75	35.26	2,330.02	66.22
hourly costs of the excavator [€/hour]	70	75	21	93	39

In table 5 it is shown the machine/labor ratio which indicates the disproportion of this ratio in the world and explains the differences in the decision between the manual and machine excavation in developed and developing countries.

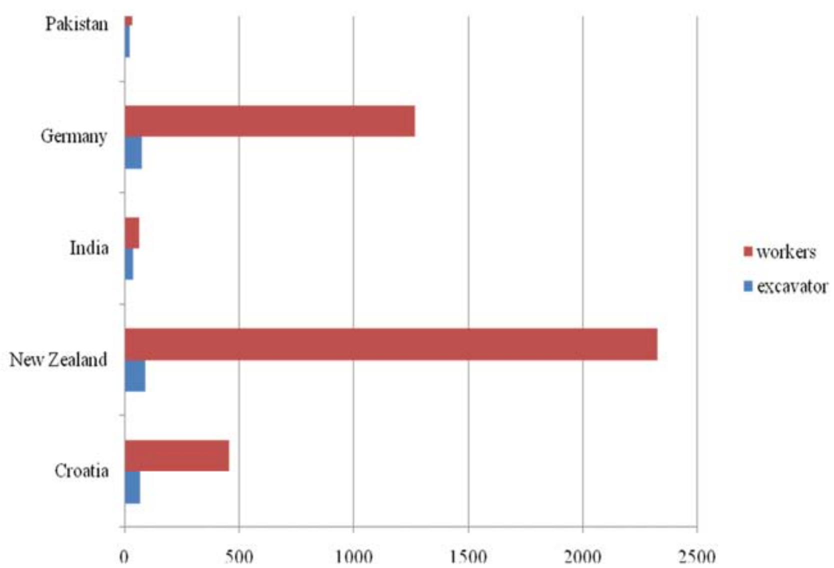

Figure 3. Comparison between costs of excavator and workers required to achieve the same productivity

Comparisons are now presented in Table 5 and Figure 3, respectively. Table 5 interprets the required number of low-skilled workers to match or replace the production capacity of one excavator, whereas Figure 3 represents the hourly costs of one excavator in comparison with the total number of low-skilled workers required to perform the same work item. It is evident from this comparison that economies with a surplus amount of low-skilled labor within the construction sector might perform the studied excavation task by manual means, wherein the little extra costs as compared to that of an excavator will generate more labor-hours of employment. This might result in a better social harmony and thereby enabling the workers to fulfill basic necessities in the society which would have been in much danger in the case of technology adoption. In order to reach the target of meeting increased labor participation goals, construction contractors have to adopt the use of low-skilled labor to execute excavation works, which is a most common activity in construction of any facility. Likewise, developed economies can easily adopt the technology options in order to follow a more economically viable solution.

5. Conclusions and discussion

Low-skilled labor marks a significant part of the construction sector, performing daily production tasks that don't require specific technical knowledge or confirmed skills. Hand-work, excavations, material transfers or repetitive tasks are typical unskilled labor positions. Low-skilled laborers are usually hired on day-to-day basis, or seasonally, directly by contractors or through employment services where workers wait for daily employment. Today the construction market demands an increasing skill level. Many jobs that were once considered unskilled labor now demand some kind of formal skills. The jobs that require unskilled labor are continually decreasing due to technological and societal advances. Jobs that previously required little or no training now require training – manual work today is assisted by different kinds of technology, requiring the worker to acquire necessary technological skills. Unemployment and increasing numbers of low-skilled workers are serious problems of most developing countries, but developed countries are affected as well due to work migrations. As stated in the beginning of the paper, there is high potential for some valuable and more in-depth analysis regarding the integration of low-skilled workers. Up to now and without this thorough research, it is yet hard to understand and predict labor market of highly populated countries. In days of high work migration and rising number of workers which have no or low-skills, engineering optimization should be revised and aware of the current social situation.

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Critical factors influencing the engineer's selection of the country to work abroad

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Abstract

The decision to work abroad is influenced from a great number of factors, including cultural, social and psychological ones, which are also critical for a successful adjustment to the host country. The decision should be the outcome of a very delicate decision-making process, which, however, is currently not available as both literature and practice clearly indicate. This paper attempts to identify and analyze those factors with an impact on the selection of the country to work abroad in the case of engineers. An extensive literature review revealed all the factors related to the expatriation and relocation issues of an expatriate focusing rather on the socio-cultural and personal dimensions, than those of the working environment and job satisfaction, which are related to the job's description. Based on the findings of the literature review an international questionnaire survey for engineers was prepared and conducted aiming at: a) evaluating these factors, in terms of importance for the potential expatriate and b) deciding on their use in a formal methodology for the selection of a country to work abroad. The collected data were statistically analyzed and the correlations between the factors were investigated to identify those among them that are critical to include in a formal country selection process. A major finding of this research is that the field's literature highlights a different set of critical factors compared to those indicated by the questionnaire survey. Furthermore, a second important finding is that the critical factors present very loose correlations, which indicates that any model aiming at supporting the decision-making process for selecting the country to work abroad should introduce them very carefully. The two findings lead to the conclusion that a proper selection of the factors to incorporate into a country selection method process is required.

Keywords**:** correlation analysis, cross-cultural adjustment, expatriates, international career, international HRM.

1. Introduction

Deciding for a job offer in a foreign country is a complex task because of the various factors that influence such a decision. Acceptance or rejection of such an offer largely depends on parameters that are not directly related to the job offer itself (e.g. working environment, salary level, career path, etc.), but on the capacity of the expatriate employee to adjust to the new working conditions. The existing literature on the topic is focused on the identification of those factors with an impact to the final decision (e.g. demographic, cultural, personal traits, etc.) and the description of the correlations of those factors – individually or in groups – to the decision (Shaffer et al. 2012, Selmer and Lauring 2011, Ryan and Twibell 2000, Tharenou 2008, Dickmann et al. 2008, etc.).

This paper presents the first step towards the development of a methodology for engineer to select a country to work abroad. In specific, this paper presents the findings of the analysis of the factors that influence an engineer's selection of the country to work abroad, in order to identify the most critical among them and include them in a systematic methodology for the respective decision-making process. The research focuses only on the factors related to the adjustment capacity of the expatriate excluding those which are related to the job characteristics. The remainder of this paper shortly presents the context of the research topic and the existing proposals for a methodological approach to it. Successively, it presents in detail research results on the criticality of the decision-making criteria, which is determined with the use of a correlation analysis of data collected through a questionnaire survey. The originality of this research lies in the fact that for the first time the identified factors are investigated as a whole and not individually or partially (e.g. in small groups of two or three elements). This research approach results in very interesting findings that are properly discussed, thus leading to significant conclusions.

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2. The influencing factors for selecting a country to work

Expatriating for professional reasons is, currently, an increasing phenomenon, which spans all geographic regions and all socio-economic classes of the population in developing and developed countries (Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat 2013). Previous research has identified several factors that have an impact on this phenomenon, irrespective of the type of job of the expatriate.

Selmer and Lauring (2011) and Carr et al. (2005) in their studies identified five categories of motives to expatriate: a) career development, b) financial incentives, c) family reasons, d) life change/escape, and e) adventure/ travel. Richardson and Mallon (2005), Richardson and McKenna (2003), and Richardson and McKenna (2002) focused their research on professionals in academia and identified similar categories of motives to expatriate.

Dickmann and Mills (2010) propose the factor of location in addition to career and developmental considerations, organizational factors, individual motivation, social life considerations and national factors, which - according to their extensive literature review - constitute the most influential factors in deciding to work abroad. The location factor, according to Dickmann et al. (2008), corresponds to the capacity of the expatriate to adjust to a different culture and different living conditions; cultural distances and adaptation processes, and emotional and intellectual adjustment to new environments have attracted the interest of other researchers as well (Bhaskar-Shrinivas et al. 2005).

Ward and Kennedy (1999) broadly identified the psychological and socio-cultural domains for analyzing the cross-cultural adaptation issue. The psychological domain is associated with personal traits and understanding of situations such as satisfaction, socialization, etc., while the socio-cultural domain is associated with behavioral competencies and the capacity of an individual to acquire knowledge and skills. A similar approach is suggested in the context of Social Cognitive Career Theory where career interests and career choice goals for employees are determined based on both: a) cognitive properties and environmental factors, either experienced or anticipated by the employees and b) environmental opportunities, support and barriers that the employees experience or expect to experience (Tharenou, 2008). Personal agency constitutes a critical factor for the decision to expatriate, since it is positively related to the employee’s belief that he/she can, successfully, confront the challenges in a new culture (Tharenou, 2008).

The identification of more factors that influence the decision to work abroad can be achieved indirectly by reviewing other aspects of the expatriation phenomenon. Howe-Walsh and Schyns (2010), Suutari (2003), and Puck et al. (2003), for example, have supported that expatriates’ adjustment is a combination of individual psychological processes and performance in work. Personality characteristics related to the subjective adjustment (i.e., the non-quantifiable, psychology-related process of adjustment) include cultural flexibility, social orientation, communication and the willingness to communicate or the motivation to go overseas (Takeuchi et al. 2002). On the other hand, language proficiency, previous international experience, prior knowledge of the host country, acquaintance of host country nationals and spouse and family adjustment are factors influencing the objective adjustment (i.e., the quantifiable experience- and performance-related process of adjustment) (Bonsiep et al. 2003, Takeuchi et al. 2002).

3. Current decision-making approaches for selecting a country to work abroad

A major finding of this research was that a method for selecting a country to work abroad does not currently exist. The extensive literature review that included more than 120 related sources (papers, books, etc.) revealed very clearly that the research focus is on the investigation of the dependencies between the influential factors and the decision for the expatriation, rather than on the investigation of a complete decision-making method that could systematize the process and support the future expatriate to his/her selection of the country to work abroad.

Chen and Tzeng (2004) were the single case of researchers that were identified using a fuzzy analytic hierarchy process and a fuzzy integral to determine the weighting of subjective preferences and derive the performance values of country alternatives for a work abroad. In particular, Chen and Tzeng (2004) considered the decision of whether to take or refuse an assignment abroad as a fuzzy multiple criteria decision making problem, where the fuzzy Analytic Hierarchy Process was applied to determine the weighting of the criteria and Grey Relation model and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method were combined to evaluate and select the best among the alternatives.

The lack of a specific decision-making method for the selection of a country to work abroad – with the exception of the work by Chen and Tzeng (2004) – suggests a very interesting topic for further research. Given that, as already shown in Section 2.0, the mobility of professionals is an increasing phenomenon, a formal and systematic method for the selection of a country to work abroad would constitute an important tool for construction companies that need to assign employees for work in foreign countries as well as for individuals that investigate expatriation.

The first step towards the development of such a method is the identification and selection of the variables to include. An initial identification was performed through literature review as described in Section 2. The identified factors were then investigated for verification and significance through a questionnaire survey and statistical analysis of the results, respectively. These processes are presented in the remainder of this paper and constitute the main research effort.

4. Research methodology

The factors influencing the selection of a country to work abroad constitute the variables or the criteria of any method applied to decide between various available alternatives. Therefore, a clarification of the factors that should be included in a decision-making method, as well as, the weighting of those factors is a prerequisite for the development of the method. Based on the findings of the literature review an international questionnaire survey was designed and conducted aiming at: a) evaluating the identified factors, in terms of significance for the potential expatriate and b) deciding on their use in a formal methodology for the selection of a country to work abroad. The survey was addressed to engineers; the collected data were statistically analyzed and the correlations between the factors were investigated.

Thirty factors that comprehensively cover the range of factors highlighted in the literature were selected. These factors were grouped in the following six categories: a) personality factors, b) career and professional development factors, c) experience related factors, d) family factors, e) spouse/partner related factors, and f) host country related factors including local, geographical, and national considerations. These factors were evaluated by the contributors to the questionnaire survey, in terms of their significance in the selection process of a country to work abroad. The evaluated factors are presented in Table 1.

4.1. Data collection

The data were collected electronically between August-September 2013 with the use of a commercial web survey software package. The survey was addressed to engineers who: a) are currently working, b) have worked in the past, c) have attempted, in the past, to work and d) plan to work, in the near future, abroad. A total of 114 valid responses were collected representing a population of engineers with the following characteristics:

- They were working in 20 countries, worldwide, including the Arab World (18,4%), the Netherlands (16,7%) and Great Britain (15,8%).
- They were of 20 different nationalities, including 11 countries from the European Union and the rest from all over the world.
- They were mainly of male gender (66,7%) and single (73%).
- They were engineers of all disciplines with a majority of civil engineers (44, 7%) and architects (12%).

Additional useful data were collected in the survey, including: a) the type (e.g. senior position, designer, etc.) of the current and the previous position abroad, b) the type of the organization of employment (e.g. public authority, construction company, etc.) of the current and the previous position abroad, and c) the period of stay at the host country. An important characteristic was that a significant percentage of the participants were not expatriating for the first time, but they had more than 5 years experience abroad in four or more countries.

4.2. Data analysis

The collected data comprised the participants' evaluations of the thirty factors in terms of significance to the decision of choosing a country to work abroad. A five-point (1 for very weak to 5 for very strong significance) Likert scale was used for the evaluations. The collected data were tested for their robustness through the Cronbach's Alpha reliability test, which resulted in a very sufficient value of the respective coefficient ($a = 0.869$). The collected data were also tested for normality through the Kolmogorov-Smirnov test, which indicated a lack of normality for the data distribution. Having identified the properties of the available data a descriptive statistical analysis was conducted to: a) rank the factors under study, in terms of significance for the selection of the country to work abroad and b) identify dependencies between these factors. The ranking was achieved by calculating the mean number of the evaluations of the survey's respondents, while the potential dependencies were tested by applying Kendall's tau b and Spearman coefficients, which are more accurate to Pearson's coefficient for data that lack normality. The analysis was performed with the use of the SPSS v.17.0 software pack and the results are presented in Section 5.

5. Discussion of the results

The analysis of the survey data aimed at: a) prioritizing the investigated factors, in terms of significance and b) revealing the correlations between them in the context of selecting a country to work abroad. Tables 1 and 2 summarize the findings, respectively.

Table 1: Ranking in terms of significance of the factors influencing an engineer's selection of the country to work abroad

Factor	*Ranking*	*Mean*	*Factor*	*Ranking*	*Mean*
Willingness of partner to move	1	4.66	Own family adjustment	16	3.60
Career advancement	2	4.45	Career risk	17	3.56
Own personality advancement	3	4.40	Previous own experience in international cooperation	18	3.46
Own personality traits	4	4.22	Host country 's natural environment	19	3.45
Work –life balance	5	4.14	Fluent use of the host country' s language	20	3.44
Safety-Security in the host country	6	4.12	Proximity to the home region (ease of access)	21	3.35
Own children's education needs	7	4.09	Host country's international position	22	3.30
Host country's way of living (cost of living, standard of living)	8	4.09	Host country's culture	23	3.29
Marital status	9	3.89	Previous own knowledge of the host country	24	3.13
Spouse professional and personal concerns	10	3.88	Host country's climate	25	3.05
Host country's health system and medical facilities	11	3.88	Host country' s traditions	26	2.77
Expected length of stay	12	3.88	Existence of home country's expatriate communities	27	2.68
Host country' s educational facilities	13	3.87	Friends'/relatives' opinion	28	2.68
Host country's infrastructure	14	3.75	Host country's history	29	2.47
Personal relationships at home country	15	3.64	Host country's religion	30	2.45

The prioritization presented in Table 1 is based on the mean value of each factor, according to the responses of the survey participants to the question: "*Rate each factor between 1-5 (1 for "very weak" and 5 for "very strong"), in terms of significance for your decision to select a country to work abroad*". The results clearly indicate the willingness of the partner to relocate as the most important factor influencing the decision to work in a country abroad. The next five factors are focused on the potential expatriate's goals and characteristics, while family issues first and host country's conditions then follow. Traditions, religion, climate, history and the existence of communities of the expatriate's home-country as well as the friends'/relatives' opinion seem not to affect the engineers' decision. Therefore, it seems that the selection of a country to work abroad is primarily a personal matter related to the individual's personality and his/hers career plan, which, however, is conditional on the support of the individual's partner in life.

The conducted Kendall's tau b and Spearman correlation analyses indicated the same number of correlations between the variables, except for limited specific cases where the Kendall's tau b correlation coefficient was rather increased compared to the Spearman correlation coefficient. Table 2 presents the results drawn from the Kendall's tau b correlation analysis.

Table 2 presents the positive correlations between the critical factors and the other factors from the group. Criticality was determined based on these correlations, which indicate an important role in the decision-making process, since they influence the evaluation of other factors in respect with the existing correlation (i.e., a significant correlation between two factors results to dependent values of significance for the correlated factors).

As shown in Table 2 the identified correlations are all positive, but they are very loose; only in one case the correlation coefficient is greater than 0,7. This finding is very important towards the development of a methodology for selecting a country to work abroad, since it indicates a significant level of independence between the factors, which shall result to certain assumptions that will constitute the basis for the new methodology.

Table 2. Kendall's tau b correlation analysis results

Critical Factor	Correlation factor	Correlation coefficient Kendall's tau_b
Willingness of partner to move	Marital status	,604**
	Spouse professional and personal concerns	,751**
	Own family adjustment	,562**
	Own children's education needs	,565**
Spouse professional and personal concerns	Marital status	,517**
	Own family adjustment	,509**
	Own children's education needs	,511**
Own family adjustment	Marital status	,514**
	Own children's education needs	,623**
	Own children's education needs	,457**
Host country's religion	Host country' s traditions	,566**
Host country's infrastructure	Safety-Security in the host country	,358**
	Host country's health system and medical facilities	,480**
	Host country' s educational facilities	,406**
	Host country 's natural environment	,457**
	Host country's culture	,394**
	Host country's international position	,386**
Safety-Security in the host country	Host country's health system and medical facilities	,609**
	Career advancement	,320**
Host country's health system and medical facilities	Host country' s educational facilities	,415**
	Host country 's natural environment	,440**
Host country 's natural environment	Host country's culture	,376**
	Host country's history	,348**
	Work-life balance	,207*
Own personality advancement	Own personality traits	,406**
	Career advancement	,394**

Sig. (2-tailed): all at 0.000
*P=0.5 **P=0.1

The results presented in Table 2 reveal a second interesting finding; the survey indicates a group of critical factors for selecting the country to work abroad, which is very different from the one suggested and applied so far. While many of the analyzed factors had been identified in the literature, there were also some, such as security-safety in the host country or expected length of the mission, which had been largely overlooked and through this research they are re-introduced in the analysis.

6. Conclusions

Engineers deciding on the country to work abroad are heavily influenced by a number of factors, which are irrespective of the offered job's features. Several factors of this type were identified through literature review, in the context of this research. A questionnaire survey that was conducted, also in the context of this research, verified that engineers do consider these factors when deciding to work abroad. A descriptive statistical analysis of the survey's results provided a ranking of these factors in terms of their significance for engineers towards the selection of the country to work abroad. The top five factors, according to this ranking are: a) willingness of the partner to move, b) career advancement, c) own personality advancement, d) own personality traits, and e) work-life balance. It should be noted, that the analysis of the survey's results reveals a different ranking compared to other similar efforts in the existing literature. A probable reason for that may be the fact that it was probably the first time where all the identified factors were investigated, concurrently, in the same survey, thus creating an inclusive and more complicated framework for the respondents, who answered considering more dimensions of the issue than usual. The most important finding of this research, however, was that the correlation analysis indicated lack of dependencies between the critical factors that influence the engineer's selection of the country to work abroad. This is a very important finding, because it determines the methodological approach to construct the decision-making problem of selecting a country to work abroad.

The following step of this ongoing research will be to investigate the relations of the identified factors with the reasons of failure for an engineer to adjust as an expatriate in a foreign country. The conclusion of this step together with the conclusions of this research shall determine the variables/criteria that will be introduced to a new method for engineers to select a country to work abroad. This method is expected to be a very useful tool both at the corporate and the individual levels for planning the use of human resources abroad and the possibility to work abroad, respectively.

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Employers' expectations: a probabilistic text mining model

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Abstract

This study uses text mining techniques to analyze employment data posted over the internet. The objective is to identify knowledge areas, skills and expertise relevant to jobs in the construction industry. We utilized the fast growing online job search engines to understand the construction job market and employer expectations. Over 20,000 job advertisements were downloaded from various websites between Oct 14th 2012 and March 15th 2013. We developed a text mining method to identify derived job qualification information from the downloaded pages. The developed algorithm is capable to derive rules by automatically extracting statistically significant patterns present inside preselected qualifications. The selection rules can then be used to detect the presence of these qualification in new pages. Once the qualification are identified, we used the Latent Dirichlet Allocation (LDA) model to identify groups of skills that are required by employers. One of the major advantages of implementing LDA model is that it is an unsupervised approach and no training is needed. The algorithm was applied to a case study as an illustrative example.

Keywords: Construction Management Skills; Employer Expectation; Text Mining; Topic Model

1. Introduction

The construction industry is one of the nation's largest industries. There is undoubtedly a demand for professionals with skills necessary to successfully manage today's complex construction projects. Without capable workforce, companies will be unable to fulfill their potential growth.

Training is fundamental to develop the necessary skillsets particular to the construction industry. However, training must be demand-led (Fluitman et al.1989) by the market. While formal courses are offered to equip job seekers with derived knowledge and skills, people still need to recognize industries' requirement. To effectively do so, it is advantageous to understand the job market requirements in greater detail (e.g., skills, qualifications and experiences). Moreover, the formal education programs must be constantly enhanced to address the needs of the industry and hence the job seekers. Extensive studies on identifying key competencies for construction graduates have been conducted in the past 30 years. For example, a previous research conducted by Lees (2002) stated that education should enhance employability by focusing on knowledge and understanding, developing skills, self-efficacy beliefs, and strategic thinking and reflection. This study also found that employers view team spirit as more important than numeracy and literacy. Archer and Davidson (2008) identified communication skills, teamwork skills, integrity, intellectual ability and confidence as important employability skills. Farooqui and Ahmed (2009) developed a questionnaire-based survey to identify required key skills from graduating construction management students, both undergraduate and graduate level. Rawlins and Marasini (2011) conducted a survey-based study of skill-gaps on construction management program in UK. Arain (2010) identified a range of necessary expertise for students to practice successfully in the construction industry. Ahn et al. (2012) examined U.S. construction industry perceptions regarding key competencies for construction graduates using a survey of recruiters for over 100 construction companies located in the eastern United States.

Most of the existing efforts to identify the key skill sets in the construction industry have been conducted by interviewing or surveying industry representatives. This approach is usually limited by the number of organizations who are willing to respond and by the variability introduced by the subjective nature of survey and interviews. This research introduces a new approach to address this issue by analyzing online job advertisements. Job advertisements posted by construction companies are usually found in various job search engines (e.g., Indeed.com and Monster.com). The fast growing online job search engines make it feasible to look for job skills information from massive amounts of readily available data. Job search engines provide millions of job openings with daily updates. Also, they provide detailed information on qualifications and special requirements for each job opening. Since the online job search services have become more and more popular, it is important to utilize this digital world material and analyze the advertisements of job openings. In this research, we collected more

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than 20,000 construction related job openings in the past several months and analyzed this large sample to extract the employers' expectations.

This paper is organized as follows. The first section discusses the methodology used to extract job qualification information from online advertisement pages. The second section discusses the results collected. The last section concludes this research and describes the future steps.

2. Methodology

To achieve the research objective, we developed a text mining method. This method consists of three main components:

1. Text preprocessing.
2. Qualification sentence identification.
3. Utilization of the LDA topic model in extracting the sought skill sets.

2.1. Text processing

The first step of the developed method is to prepare job advertisements in bulk. A computer program was developed to search Monster.com and Indeed.com between Oct 2012 and July 2013 for construction related jobs. More than 20,000 job advertisements webpages were downloaded during this time period. The downloaded webpages were preprocessed by removing the HTML tags and special character. This is because most of the job advertisements web pages are written in HTML, which uses open/closed tags to indicate webpage commands, i.e., “<” and “/>”. By removing those HTML tags, the computational burden of the information extraction is reduced. We also used Natural Language Toolkit (NLTK) (Bird et al. 2009) to segment the text into individual sentences. At the end of this step, the downloaded job advertisements were processed into a large pool of sentence set denoted by $S = \{s_1, s_2, \ldots\}$.

2.2. Identify qualification sentences

Once the sentence segmentation was completed, we started to extract sentences that contained job qualification information from S. An online job posting webpage is usually composed of information such as job-title, location, employer name, job description, job qualification, advertisements, etc. For instance, the following ten sentences are taken from an online job post:

1. *“XXX Inc. is comprised of talented professionals like you”.*
2. *“They are intuitive, goal oriented, and think progressively while working in a variety of roles to provide the highest level of client satisfaction”*
3. *“It is this mindset of success, coupled with our opportunities that will help develop and define your career”*
4. *“We need a Construction Estimator“*
5. *“Need to have at least 10 years experience”*
6. *“Willing to work long hard hours”*
7. *“There maybe some weekends”*
8. *“Must be familiar with reconstruction/restoration and some stucco”*
9. *“Have experience with excel, work and outlook”*
10. *“If interested please send us your resume”*

In this example, only the sentences 5-9 contain information about job qualification. Therefore, it is important that the adopted method is able to differentiate sentences that contain job qualification information from those that do not. In this research, we utilized the naive Bayes classification method to help determine if a given sentence contains job qualification information or not. We consider each sentence s to be represented as $n-$ dimensional vector, X, of different feature values.

$$X = (x_1, x_2, \ldots, x_n)$$

where x_i represents the value of the ith feature and n is the number of features. In this research, the following features were used.

1. First word of the sentence
2. Last word of the sentence
3. First two words of the sentence
4. Last two words of the sentence
5. All consecutive pair of words

Following is a simple example to illustrate how the features of a sentence are generated.

"*Must have excellent communication and written skills.*"

For example, the corresponding features for the sentence above are:

1. *"must"*
2. *"skills"*
3. *"must have"*
4. *"written skills"*
5. *"must have", "have excellent", "excellent communication", "communication and", "and written", "written skills"*

The intuition standing behind this is that if a sentence starts with (or ends with, or contains) the words "must have", or "is preferred", or "proficient", it is very likely that this sentence contains job qualification information. With the features defined, the Bayes classifier assigns each sentence to one of two classes S_1 (sentences containing job qualification information) and S_2 (sentences with other contents). A sentence s is classified to the class for which it has the highest posterior probability conditioned on its X. That is, s is classified to class S_i if and only if,

$$p(s \in S_i|X) \geq p\left(s \in S_j|X\right), for\ j \in \{0,1) \ and\ j \neq i$$

According to Bayes Theorem,

$$p(s \in S_i|X) = \frac{p(X|s \in S_i)p(s \in S_i)}{p(X)}$$

Since $p(X)$ is a constant factor which is equal for all classes, only the numerator $p(X|s \in S_i)p(s \in S_i)$ need to be calculated. Both of these two values, $p(X|x \in S_i)$ and $p(s \in S_i)$, can be calculated from the data set. However, it can be very challenging to compute $p(X|s \in S_i)$. If each component x_i of X can have one of r values, there would be r^n combinations to consider for each class. In order to simplify the calculation, the assumption of conditional independence was made. In other words, for each class, the attributes are assumed to be independent. The classifier resulting from this assumption is known as the Naive Bayes classifier. This assumption leads to

$$P(X|s \in S_i) = \prod_{k=1}^{n} p(x_k|s \in S_i)$$

To develop this classifier, we prepared a training set of 1,000 sentences and a testing set of 500 sentences. The training and testing sets were randomly selected from online job advertisements. The classifier had a precision rate of 0.83 and a recall rate of 0.90. Precision is the ratio of the number of sentences which was determined correctly by classifier to the number of sentences which classifiers classified to the S_1 class. Recall rate is the ratio of the number of sentences which was determined correctly by classifier to the number of sentences in S_1.

2.3. Topic model

Once the qualification sentences are extracted, we applied the Latent Dirichlet Allocation (LDA) topic model to identify the skills. This model is a popular method for modeling term frequency occurrences for documents in a given corpus. A topic basically consists of a set of words that co-occur frequently. A document is described as mixture of different topics. In this study, the qualification sentences are treated as the documents and the skills are the topics to be discovered. The LDA model is a probabilistic topic model, which uses a generative probabilistic model for collections of discrete data (Blei et al. 2003). One of the major advantages of implementing LDA model is that it is an unsupervised approach and no training is necessary. In this paper, we implement the LDA model through the Gibbs sampling algorithm (Geman and Geman, 1984).

3. Case Study

In this case study, we applied the above methodology on more than 20,000 construction related job advertisements from online job search engines. Figure 1 shows the percentages of major job positions in the collected data. There are more than 7,000 project manager positions in the dataset. The rest are project engineers, estimators, superintendents and schedulers positions.

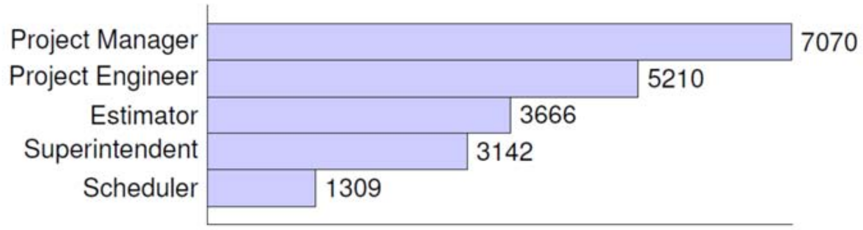

Figure 1. Number of Advertisements by Job Type

As discussed earlier in this paper, one of the advantages of implementing the LDA model is that it's an unsupervised approach and no training is needed. The only input required is the number of topics K. In this study, we set K = 10 such that the top 10 skills are identified for each of the job type in Figure 1. Table 1 - 5 present the results of the LDA model. In addition, the representative examples for each topic are provided under each Table. As shown in Table 1 - 5, the major skills required by all job types are listed as follows.

1. Communication (10th topic in Table 1, 5th topic in Table 2, 4th topic in Table 3, 6th topic in Table 4, 10th topic in Table 5; including words like skill, strong, communication, written, excellent, organizational, good, verbal, interpersonal, et al.). Some examples of job qualification sentences are:
    a. *"Ability to communicate effectively both verbally and in writing."*
    b. *"Great interpersonal and communication skills (both verbal and written), the ability to interface and influence at all levels of an organization."*
    c. *"Good verbal and written communication skills, as well as respect for customers and co-workers are a must."*
2. Degree (1st topic in Table 1, 1st topic in Table 2, 9th topic in Table 3, 1st topic in Table 4, 8th topic in Table 5; including words like construction, degree, engineering, management, preferred, related, bachelor, field, equivalent, civil, et al.). Examples are:
    a. "*Bachelor's degree in Construction Management or Engineering"*
    b. *"Bachelors or higher degree in an engineering or construction related discipline"*
    c. *"Four-year college degree in Engineering, Construction Science or related field or equivalent combinations technical training and or experience."*
3. Team work (4th topic in Table 1, 5th topic in Table 2, 6th topic in Table 3, 5th topic in Table 4, 5th topic in Table 5; including words like ability, effectively, team, client, manage, multiple, customer, communicate, level, service, et. al.). Examples are:
    a. *"Strong management, leadership and teamwork skills."*
    b. *"Must be pro-active, adaptable and able to motivate team members."*
    c. *"Must be able to work as part of a team."*
4. Microsoft office software (2nd topic in Table 1, 8th topic in Table 2, 3rd topic in Table 3, 7th topic in Table 4, 3rd topic in Table 5; including words like computer, microsoft, word, project, office, excel, software, proficient, working, use, et. al.). Examples are:
    a. *"Personal computer knowledge, including Microsoft Word and Excel."*
    b. *"Proficient in Microsoft Excel & Word."*
    c. *"Proficiency with all MS Office products (Word, Excel, PowerPoint, etc."*

There are also skills that are particularly demanded by a certain job type. For example, the ability to use Primavera and the knowledge of Critical Path are identified as schedulers' skills in the 7th and 2nd topics of Table 2. Examples related to those topics include:

- *"Experience with Primavera is required"*
- *"Intermediate level knowledge of Microsoft Office and P6 Primavera Scheduling Program"*
- *"minimum of 5 years direct experience in applying scheduling principles to construction projects using the Primavera suite of software"*
- *"Able to run and analyze the schedule Critical Path"*
- *"5-10 years proficient knowledge in Primavera and Critical Path Methodology."*
- *"Five years experience with all aspects of Critical Path Method scheduling and its application, etc."*

For project engineer jobs, the professional engineers (pe) license requirement is identified in the 9th topic in Table 4.

Examples of job advertisements are:

- *"A bachelor's degree in Engineering is required and Professional Engineering License in good standing with at least one state is preferred."*
- *"Professional Engineering (PE) license and/or PMP certification (preferred)"*
- *"An advanced Degree in Engineering, Engineering Management or MBA and a Professional Engineer license (PE) is preferred.*"

The ability to read specification and drawings is required by the cost estimator position (6th topic in Table 1). Examples are:

- *"Working knowledge of drawing systems and ability to coordinate specifications and drawings"*
- *"Experience in CAD and/or other digital drawing tools helpful"*
- *"Problem solving issues and questions related to drawing and specifications"*

For project manager, the ability to understand contract is also identified in the 2nd topic of Table 5. Examples are:

- *"Assists in conducting fee negotiations, preparing contract agreements and is sufficiently familiar with all agreements between the firm and the client to effectively manage the project in a professional and economic manner"*
- *"Knowledge of contract services and contract terms and conditions"*
- *"Ability to assess contract compliance and product/service quality"*

Table 1. Cost Estimator

Topic number	Topic words
1	construction, degree, engineering, management, preferred, related, bachelor, field, equivalent, civil
2	software, excel, microsoft, knowledge, word, office, computer, proficient, working, estimating
3	building, customer, service, client, both, new, relationship, professional, maintain, working
4	ability, work, environment, team, effectively, well, deadline, multiple, communicate, time
5	able, job, perform, travel, individual, essential, should, willing, site, various
6	specification, plan, ability, read, drawing, interpret, project, requirement, document, understand
7	experience, estimating, construction, project, 5, minimum, industry, estimator, candidate, commercial
8	cost, project, estimate, knowledge, bid, system, control, estimating, design, process
9	problem, solving, company, complex, concrete, situation, development, deal, proven, provide
10	skill, strong, communication, written, excellent, organizational, good, verbal, interpersonal, computer

Table 2. Scheduler

Topic number	Topic words
1	experience, construction, project, degree, engineering, scheduling, management, related, bachelor, 5
2	schedule, able, analysis, cost, critical, environment, resource, path, impact, program
3	work, environment, able, multiple, scheduler, manager, position, yr, should, read
4	ability, deadline, demonstrated, multiple, others, drawing, environment, fast-paced, job, obtain
5	skill, communication, strong, written, team, excellent, demonstrated, verbal, client, effectively
6	financial, process, provides, area, development, well, risk, reporting, business, requirement
7	primavera, knowledge, p6, working, software, scheduling, p3, using, preferred, candidate
8	microsoft, excel, proficient, office, word, computer, proficiency, application, powerpoint, suite
9	work, production, good, able, rsquo, environment, safety, job, vessel, plant
10	demonstrated, ability, travel, complex, function, environment, contractor, maintain, condition, solution

Table 3. Superintendent

Topic number	Topic words
1	project, plan, specification, construction, site, schedule, safety, job, work, quality
2	ability, able, read, travel, willing, interpret, understand, perform, job, report
3	computer, microsoft, word, project, office, excel, software, proficient, working, use
4	skill, strong, communication, written, organizational, excellent, leadership, good, interpersonal, verbal
5	ability, able, area, license, work, up, driver, position, certification, valid
6	work, environment, ability, team, multiple, manage, company, deadline, proven, task
7	ability, effectively, problem, customer, communicate, subcontractor, employee, maintain, solving, client
8	knowledge, construction, working, control, equipment, maintenance, building, system, cost, electrical
9	degree, preferred, management, construction, field, related, engineering, experience, bachelor, college
10	experience, construction, project, 5, minimum, superintendent, 10, candidate, commercial, supervisory

Table 4. Project Engineer

Topic number	Topic words
1	engineering, degree, bachelor, related, mechanical, civil, field, b, construction, electrical
2	design, experience, system, process, equipment, knowledge, operation, power, building, control
3	ability, work, able, environment, travel, multiple, manage, time, independently, task
4	project, construction, specification, cost, technical, plan, requirement, drawing, schedule, support
5	ability, team, effectively, client, level, customer, communicate, well, service, position
6	skill, strong, communication, written, excellent, good, problem, verbal, organizational, interpersonal
7	knowledge, working, office, word, microsoft, software, excel, computer, proficient, autocad
8	experience, project, management, construction, minimum, 5, industry, 10, manufacturing, 3
9	preferred, engineer, candidate, professional, within, license, e, environmental, pe, state
10	environment, business, safety, job, perform, area, demonstrated, able, position, apply

Table 5. Project Manager

Topic number	Topic words
1	experience, project, construction, management, minimum, 5, manager, 10, commercial, managing
2	project, specification, plan, schedule, cost, contract, demonstrated, planning, management, development
3	microsoft, office, excel, word, software, computer, knowledge, proficient, project, program
4	knowledge, design, working, construction, system, building, process, facility, safety, operation
5	ability, effectively, team, client, manage, multiple, customer, communicate, level, service
6	experience, preferred, candidate, professional, engineer, industry, certification, successful, should, within
7	work, environment, able, ability, travel, perform, job, time, position, individual
8	degree, engineering, bachelor, construction, management, related, field, civil, b, equivalent
9	ability, problem, technical, business, read, complex, solving, issue, interpret, understand
10	skill, strong, communication, written, excellent, good, organizational, verbal, interpersonal, oral

4. Conclusion

In developing career pathways in construction industry, it will be important to give students skill sets which can be useful in their future career. In addition to the existing curriculum, it is also important to look at adding more industry needed skills. This research aims to provide insights into the skill sets through text mining the online information sources. In the case study, the proposed methodology is able to effectively extract skill sets from online job advertisements. The same methodology can be applied to job positions in other industries.

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Continuous valuation model for work-in-progress investments with fuzzy logic method

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Abstract

Currently, banks and other financing institutions ask for detailed project documentation in order to finance major building projects. Among other requirements, continuous valuation reports are to be provided by investors under the term of building works to prove current Market Value of the project. There is no scientific model for work-in-progress valuation, so appraisers are forced to use subjective judgements. A credible and objective valuation method should help to minimise banking risk and, as a result, to increase lending activities. In the scientific literature, the fuzzy logic concept has been suggested to utilise for valuation purposes, but until now, it has not been not investigated for work-in-progress situations. Under the term of building, non-defined ("fuzzy") variables are usable and appropriate to predict the future. In this article, the author will describe and present a valuation model, which - in conjunction with automated project management tool - gives the best estimation of the actual Market Value of the project. The proposed model is based on Discounted Cash Flow (DCF) analysis. The article will also cover a case study to demonstrate the strengths of the model.

Keywords: fuzzy logic, Market Value, property, automated valuation model (AVM), work-in-progress, EVA.

1. Introduction, the reasons of research

Nowadays, after the great collapse of real estate market, financial institutions and other organisations dealing with real estate finance (including the providers of certain community sources) demand the submission of excessively detailed project documentations. The documentation has to contain the market appraisal being monthly or quarterly updated during the construction works. There are no standard, scientifically established models for the statements of Market Value[1] of on-going projects; experts, while recording technical parameters, are enforced to evolve the Market Value by their own personal opinions. The technical literature of project management does not discuss the Market Value, however deals with the changes and monitoring of built-in technical contents. The lattest method nevertheless does not follow the changes of the real estate market and the actual Market Value of the on-going development. The introduction of fuzzy logic into the practice of valuation still provides the possibility of keeping the subjective (soft) elements of the experts' opinions however provides a well-organised calculation model for the hard facts being taken into account.

2. Valuation models and methods at a work-in-progress investment

The banking practice of great-volume commercial real estate projects before the crisis did not consider essential the market valuation of the development period. Investors considered it enough, in case the main indices, f.e. occupancy rate, and completion level, quality, followed the regulations of the loan agreements (Nádasdy et al, 2011).

The EVA-method (Earned Value Analysis) is a common and well-known project management tool, suitable to measure the financial and temporal performance of the project. Many technical articles discuss the suitability and enlargement of this method. A comprehensive analysis is published by Anbari (Anbari, 2003) for instance. The EVA approach investigates the project focusing only on financial and technical progression during the construction works, its assessment bases are the planned budget and the scheduled time. In this examination, the market evaluation of the project and the changes of market data and according to these, the changes of everyday Market Value are not enlisted; we would say that the examinations of EVA are suitable for the control of the suitability of the static, technical criteria. At the same time, the indices generated by the EVA are input information for the market valuation process. It is interesting that at the time of development of EVA

[1] In present study I use the Market Value according to the definition of RICS as follows: „Market Value is the estimated amount for which an asset or liability should exchange on the valuation date between a willing buyer and a willing seller in an arm's length transaction, after proper marketing and where the parties had each acted knowledgeably, prudently and without compulsion"

methodology, the utilisation of fuzzy language had been risen using soft descriptive variables instead of the usual discrete quantitative quantities (Noori et al, 2008).

3. Valuation based on fuzzy logic

The fuzzy logic was established in 1965 by Zadeh, when he described the so-called fuzzy set theory and defined the different operations (Zadeh, 1965). Many used his works in the past fifty years, and by today, fuzzy logic has become a general practical application in control system (Kovács, 1993). The basic idea is that one certain element might belong to an set at different levels; this theory maps the vague nature of human thinking and the grammatical means of expression (Byrne, 1995). Different authors have examined the possibility of appliance of fuzzy logic in real estate appraisal. (F.e. Yalpir, 2011; Glumac, 2011, French, 2010, Zurada et al, 2006, Bagnoli, 1998 etc). All articles are common in that the authors consider the fuzzy method, the "soft" descriptions much more appropriate to real estate market forecasts, than valuations given by concrete data or ranges. For example for estimation of apartments' prices in Turkey, Yalpir introduces a simple correlation that describes the market better than the usual hedonistic model (Yalpir, 2011). The method of fuzzy logic also suitable to provide information about the risks of the market for investors, as also in this case, it is to model the common effects of vague forecasts. (Hui et al, 2009). Authors have found the fuzzy logic also in the valuation process, and developed a method to measure the environmental output of the contractors for example (Yao et al 2007). Lee and his co-authors have worked out a complete mathematical real estate appraisal model, where the ranking of the variations were considered as experts' exercises.

Everyday professional practice as well as the different international methods in real estate appraisal (RICS, TEGOVA, IVS) prescribe to define and authenticate an exact amount as Market Value. Following the crisis in real estate industry, the professional dispute has started how to comment on the possibilities of surety and domain along the provided discrete value. While a value-range or a triplet of an optimistic/realistic/pessimistic value might provide more information for the users about the uncertainty of expected values, it is also possible that users misunderstand and use in a wrong way. French in his article suggested to interpret the appraised values in a graph of density function to visualise the punctuality of valuations. (French, 2011). Theoretically, certain valuation variables might be regarded as random variables to set up an evaluation model; however, its closed mathematical solution can only be accomplished following making significant simplifications (Hajnal, 1994). The uncertainty of variables usually replicated with different simulation models (the Monte Carlo method, for example), while such solutions calculate with discrete values and assigned probabilities. It is important to note that the operations with the random variables (f.e. the Monte Carlo analysis) are formally similar to the fuzzy approach however its contents are purely different, as it utilises the inner rules of a non-linear world to establish the final conclusions (Bagnoli, 1998). In recent years, the methods of real estate appraisal have been fortunately growing (Pagourtzi, 2003; Kauko, 2009). Many "non-traditional" valuation methods have appeared in scientific publications, out of some are already introduced in everyday practice. The "non-traditional" methods are the different regressive, hedonic models, the artificial neurotic nets, the process of requesting experts' opinions as well as fuzzy logic. In many of his studies, Kauko examines the fuzzy logic – based mathematics applicable at mass-like valuations. (f.e. Kauko 2003). He explicates by a detailed mathematical justification, that fuzzy logic, in highly uncertain valuation cases and markets, gives a better appraisal than either traditional valuation methods or the hedonic valuation model utilising the multi-regressive theory (Kauko, 2009). Van Kooten suggests the appraisal based on the fuzzy logic on the estimation of defining value of natural resources invaluable with comparative methods (van Kooten, 2000). This proposal might be normative in our studied case as on-going investments are usually not subjects of transactions, therefore cannot be evaluated by comparisons.

4. Advantages of fuzzy approach, specialities of the problem from the point of view of the appraisal

The all-time Market Value of the real estate is excessively interesting information both in the point of view of the bankers and the investors; presently used techniques however do not provide solutions for the estimation of Market Value while the construction works are in progress. Its' reason is that investment activity had been extremely high before the real estate crisis, and preliminary expectations usually achieved or even exceeded the forecasted market value of the completed project. Along with the entry of the new market paradigma, it has been clear that the value of real estate can also increase or decrease either in short and long term. At the same time, investors have been heavily controlled by creditors' control, since the financiers wish to decrease the number of bad or falling projects. Because of all these, the appraisals have faced the requirements of the demand to provide well-based Market Value estimations also during the construction phases of projects.

In the period of the construction works, the uncertainty of the appraisal is the highest (vide Figure No. 1). Therefore, there are no similar buildings in transactions to those ones that are under construction, within this period, it is not possible to apply the comparison-based method. In case of commercial real estates, the cost-based approach is not convenient for investment and loan providing purposes either, hence only the yield-based approach and its model, the DCF (Discounted Cash Flow) can be contemplated. The general formula of the DCF model is as follows:

$$V = \sum_{t=0}^{n} F_t \frac{1}{(1+i)^t}, \ where \qquad (1)$$

n: number of investigated periods,
i: applicable market yield, and
F_t : net revenue realised in 't' period.

However, as the uncertainty in the period of construction is very high concerning the variables of the cash flow while forecasts are plastic, they are "soft".

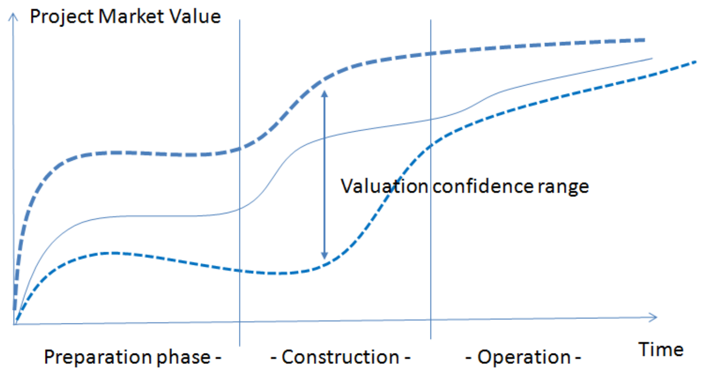

Figure 1. Change of valuation confidence range in time

5. General description of the suggested model

The model suggested by the author integrates the advantages of DCF method and fuzzy approach and makes it possible in the different phases of construction for the appraiser by the consistent process to put up estimations to the actual Market Value of the project. First thing is to examine what type of information are available about a project under construction, secondly, that these information have impacts to which DCF appraisal variables. The financing partner usually receives information from four sources relating to the projects. These are the *technical area* (by the technical supervisor appointed by the financier), the *sales area*, the *legal area* and finally the bunch of *general market information*. Some of these information are quantified such as the expected costs of additional work at the technical field. Some are verbal 'fuzzy' information such as the setting of the real estate investment market. The following Table No. 1. shows the specific data of an institutional real estate development that are influencing the Market Value.

Table 1. Main data influencing Market Value during the construction process

Technical information	S&C budget
	Additional Budget
	Fit-out Budget
	Shell&Core completion
	Fit-out completion
	On-going disputes
Letting information	Vacancy

	Average rent
	Average rental term
	Tenant hand-over
	On-going leasing activity
Legal information	Permitting
	Occupational permit
	Letting
	Investment
Market information	Market trends
	Market vacancy rate
	Market absorption rate
	Yield
	Cost of Capital

During the construction works, the DCF model in some of its elements (for example in conditions of finance) is already fixed, some elements are however influenced by the information above. The involved variables of the DCF model are: Hand-Over Date; Total Budget; Rental Income; Rental Term; Vacancy; Absorption; Interest Rate and Exit Rate. The 'Vacancy' for example can be equally modified by the rental negotiations, the tenancy legal and market circumstances. The point of the suggested model is, that the information arrived at a certain time – following their 'fuzzyfication' – is converted into DCF variables according to a planned logical scheme by utilising fuzzy rules and prepare the DCF analysis with these. Simplier and more difficult computer solutions are available for the operations on fuzzy sets, for example an easy internet application[1]. The process of the fuzzy model calculating the variables is shown on the following picture (Figure No. 2).

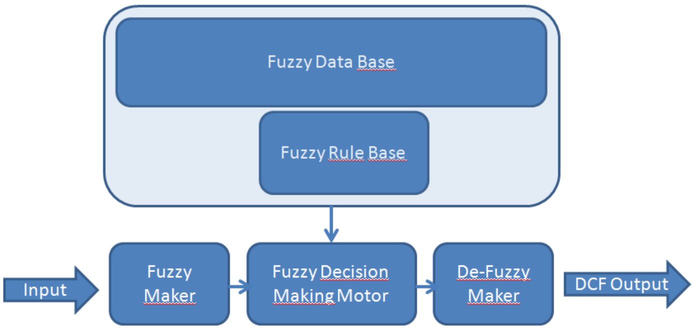

Figure 2. Process of the set of variables

6. Case study by applying the model

The aim of our case study is to introduce the effectiveness of the method. The subject of the case study is an office building for lease being constructed in the years of the market depreciation, meaning within a continuously changing market relations. Regarding that the building had been constructed by re-building and expansion of an earlier monument of a school building, the implementations required complex technical works. All the real estate appraisals are available for us prepared by the appointed appraisers, moreover, we are in the possession of the monthly reports indicating the actual prospects of the certain fields verbally. By analyzing the reports it has become possible, the (post-factum) preparation of the systematic, fuzzy logic based valuations and their comparison with the official appraisals. In our case study, we have examined the two key variables of the project, namely the date of occupancy permit and the exit rate, and we have created the above system of rules for these latters. With regard to the generally unfavourable market expectations of the years 2008 and 2009, the input variables could apply the following fuzzy values:

[1] http://cld.mst.uni-hannover.de/cldtools/faces/fuzzyCalc.jsp

Considering the handover date	Finishing date of Shell&Core	As planned	Small time-lag	Great time-lag
	Finishing date of tenants' fit out	As planned	Small time-lag	Great time-lag
	Disputes	nil	Manageable	Significant
	Starting date of Tenancy	As planned	Small time-lag	Great time-lag
	Issuance of Building permission	As planned	Small time-lag	Great time-lag
	Issuance of permission	As planned	Small time-lag	Great time-lag
Considering the EXIT rate	Legal circumstances - EXIT	Stagnant	Bad	Very bad
	Change of market	Stagnant	Weak	Very weak

The possible values of the two examined output fuzzy variables:

Issuance of permission	As planned	Small time-lag	Great time-lag
EXIT rate	As expected	Unfavourable	Highly unfavourable

The system of fuzzy rules have been set up between the input and output variables. The system rules have altogether 729+9 rules. We introduce sample rules each for the two output variables as follows:

- *IF the ' Shell&Core finishing date' are As Planned and the 'Finishing date of tenants' building out' is in Small time-lag and the 'Disputes' are Manageable and the 'Starting date of Tenancy' is in a Small time-lag and the 'Issuance of Building permission' is As planned THEN the 'Issuance of permission' is in a Small time-lag.*
- *IF the 'Legal circumstances considering EXIT sales' is Bad and the 'Change of Market' is Weak THEN the 'EXIT Rate' is Highly unfavourable.*

In the interest of 'defuzzification' of calculation results as fuzzy variables, we created customized rules based on our practical experiences. With these variables, we used the DCF model for the certain valuation periods. We compared the original Market Values with the re-valued results with fuzzy method on Figure No. 3.

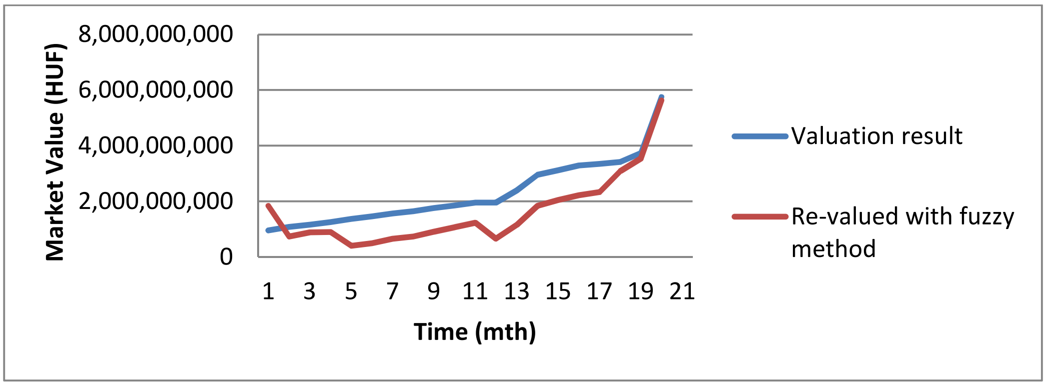

Figure 3. Comparison of Market Values

7. Summary and conclusion

The study case presents well how to make the estimation of Market Value more reliable by systematic construction of variables. The fuzzy language is a great assistance in this procedure as many of the variables are non-quantitative while other variables, even if they are given numerically, these discrete numbers still contain significant uncertainty. Preparing such a fuzzy knowledge base and a decision-making motor for general cases might be the subject of further research works. The model described above could be linked to an automatic project management toolbar or platform that might have further possibilities to define everyday value of the project automatically and reliably for the financiers.

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Tacit knowledge contained in construction enterprise documents

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Abstract

This paper deals with knowledge management in a construction enterprise. Proper knowledge resources are needed to perform tasks specific to construction enterprises. The knowledge is acquired from publications, legal regulations and standards. This is the so-called explicit knowledge. Large knowledge resources are also contained in employees' minds and derive from their personal experience as well as from databases and documents drawn up for the needs of construction projects. This is the so-called tacit knowledge. Its acquisition can significantly aid construction enterprise management processes.

An IT model of the Knowledge Map designated to small and medium sized construction companies has been developed. The model can be used to save, store and process acquired knowledge and then to exploit it in enterprise management processes. The model has been implemented in two enterprises carrying out design and construction work. Seven knowledge domains important for the proper management of a construction company have been distinguished in the proposed Knowledge Map. One of them is the Documents domain. It stores sample documents appearing at the different stages of construction project implementation and documents occurring at enterprise management level. The samples are used to create new documents. The documents created in the course of enterprise activity form an information base which can be analysed to draw conclusions aiding future management processes.

This paper focuses on tacit knowledge resources contained in documents drawn up for the needs of construction projects. The tacit knowledge areas in the documents, connected with the resources used and the processes carried out, are indicated. Considering the huge number of documents occurring in a construction enterprise, it was deemed necessary to classify them according to different areas of enterprise activity. On the basis of the frequency of use of the particular samples to create documents needed for carrying out a construction project, the more important and less important documents were identified. The analyses also showed that the quality of the documents has a bearing on such project process parameters such as implementation time and cost.

Keywords: construction business, Knowledge Map, knowledge management, documents, tacit knowledge.

1. Introduction

Knowledge is one of the most important resources of an enterprise. Skillful knowledge management can bring significant benefits including labour productivity growth, an increase of quality of provided services and also a strengthening of the competitive position of an enterprise. Knowledge resources of an enterprise can be divided into: explicit knowledge which is possessed from publications, law regulations and standards and also tacit knowledge which is not written anywhere, is kept in the minds of employees and results from their personal experience. Tacit knowledge is also contained in databases and documents prepared for ongoing construction projects and for the correct functioning of an enterprise. Acquisition of such a type of knowledge resource can greatly support management processes in a construction company [Hernád , JMC , & Gaya , CG 2013 Nagati , H., & Rebolledo , C. 2013 , Pathirage , Ch. , P. , Amaratunga , D. , G. , & Haigh , R. , P. : 2007].

The paper presents the computer model of the Knowledge Map which supports the management in a construction enterprise. The model was developed based on the results of tests and analysis carried out in small and medium-sized construction enterprises in Poland. The proposed model uses the process approach for management and includes processes carried out at enterprise level and in the widely considered investment process in the construction industry and also the documents associated with these processes. Due to this assumption the proposed Knowledge Map has universal character and it is possible for it to be applied in construction enterprises conducting both design and executive activity. This model was implemented in construction enterprises.

The article also contains conclusions formulated during the practical use of the Knowledge Map, which are associated with the formation of documents for the purposes of carried out processes.

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2. Methodology of research

The methodology of research conducted with regards to the formulation of the model consist of three stages. The objective of stage 1 was to obtain information which would allow assumptions to be made regarding the formulated computer tool. Research was conducted in two phases.

On the basis of preliminary studies which were carried out in several construction enterprises with the use of the direct interview method, a research questionnaire was formulated which included questions about four areas related to enterprise activity, such as: 1) general data e.g.: location, number of employees; 2) the scope of conducted activity; 3) computer programs used; 4) processes implemented in all spheres of enterprise activity.

On the basis of current laws and regulations and also requirements included in management standards of ISO 9000 series, a set of processes was defined. The task for respondents was to mark processes occurring in an enterprise and to add such processes which were not included in the questionnaire but still happen in an enterprise.

On the basis of the above conclusions, the following assumptions regarding the formulated model were made:

- The process approach to management will be considered in the model, which means that all the typical processes occurring in the construction industry will be included in it.
- The model will be applicable in mainly small and medium-sized enterprises for which there is a lack of simple tools which support management.
- The adopted solution will be flexible and will enable rapid adaptation to the different cases of carried out business activity.

In the second phase, audits in 20 selected companies from the sector of small and medium-sized construction enterprises were carried out. Research was conducted by authorised experts in the area of implementation of quality management systems according to ISO 9000. The purpose of audits was the identification of the organisational state of construction enterprises and detailed analysis of used management processes due to the requirements of ISO 9000 standards.

The purpose of the second stage was to develop a model of the Knowledge Map [Lin et al. 2006, Suyeon et al. 2003, Yang 2007,] based on information obtained from the research and audits. Knowledge areas about a construction enterprise related to process management were identified.

The Knowledge Map was implemented in two construction enterprises, namely, in executive enterprise A and project enterprise B.

3. Knowledge Map structure

Knowledge Map software is based on the combination of the knowledge management idea and the process approach to management. The Knowledge Map structure consists of seven main domains of knowledge relating to an enterprise, referred to as: *System and environment*, *Assets and resources*, *Processes*, *Documents*, *Completed and ongoing projects*, *Analysis and correction* and *Lessons learned*. Each of the domains have been divided into three knowledge components [Hoła B., Polak A., Sawicki M., Gawron K., Morka M., & Skibniewski M. : 2012a]. The structure of the Knowledge Map and the development of the field Processes and Documents is presented in Figure 1. [Hoła B., Polak A., Sawicki M., Gawron K., Morka M., & Skibniewski M. : 2012b].

The first domain of knowledge, defined as System and Surroundings, is used to identify a construction company and its business environment. This domain contains knowledge about the field of business activity, the organizational structure of the company, government departments and organizations with whom cooperation is either required by applicable laws and regulations or by the nature of business or technology employed.

The second domain of knowledge contains information about assets and resources at the disposal of a construction company. This domain is used to identify the tangible and intangible resources of the company. The tangible resources include personnel, owned equipment and tools, as well as real estate. The intangible resources include intellectual property such as trade secrets, patents, trademarks and copyrights.

The domain processes consist of the applicable processes identified from the completed surveys of the construction companies. This set of processes is divided into three subsets, i.e. main processes, supporting processes and management processes. The elaboration of individual process procedures follows the requirements of the PN-EN ISO 9001:2008 “Quality Management Systems – Requirements” standard.

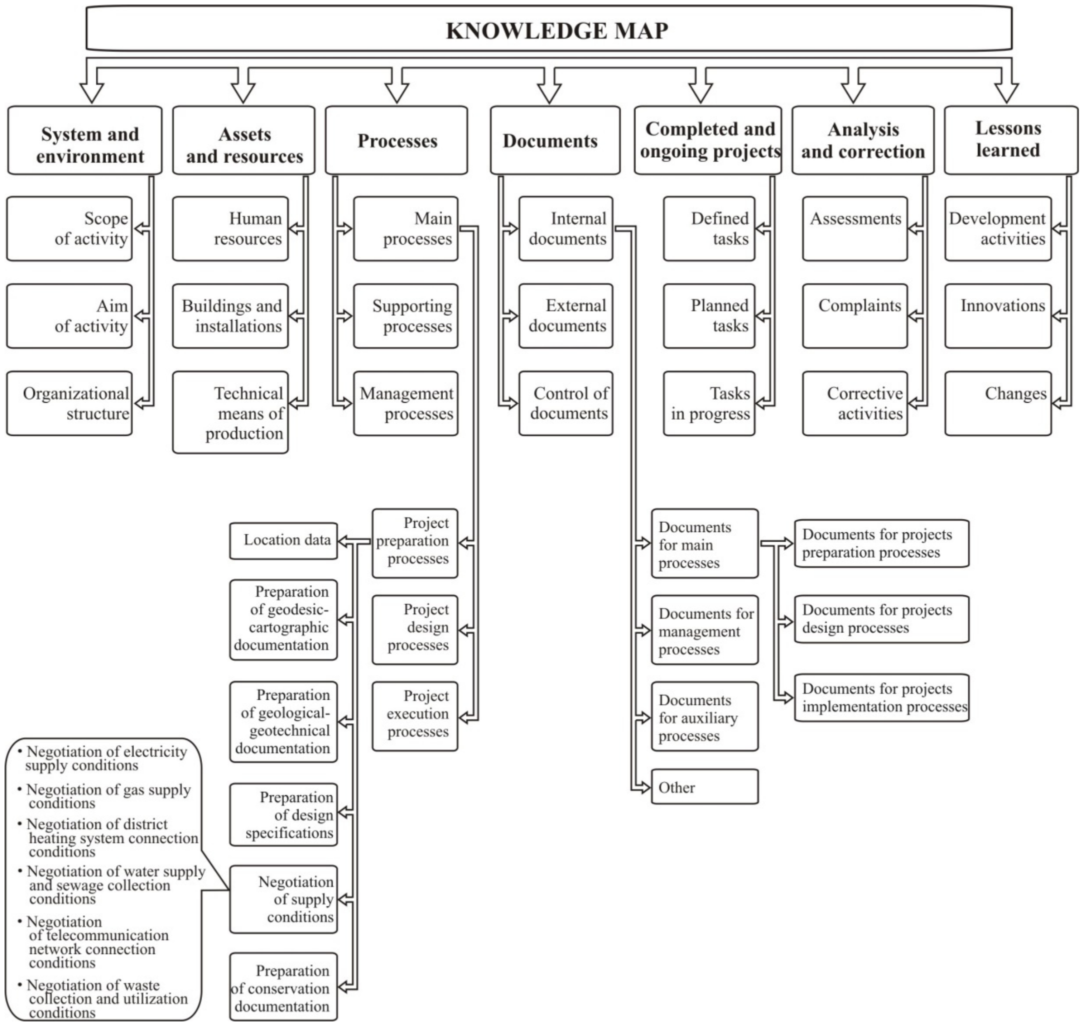

Figure 1. Scheme of Knowledge Map structure with the development of selected items.

The "Documents" domain of knowledge was divided into three subsets. The first is formed by the internal documents created within a construction company. The second subset contains external documents required by laws and regulations such as: legal acts and decrees, design codes and applicable standards. The third subset, "Control of documents," specifies the people responsible for creating, supervising and approving the documents, as well as storage of the documents.

The "Completed and Ongoing Projects" domain of knowledge features a dynamic character of the Knowledge Map. In this domain the user will find information about the completed projects or ongoing site work, or about projects still in the planning or design phases. Using the questions contained in the "Defined Tasks" subset, the user can group the processes for each construction project of interest.

The following components are included in the "Analyses and Corrections" domain of knowledge: assessment of processes, staff and suppliers as well as complaints from internal and external customers together with corrective actions taken. The element labeled "Assessments" includes the methodology of assessments of the completed processes, as well as of the project personnel and suppliers. Information concerning lodged complaints, which forms the basis for revisions in service quality and business management, is very important for the proper functioning of a construction company in a competitive market.

The last but equally important domain of knowledge detailed in a knowledge map concerns "lessons learned." The Lessons Learned domain records business process improvements resulting from the completion of a construction project, individual and collective experience, implementation of employees' ideas, applications of product or process improvements, and other innovations and changes resulting from them. On the basis of information available it is possible to formulate conclusions and predictions. As long as information has a descriptive and historical character, knowledge concerns future events. It can be concluded that identification and recording of the Lessons Learned contents (innovations and changes) is a condition for the existence of a knowledge management system. This condition can be satisfied by the proposed Knowledge Map.

4. Identification of tacit knowledge contained in documents

The Documents domain contains specimen documents connected with the processes identified in the construction enterprises. The base of specimens and templates was created after the analysis of over 660 documents collected in the course of audits conducted in construction enterprises. Ultimately, the database contains 250 documents with a unified nomenclature. Since the list of documents is not closed, new documents can be added as new processes are introduced in the enterprise.

A preliminary analysis of the documents has shown that they contain a lot of information which can be exploited in the management of construction enterprises. Information concerning construction processes, as well as management and auxiliary processes, can be acquired from the documents.

4.1. Recurrence of a document in enterprise activity

The analysis has shown that documents produced for the needs of enterprise activity are characterized by different recurrence. Therefore, especially in the case of highly recurrent documents, an efficient system of producing and recording documents and processing the information contained in them plays a vital role. The number of visits to the page containing a given document can be adopted as the criterion of document importance. The importance of the information recorded in documents and its use to produce other enterprise documents should be the basis for developing a model set of information essential for enterprise activity.

4.2. Time needed to produce a document

A factor which has a bearing on enterprise management efficiency is the time of execution of particular operations. Well prepared specimens and templates facilitate the creation of recurrent documents and reduce the time of their production. Due to the use of templates, documents will be produced automatically, decision taking connected with the creation of a document will be minimal and the number of errors will decrease. As a result, the time of producing a document, especially when newly employed persons are assigned this task, will shorten.

4.3.Time of document circulation in the investment process

On the basis of the recorded document production times and the administrative deadlines specified in the Code of Administrative Procedure for official documents, this part of the project realization cycle time can be determined, which is connected with the creation and circulation of documents between the entities involved in this process. Owing to this knowledge, the whole investment process and the processes situated on the critical path can be monitored, corrective measures can be taken in emergency situations and the next projects can be properly planned using the experience gained. On the basis of the acquired knowledge the project realization cycle time can be verified and referred to the relevant project owner requirements. This procedure, supported with proper documents, makes the company which offers its services more credible. Thanks to the acquired knowledge, and supported with long-standing experience, model cycles for preparing different kinds of projects in different model realization conditions can be developed.

4.4. Knowledge in documents connected with processes

An analysis of the documents occurring in resource management processes has been carried out. As regards human resources, the Knowledge Map model contains documents connected with the particular employees, required by the Labour Code and other laws, informing about: his/her employment, course of employment and dismissal or resignation. On the basis of the collected documents conclusions can be drawn concerning the professional development of a given employee, and taking into account the information contained in the records of the particular processes, the range of his/her work activities and the time of effective work during a working shift can also be ascertained.

From analysis of the documents connected with all employed personnel, the following conclusions of statistical nature can be drawn: the age bracket of employees; their average age; the minimum, maximum and average length of their service; the causes of their resignations or dismissals from work; the professional profile of employees; the tendencies in their professional development; the number of employees per full-time job; the number of persons injured in accidents at work; the number of persons working in occupational hazard conditions and trends in work safety .

As regards physical means, the Knowledge Map contains the following documents: the bill of sale, the operation and maintenance manuals, the user's manuals, the results of technical tests and information on the current condition of a resource. From the documents, the specifications of the equipment park and the technical condition of the equipment can be ascertained. Combining this information with the data contained in the *Completed and Ongoing Projects* domain, the current location of a piece of equipment and its operating costs can be determined, and when the construction season is over, the resources can be evaluated with regards to the degree of their utilization, their cost-effectiveness and also their sale or replacement with new equipment.

The knowledge concerning owned resources is also an important resource exploited in the preparation of new projects. An assessment of the enterprise resources for the needs of a new order enables proper decisions to be made on adding the missing equipment to the equipment park and getting rid of unnecessary or ineffective equipment, which will globally contribute to a reduction in the company's operating costs and will improve its profitability.

5. Knowledge in documents created in Knowledge Map software

The aim of building the Knowledge Map model was to obtain a tool which aids the management processes in an enterprise. Using the Knowledge Map, software documents describing the dynamic states of an enterprise's particular components and systems can be created, on the basis of which long-term histories of the changes can be produced. The documents describing the particular states of an enterprise's components include: reports containing evaluations of processes, employees, suppliers and subcontractors; lists of documents; resources and also completed or ongoing processes etc. On the basis of these records, long-term histories of changes can be produced, development trends in a given area of enterprise activity can be analysed and conclusions concerning preventive and corrective measures can be made.

6. Conclusions

An efficient document management system is an essential component of the construction enterprise management system [Meziane, F.; & Rezgui, Y. 2004]. Documents created for the needs of enterprise activity contain knowledge which can be exploited in management processes to increase a company's productivity and competitiveness on the construction market [Hamzah A-R., Chen W., & Shamini B., M 2012, Hernad, J.M.C. , &Gaya, C.G : 2013]. The following conclusions emerge from the studies and analyses of the documents contained in the Knowledge Map model, carried out as the model was being implemented in a construction enterprise:

- In order to improve a company's management system and achieve better economic performance it is essential to properly collect, record and process the possessed information [El-Diraby, T. E., &Zhang, J., 2006, Lin, Y. C., Wang, L. C. & Tserng, H. P., 2006, Meziane, F.; & Rezgui, Y. 2004]. The acquired data can be helpful in the creation of similar documents for future projects, which can contribute to a significant reduction in the time needed to prepare them and in the costs involved.
- A specially developed codification system needs to be used to describe particular documents in order to filter the search of the existing set according to defined criteria [Karanikolas, N.N. , & Skourlas, C. 2010].
- The documents created for the needs of enterprise activity are characterized by different recurrence. In order to determine the degree of utilization of the documents in an enterprise a counter of document hits and editing time should be installed in the IT-based Knowledge Map model whereby a bank of statistical information on the rank of the particular documents can be created.
- The analyses have also shown that the quality of the produced documents has a bearing on such investment process parameters as implementation time and cost. In order to create reproducible documents editing-facilitating templates should be used. Owing to this, the operations will be performed automatically and the number of decisions relating to the creation of a document will be minimal. As a result, there will be fewer errors and the execution time will be shorter, especially when newly employed persons perform these operations [Nam, S., Lee, S., Boram Kim, J.G., Kim, & H.-G. STEP: 2014].
- By introducing document production time recorders it will become possible to create a base of standards. The acquired knowledge supported with long-standing experience and the current regulations contained in the Building Code and the Code of Administrative Procedure will provide the basis for developing model project preparation cycles for different model realization situations.
- Thanks to the document-related information contained in the process procedures a set of documents required for a new project will be able to be quickly determined. This will facilitate and accelerate the preparation of the documentation.
- From the accumulated knowledge on the completed projects the following can be ascertained: the actual time it takes to obtain particular administrative decisions, the most common errors in the preparation of

documentation, and also the persons preparing, verifying and issuing particular decisions. This knowledge can be helpful in preparing offers for future projects.

- As regards to an enterprise's human resources, from the collected documents conclusions can be drawn about the professional development of a given employee and taking into account the information contained in the records of the particular processes, the range of his/her work activities and the time of effective work during a working shift can be ascertained.
- On the basis of the records, long-term histories of the changes taking place in an enterprise can be produced, development trends in a given area of enterprise activity can be analysed and conclusions which have a bearing on decisions can be drawn.

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Identification of sources causing low effectiveness of traffic structures

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Abstract

The paper describes sources that usually causing a low effectiveness of the process of preliminaries, briefing, construction and operation of public traffic structures in the EU countries. The first concern is the number of claims and the approach to settling disputes. Also of concern is the inconsistent project supervision by the public owner. The paper describes specific measures, methods and practices that will improve the current unsatisfactory state of matters in this field. If accepted by the public sector, the results may lead to increasing the transparency of the public commissioning process in traffic structures, to name more effective public spending of money from EU structural funds and to improving the longevity, sustainability and utilization of traffic infrastructure.

Keywords: construction costs; effectiveness; public contracting authority; public sector; traffic structures.

1. Introduction

Construction and operation of traffic structures in the EU countries tackle many problems at the present. It is not only because of the ongoing economic crisis that the public has been getting more interested in the quality of construction of traffic structures, their benefits and final price. It is essential that the state has available a clear concept of the long-term preparation and planning of new projects of highways and is able to state its justified requirements to the public sector; even if it contradict the interests of various lobby groups. This may be achieved by improving the quality of the legal environment and setting up effective systems of control by the public sector.

2. Claims and settling disputes

A claim is a dispute between two or more contracting parties that cannot be settled by standard contract terms or negotiations. In most cases these disputes concern the value of money one contracting party owes to the other, and the settling of requirements/claims by one party due to a greater number of client changes compared with the original project.

Studies (Glover, 2008; Segalla, 2013; Oluwole, 2012) show that in more than 60 per cent of disputes between the owner and the contractor, resulted from poorly and insufficiently developed documentation of the specifications and plans; and it is the public sector - owner that is responsible for their completeness and correctness. This documentation contains namely the project documents, the contract documents, the construction time plan, and the budget. Owners often employ various design offices and outsourced consultants to develop this documentation for that project. Nevertheless, this method results in the quality of which cannot be 100% guaranteed, i.e. it will be clear of mistakes and various omissions. These consultants are not responsible and they are not fully responsible for solving consequences resulting from items omitted in course of the development of the documentation of the project (Long, 2013, Johnston, 2010).

The following items belong among the most common causes of future disputes between the owner and the contractor (builder) or subcontractors:

- The documentation of the project was not sufficiently developed in terms of the scope and quality.
- Vague responsibilities of contracting parties for performance of individual parts of the project.
- Vaguely defined criteria for checking the quality and time sequence of construction.

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- Owner's interfering in the construction process and additional changing of project parameters scope in the course of construction.
- Insufficient coordination and management of subcontractors at the site.
- Poorly conducted bid for the main contractor and subcontractors.
- The time plan contains construction periods hard to maintain or it is developed in an over general form.
- One of the contracting parties breaches some provision of the contract for work.
- The project manager interprets some contractual provisions in a different way than the owner.
- The owner does not accept building contractor's additional costs incurred due to extra work.
- Different building materials and/or technologies are used without in advance approval by the owner/designer.
- Force Majeure occurs (accident, work injury, a structure is damaged due to worsened weather conditions, floods, etc.) negatively affecting the time progress and total costs (Morris, 2005).

2.1. Typical areas of claims

From recently conducted studies (Bryson, 2013; Braimah, 2013; Lambropoulos, 2013), the results show that there are several typical areas that occur during a standard construction process. The following disputes between the owner and the building contractor come the most often. Contracting partiers should focus on management and prevention of risk occurrence first in these areas. The following conflicting areas are:

A. Project documents

Project documents of civil structures usually contain drawings (master/site plan, longitudinal profiles, outlined road junctions and branching, sample cross sections, excavation drawings, drawings of culverts and retaining walls, drawings of junctions, branch and slip roads, drawings of buildings, their floor plans, sections and elevations, and similar), a technical report, and detail structural and other calculations. The construction project manager will get these project documents in order to manage the agreed contract. The manner how the construction project manager interprets information contained in these project documents is the main source of potential future disputes between the owner and the contractor. This is why it is very desirable that the construction project manager reviews it in detail early in the process and together with the owner clarifies and/or add possible unaccounted items or changes needed.

In some cases the construction project manager may, in pursuit of generating a higher added value to the project, replace approved building materials and equipment by other products, not only with approval by owner. It is important that the owner does not choose a passive approach, and that he/she regularly monitors and controls the whole construction process to eliminate otherwise expensive and long disputes between the owner and the building contractor. Using inappropriate materials and equipment may also cause the whole construction to become more expensive and delay the end of the project for these inappropriate materials and equipment may have to be removed and replaced by approved and satisfactory structural elements (Haimes, 2005).

B. Founding

In most cases, information on subbase conditions is presented in project documents. It builds on conducted technical-geological, hydrogeological, radon, and pedological surveys. The problem arises often logically at the commencement of construction that the planned assumptions on the subbase geological conditions presented in project documents do not correspond with the reality. The contract for work should clearly describe who is responsible for occurrence of this risk. If the contract does not contain the particular clause, the construction project manager must immediately inform the owner about this fact and together they should try to find some solutions, then costs must be recalculated and the cost to be spent in order to finalize the project to the original plan scope.

C. Change of project parameters as required by the owner

A situation may arise often on bigger projects when the owner requires a certain project change in course of construction. The reason for this may be the fact that the owner performed the preliminary project phase inconsistently, or certain circumstances of their future operation phase of the planned project changed. These changes are listed as demand in the location, insufficient funds, and entry of a new competitor to the market, political risks, and legislative risks and other. If such a situation occurs, the construction project manager must not accept a proposal to change the project if given verbally. A request to change a project scope must always be written and supported by detail drawings of these variations, description of standards, and a modified itemized costing. An agreement must include the altered time plan if the total construction time is extend.

D. Extension of the planned construction time

As stated before, any change of parameters initiated by the owner or the contractor's project team may results in an extended construction time. The construction project manager must regularly update the project time plan. The time plan should note each important event that has affected the time spent on the individual working activity. These include the weather abnormal for the particular season, strikes, delayed supplies of materials, over controlling by the owner's representative, problems with subcontractors, technological problems, failures of machines and equipment, etc. Time plan variations are often submitted to the owner for request approval. If the owner refuses to approve a modified time plan or additional time, his/her written explanation must be submitted with the detail. This way may prevent potential future disputes in the course of handing over the completed building to the owner (Schneiderova, 2013).

To plan the construction process, it is recommendable to use some proven method of construction planning, for example the Critical Path Method (CPM). This method among others allows the team to identify the project critical path. This is a sequence of consecutive works that could inevitably lead to an extended construction time, if delayed. Using CPM the construction project manager may identify critical points of the project and search for measures that will make the critical point less disruptive (Schneiderova, 2007).

E. Owner's requirement of earlier completion of the project

The original construction time plan may be shortened in the case the owner requires a complete project earlier. If so, a detail cost analysis must be worked out including at least the following parameters:

- Quantification of costs of overtime labor and extra use of machinery.
- Quantification of costs required to speed up deliveries of building materials.
- Quantification of costs of subcontractors schedule being compressed.
- Quantification of costs for additional guarantees and insurance requirements.
- Quantification of costs related to modifying the time plan and additional management and coordination by the project team.

2.2. Recommendations mitigating occurrence of possible disputes

The following recommendations for the owner and the contractor may limit incidence of disputes and decrease the costs spent on their settling:

- Proceedings and assumptions are clearly defined for handing/taking over parts of the project by outside subcontractors/contractors.
- Each used building material and equipment is precisely specified and standardized to prevent interchanging.
- Only standard and proven technology processes are used.
- The documents of the project are specified clear and complete, and given as a requirement on cost quotation.
- The owner assumes that the project will be completed in a reasonable time considering the selected construction techniques, project scope, and season.
- There are no discrepancies or error between the bill of quantities and project documents.
- Owner's technical resident engineer continuously inspects and monitors the construction process and closely cooperates with the contractor.
- Clear requirements were agreed in terms of environmental protection, safety of the work, fire protection, construction waste, and extra building material not used.
- The contract for work precisely describes funding and invoicing processes regarding partial construction work.

3. Project control

Project control is a construction process aimed at meeting project's planned requirements as defined in project documents, time plan, financial plan, and the contract for construction. A team of professionals usually performs project control (or independent professional company). They first study the project in order to become familiar with the overall project intent and its scope. Then study project documents, planned technology processes, the time plan and contract documents in detail. The project team then defines the project road map. This is a tool defining specific works, relations and milestones covering the whole construction phase of the project. This road map allows continual control of the work progress and thus adopting necessary remedial measures, if needed (Gould, 2002).

3.1. Project control process

The project control process is a perpetually repetitive cycle (see Figure 1). The process starts with a detail analysis of the work plan of the project (item [1]). This work plan contains an itemized financial plan, a work time plan, approved project documents, a bill of quantities, contract documents, a staff organization chart, administrative procedures, contractor's standards and regulations, and other important information essential for effective planning. The work plan should be the result of broader teamwork including construction, administrative, economic, design and management staff.

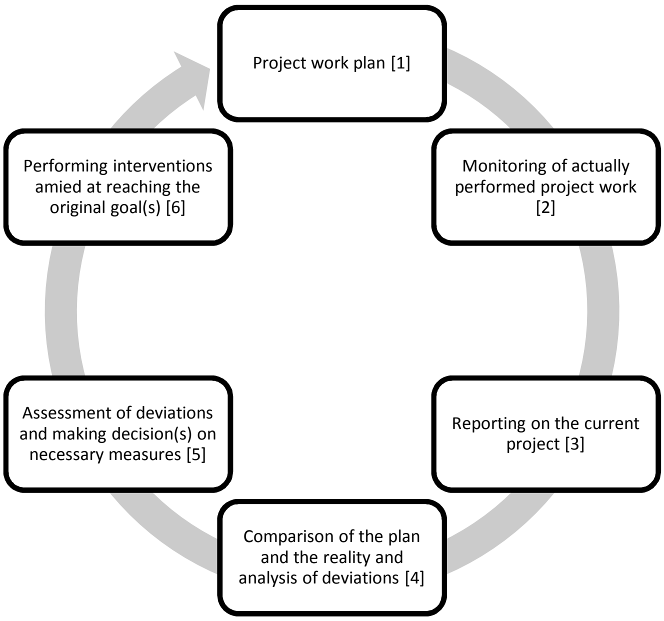

Figure 1. Project control cycle.

The progress of the actual construction work must be permanently followed and assessed (item [2]). The project manager should choose the shortest period of time that project control reporting is done and how often. The ideal inspection is checking the site every day.

Discrepancies in the records of construction work performed by the building contractor (e.g. in an invoice) is one of the key areas where a building contractor may be at odd with the public owner. This risk occurs namely in those budgetary items where build volumes are difficult to measure and compare with the original bill of qualities and project documents. These are for instance volumes of grading, road embankments, and delivered reinforcement to bridges, planning of foundation structures, and makeup and thickness of road materials. This type of construction in particular should be consistently measured and inspected.

In construct we expect many random acts will occur. Examples are sudden weather changes, temperature variations, and changes in costs of building materials, abstention of workers, unexpected miscellaneous of building equipment, power shutdowns, and late starts of subcontractors, traffic accidents, thefts, and others. Many site activities are not performed according to the original plan due to these random events. The construction project manager must always have available actual information about work progress (item [3]) based on which items have deviated from the original plan (item [4]). After the changes are assessed (item [5]) it may be decided which measures are to be adopted and carried out (item [6]) in order to bring construction back to the original project schedule (Lambeck, 2009).

3.2. Management of key resources of the construction activities

To make project control effective, it must focus on successful management of key resources consumed for the construction activities. Among these resources are labor, equipment, site and finances. The project manager must manage and organize these resources continually throughout construction in order to balance and use them in an efficient and production manner.

A. Labor

Based on the scope of the project, size, cost and its complexity, the number of staff and its structure will be involved early in the construction phase of the project. This planning draws from the construction project manager's experience and company's previously completed projects. All work must be planned to be performed under standard working conditions. The team must include managers, designers, engineers, architects, craftsmen and operators, and administrative staff.

Planning control must take into consideration that personal costs may easily exceed those originally planned ones if schedules are extended. Working with labor encounters many risks. If specific local conditions exist where local labor is scarce or the workforce is improperly structured in terms of supervision, labor issues must be planned for well in advance. These crews will naturally increase the originally planned personal costs if not handle early. Among other potential risks not included the occurrence of labor disputes and the risk of a mistake/failure done by contractor's craftsmen during construction. These risks cause financial losses due to rework and lose of productivity.

B. Equipment

Before starting construction, starts employment of mechanic operators and rental of equipment must be planned in detail and in advance for each construction phase. The construction project manager must in advance review availability and capacities of equipment to be used. Among key equipment affecting day to day costs are cranes, grading machines, and trucks.

Management in this field focuses first on identification of failures and mistakes occurring due to the use of inappropriate or incompatible equipment. Construction work may not be performed at the highest quality and the continuous flow of construction may be jeopardized by failure of any other supporting systems. Aside from a time delay also equipment (own or rented/leased) may be damaged or have breakdowns (e.g. concrete pumps). This results in financial and time losses also.

C. Site

The size of the construction space available for the planned project also plays an important role in planning, construction and the cost. Problems may come up on projects that are situated in a densely urbanized area where the complete project must be built in a confined space. In this case the construction project manager must consistently coordinate subcontractors at the site in terms of time and place, and when a subcontractor ends his/her work, the project manager must see that the allocated construction area is immediately evacuated. Control in this area focuses namely on the commencement and leaving dates of subcontractors in compliance with the construction time plan.

D. Financing

Budget of money are driving parameters the process of construction. The project manager must continually track the project income and expenditure cash flow to keep the budget balanced. He/she must ensure that the balance between the money obtained from the owner and expenditures to subcontractors, employees, purchased material, and needs of site mechanical equipment is continuously maintained. Controlling these costs in this field has to do with reviewing documents with in respect to their completeness and accuracy; such revisions control whether the exhibited scope of construction work is recorded in documents and really fully performed.

4. Conclusion

The construction process is a complicated process and there are many parties involved, it is impossible to absolutely eliminate some disputes between the owner and the main contractor or subcontractors, even if the project is well managed and coordinated. This paper suggests suitable recommendations that may limit the occurrence rate of these disputes and decrease the cost spent on their settling. This another believes that an effective and active prevention of potential disputes applied in the course of project preliminaries will enable its successful completion. Disputes happen first of all when the owner did not develop good and accurate documentation for the project. This results an inaccurate quotations being submitted and certain provisions of the contract for the work not interpreted correctly.

From recently developed professional studies results, a finding that in many EU countries public owners perform only limited control. In general, control by independent professionally qualified technical supervisors has vanished. Private companies usually perform this activity; their motivation to consistently defend interests of any particular state cannot be in principle convicting. A technical resident engineer continuously controls the quality of performed construction works, the compliance of the time progress of construction and cash flow. Limiting this control thus logically brings about an increased risk of poor quality, schedule and overruns.

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Risks associated with the stipulations of the BOT contract in transfer stage
Case study of T9 BOT project in Taiwan

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Abstract

Different risks are involved in the three stages of a BOT project. The key risk during the "build' stage is to overcoming of the stereotyping of laws and regulations, and the maintenance of the sustainability during the operation stage. However, unfamiliarity during the transfer stage often causes risks in the transfer stage being outright neglected. Although sporadic literature did raise an in-depth discussion on this issue, the discussion might have lost its reliability due to the changes in laws and regulations over the years.
The governing rules states that in a BOT contract, the transfer of a project starts one year before the end of the contract. However, one year before the end of a contract is often too late for any analysis of risks involved and to implement appropriate reactions for problems that may occur. Case studies from abroad on the way which tackle these problems should also be collected and be taken into account; however these materials should only be used as a reference due to the differences in laws and environment.
The involvement of public's opinions and public organizations is one of the keys to a successful BOT project. For the involvement of these figures can help to reduce the risks involved, and even if any of the risks happened, the damage can be reduced to the minimum. Only when government laws and regulations coincide and cooperate well with public's opinions, a BOT project can achieve its upmost return.

Keywords: BOT project, Transfer stage, Risk factors

1. Introduction

The first BOT projects can be traced back to the 19th century, as expected; a large number of these projects experienced a lot of issues and therefore, were not successfully finished. In fact, most of the current BOT projects, both international and in Taiwan are in the "operation" stage, and this makes it difficult to project the risks in the "transfer" stage. Furthermore, BOT projects usually involve a huge amount of investment with a long period of time; the whole project can be filled with unforeseen circumstances. It is important for both government and public perception to realize the risks that may occur and to prepare for the best solution.

1.1. Motivation

There are many different risks that may occur in BOT project during the different stages. The key risk during the "build" stage is overcoming the stereotypical laws and regulations, and the maintenance of sustainability during the "operation" stage. However, unfamiliarity during the transfer stage often causes risks in the transfer stage to be outright neglected. Although there is some research investigating the laws and regulations of BOT projects in Taiwan specifically, it is yet substantial enough to provide solid solutions to manage the risks and the potential crisis.

1.2. Objective

This work study is to examine diverse angles to analyze the risks and crisis that may occur in BOT projects during the transfer stage. This exercise will be undertaken by studying arguably the most complete and successful BOT project in Taiwan. Although the results may be case sensitive due to different environments and regulations, it is yet an important reference for those BOT projects in process and those countries that are interested in BOT projects in future.

1.3. Methods and procedures

This work first reviews analytical papers to confirm the risks and crisis factors, and then analyzes the methodology of BOT projects abroad to compare and contrast the suitability of such projects, given the environment in Taiwan. In addition, a series of interviews with subject matter experts to draw out potential solutions. Finally, SWOT analysis shall be utilized to tackle each risk and crisis to provide a concrete plan for risk management.

2. Case Study

The T9 BOT project can be divided into two parts. One is the sellable part which accounts for 1/3 of total project value, and the other is commercial part which will be leased to several operators or operated by Wan Da Tong, the Project Company. The sellable part includes the residential and office buildings, it was the first time a leasehold form of ownership was utilized in Taiwan. It was launched in Oct. of 2006 and sold out in 3 months. Total sales amounted to USD $245mn.

According to the BOT contract, a "Project Company" had to be set up to manage the BOT projects once operational. Additionally, a trust account, specifically for the T9 BOT project, was required to manage the revenue from pre-selling residential and office spaces. This was required to eliminate the possibility of comingling funds from one project to another. Once the operation and recurring income has become stable, the risks can be minimized during the transfer stage.

Due to the uncertainty of the first-ever leasehold project in Taiwan, the private entity was required to initiate a multi-funding system to make sure the project will be completed without any shortage of funds.

In normal construction projects, the land, being the most valuable asset, will be the collateral for bank so the private entity can secure financing. However, the land of the BOT project cannot become collateral, as they do not directly own the land. The private entity had to be innovative and reach an agreement with the government, the actual owner the land, to allow the land to become the collateral.

In order to protect the governments' interest to the land, the private entity had to create a trust account for construction purpose. All the funds will be deposited into the said account and all contractor expenses will be paid from it. The government also agrees to use the security deposit from the private entity to pay the interest for the loan should a shortage occur which can delay construction from finishing. This multi-financing method guarantees the BOT project will be built without shortage and avoid a premature transfer.

Additionally, the BOT contract also lacks the detailed planning required for the transfer stage that is a predetermined expiration date. Although it contains certain criteria to follow, the details of the methodology and the catalog managing still need further improvement.

Figure 1. Simulation of T9 BOT

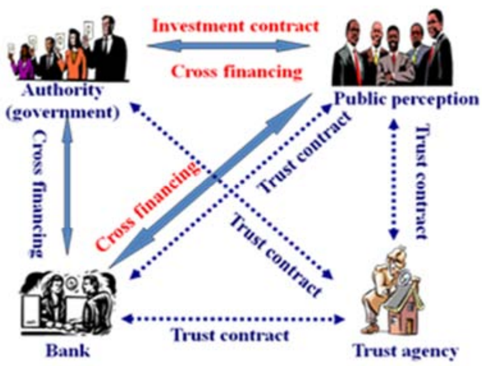

Figure 2. Illustration of cross Multi- Financing

3. Methodology

Chen (2004) has mentioned PPP (Public Private Partnership) method from the British that might have similarities with BOT projects, including:

- Selling the shares of government owned entity directly to the private entity to transfer the controlling stake and management control.
- Government buying public services from private entity through contract agreement to well-use the funds and management skills from public-private financing priority. Providing the rights if operation to mange the public service.
- Selling the public service to public perception and collect professional skills and financing methods for partnership.

However, through the interview with subject matter experts, it was obvious that most of them do not suggest the PPP or the PFI methods as they are not suitable for Taiwan. In both scenarios, the government will faced increased debt and longer legislation to create new regulations. This requires further research with regard to suitability for Taiwan, but it is more urgent to resolve the problems which BOT projects in Taiwan are currently facing.

Technical risks can be minimized through technical cooperation or consultant contracting while currency risk can be mitigated via purchasing derivative financial instruments such as insurance.

Exceptional risks such as force majeure and political issues are unforeseeable, it is important to parallel the information from both government and private entities to lower the damages and initiate a quick first response.

All of the subject matter experts mentioned the recognized market value of the assets and maintenance as the biggest risks for BOT projects during the transfer stage. Even though the assets of BOT project are made into a detailed catalog based on the regulations, there is no standard by which to value the assets. BOT projects usually have a long period of operation prior to the predetermined expiration date, experts suggested that both sides should make an agreement for third parties to judge and calculate the value 3 to 5 years prior to the date of transfer. Additionally, updating regulations that encourage the private entities to renew and continue operating the BOT project might reduce the risks in transfer stage

Most of the experts agreed that the T9 BOT project had a comprehensive risk management plan during the construction period via cross financing to avoid the risk of early takeover. However, some risks were still very plausible. Firstly, the private entity should still manage the stability of operations of public service and others, which is very important at the stage of feasibility evaluation before committing to the BOT project. Additionally, experts were also concerned about the ability of the government when they eventually take over operations while they may not have the proper training and knowhow. Although the contract contains the contracted private entity to have the right of first refusal, the regulations do not prescribe details that provide the rules for negotiating the renewal contract. BOT projects have to provide public service at the meantime; it is quite difficult for the government to have a concrete plan prior to the expiration date. Considering the condition of the environment and people, especially the T9 BOT project had a leasehold property that has been sold out; there might be a risk of the tenants and/or buyers not giving up their units and moving out on the expiration date. Detailed regulations are imperative to enforce the leasehold agreement. Otherwise, the government might have to enforce the contract via force or drastic measures which confront the very purpose of BOT projects.

4. Risks factors of T9 BOT project in transfer stage and SWOT analysis

From the provided materials and interviews with the subject matter experts, this work has concluded the risks factors for T9 BOT project to provide an idea for risks that might occur in BOT projects in general.

4.1. Risks factors of BOT project in transfer stage

The risks factors have conclude both T9 BOT project and others that they may have to resolve:

A. Changes in political climate
B. Financial risks
C. Preparation of early take over
D. Regulations with regard to the right of first refusal by the existing private entity
E. Stability of operations after taking over
F. Lack of proper training upon takeover
G. Valuation of the assets of the BOT project
H. Cataloging of assets
I. Currency and inflation
J. Extraordinary risks

K. Transferring of the leasehold property
L. Condition of the environment and people

4.2. SWOT analysis

By using SWOT analysis for this specific project, T9 BOT project, to conclude the method that may be applied to mitigate or resolve all the risk factors mentioned.

- Strength (S) of T9 BOT project:
  1. Cross financing to avoid premature hostile takeover bids
  2. Good evaluation of operation for three years in a row
  3. Private entity having stable income from other facilities in this BOT project
  4. Complete catalog of assets
  5. Technical documents are well saved
  6. The priority right of first refusal to renew the contract
  7. Insurance and consultant contact signed
  8. Sustainable as-built property
  9. Innovation and creativity of private entity
- Weakness(W) of T9 BOT project:
  1. Incomplete details and information during the transfer stage
  2. The lack of regulation of regarding the right of first refusal to renew contract
  3. Inexperience and challenge of the first leasehold property at transfer stage
  4. Environmental conditions and public acceptance
- Opportunity(O) of T9 BOT project:
  1. Early discussion and preparation for transfer stage
  2. Auditing the contract agreement with government
  3. Improvement of laws and regulation in near future
  4. Reinvestment opportunities
- Threat(T) of T9BOT project:
  1. Political issues and policy changes
  2. Extraordinary risks
  3. Political stability between Taiwan and China
- SO strategy

Due to the long operation period, it is possible for the private entity to have early discussions with government about the details of transfer stage. Complete examination on the risks factors and preparing the plan of risk management. In addition, T9 BOT project can be a good example for future BOT project in Taiwan and may increase the acceptance of this kind of method to provide public service for people.

- ST strategy

A BOT project has a long period of operational period, the stability of the political climate is a huge challenge. Facing the uncertainty of the political climate and policy changes, the private entity has to communicate with the government constantly. It is important to keep updating the operations of the project, also in conjunction with changes in policy. Preparing the crisis response method to manage the project to ensure everything is under control even when extraordinary challenges are faced.

- WO strategy

The laws and regulations of BOT project still have a lot of room of improvement; there are a lot of possibilities, such as REITs and listing the project company on the market, to overcome some weaknesses. The government should constantly update and research new methods to increase the diversity of BOT projects to have improved risk management.

- WT strategy

The trust account of the BOT project company will store requisite funds that cannot be removed or used for other public services purpose. This work suggests that the account should also be used as a tool for risk management. Although the exceptional risks have already been adjusted in laws and regulations, it is hard to imagine the execution when it comes to emergency. The private entity should have the power and right to manage a certain amount of funds for risk/crisis management purposes. Furthermore, some unforeseeable risks can be resolve in a shorter time span.

5. Risks management, crisis responses and suggestion for improvement of laws and regulations

By analyzing the result from the SWOT analysis, this work provides concrete ideas of risk management and crisis response that tackle to each risk factor that have been mentioned.

5.1. Risk management and crisis response

A. Changes in political issue

- The government should continue dialogues with the private entities before executing new policy. Private entities should come up with plans and ideas to adjust and improve the effectiveness of BOT project through policy changes.

B. Financial risks

- Proper evaluating and thorough financial planning for BOT projects for all parties involved. Cross financing method is a good way to promise the BOT project will not be in danger of hostile takeovers.

C. Preparation of early take over

- Both government and private entities should be prepared for early transfer. The government should supervise and have alerts in place to make sure the BOT project in under control. The government should also give the contractor a reasonable time for remedying the defects and preparing a process and plan for early transfer. Then the facility could be re-tendered or be operated by the government itself.

D. Regulations of the right of first refusal by the existing private entity

- It is urgent to plan out the negotiation process of the right of first refusal. Adding benefits, such as potential tax breaks, to encourage the existing private entity to continue operating the project for another fixed period of time could guarantee continuous provision of public services and reduce the need for a potentially chaotic transfer period. It might betray the original idea of BOT but it certainly cuts down the risks.

E. Stability of operation after taking over

- Constantly communicating with the operator of the BOT project to realize and understand the operational requirements to ensure a seamless transition or provision of the utmost quality to the public.

F. Lack of proper training during the transfer

- All the technical documents should be well preserved and the training process should commence at least 6 months prior to the takeover. The government could also prepare certain amount of funds for the existing private entity to continue the services after expiration date to buy time for adopting the systems during training

G. Details of the assets catalog

- The assets catalog should contain the value and the years of usability for each item. The catalog should be reviewed by the government and examined by a third party appraiser every year.

H. A standard to value the assets of the BOT project

- Impartial third party should be utilized, with assistance from both sides, to evaluate the value of the assets according to the catalog.

I. Currency and inflation

- Insurance and price agreement with contractor can reduce the risk of inflation. On the other hand, re-investment such as REITs can also create another strategic opportunity for BOT project.

J. Exceptional risks

- Banks should be involved in regulations of BOT project to prevent exceptional risk and provide reasonable funding to maintain the public services.

K. Transferring of the leasehold property

- Enforcing the leasehold contract in order for the government to execute it.

L. The environmental condition and peoples' acceptance

- It is more important to popularize the BOT project by emphasizing positive examples. Increasing the acceptance from people provides good impression to the government and, this in turn will attract attention from both private entities and society for future bids.

5.2. Suggestions for improvement of laws and regulation

BOT project has good intention by utilizing and maximizing the creativity and management skills of private entities. Government and private entities should cooperate together and keep improving.

The laws and regulations of BOT projects still require further improvement, as BOT is still a novel concept in Taiwan. This work presents the following suggestions, for further evaluation.

I. Exit strategies should be discussing prior to the BOT project getting started. BOT projects have a long contract which means a lot of uncertainty and risks; a detailed exit strategy can provide an amicable solution when major damages occur to the project. On the other hand, certain stipulations during special situations can be put in place to mitigate potential risk or minimize potential damage.
II. Besides the government and the private entity, the banks should be also involved in the BOT project regulations to assist the funding and financing. Huge amount of funds are involved in BOT projects. Few private companies have the ability to construct and operate the BOT project without funding from the banks. In addition, adding the bank in the regulations might also provide some method to secure the assets on behalf of the government.
III. The regulations about early take over should be detailed from the very beginning. There should exist certain process for parties to follow before the early take over. This will make sure the BOT project is still under control.
IV. The system of valuing assets should also be considered in the regulation. There should be a fair mechanism or organization such as third party appraisals to calculate the value and remaining value of the assets. Details of what should contain in the assets catalog would also help the procedure.
V. The regulations about tax breaks or similar benefits should be case sensitive, it would encourage and increase the acceptance of future BOT projects in the eyes of private entities.
VI. Supervising system is also considered as a solution for clearing out the malpractice that may occur in the BOT project. Using a fair and open system to supervise the project without constraining the creativity of private entities could significantly improve the BOT project.
VII. Establishing a dispute review board and dispute resolution board could reduce the conflict and accelerate the problem solving process.
VIII. Certain evaluations and regulations for priority to renew the contract should be added. .

6. **Future works**

This preliminary work provides some preliminary views regarding risk management method for BOT projects during the transfer stage. The case study itself is an example that should be applicable in every stage. T9 BOT project is planning to follow and utilize the management method and suggestions from this study. This work will closely cooperate with the on-going project and continue to generate further results over time.

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A research of building the bridge life cycle cost estimating system: A case study of Taiwan National Highway NO.1 Wugu to Yangmei segment

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Abstract

This research develops a set of bridge life cycle cost estimate system, in which contains two parts- the history cost and the project cost assessment. The history cost is to accumulate all costs occurred in the bridge subsisting period which includes the construction costs and maintenance costs, and also considers about the price index. The project cost assessment applies to estimate the total lifecycle costs of a new bridge project, and is bridge components oriented. The project cost assessment uses the historical inspection data of bridges to find out the deterioration rate of bridge's components, and the historical maintenance costs of bridges to estimate maintenance and replacement costs of the bridge's components. Finally, sum up the estimating maintenance costs, replacement costs, construction costs and demolition costs to the total lifecycle cost for the entire bridge. We can find out the cost-optimized bridge configuration in the planning and design stage by using this system. And we can also develop the most cost-effective way of repair or reconstruction programs in the maintenance and management phase.

Keywords: Lifecycle cost estimating, History cost, Project cost assessment.

1. Introduction

The bridge is important since it connects the people at different places and diminishes the economical gap between them. Especially to a place with many rivers, such as Taiwan, the bridge plays an important role in traffic. However, because there are many typhoons and earthquakes in Taiwan, how to maintain and supervise bridges becomes a critical issue.

Recently, the concept of management of life cycle has been used for this purpose. Some experts start to discuss the difference between the life cycle of the bridge and traditional maintenance. Therefore, several related concepts have been added in, such as preventive protection, estimation of budget of life cycle, deterioration prediction, risk management and resource management. Although these concepts have gradually been discussed, there is till no complete definition about how to evaluate and estimate life cycle of the bridge or how many items should be noticed. According to researches, estimation method of life cycle has been viewed as a better way to get thoroughly, objective result in the beginning of the of public construction.

According to ASTM E833-97b(Standard Terminology of Building Economics), life cycle means the period from construction to demolition, it equals to whole investment time. In addition, according to Cost Estimating Guide (1997, addressed by DOE), the budget analysis of life cycle is the best systematic and analytical method for early evaluation. Referring to BS3843, the budget of life cycle includes all costs related to product gaining, product maintenance and product disposal.

1.1. Motivation

Like other public constructions, the life cycle cost of the bridge mainly includes construction cost, maintenance cost and disposal cost. With widespread application of computer software, general engineers can precisely calculate the construction cost and disposal cost. In contrast, maintenance cost lacks objective analysis and usually be ignored. However, during the life cycle of a bridge, maintenance cost might be a critical part to judge whether a project is good or bad. Thus, developing complete management system for maintenance of life cycle is necessary and helpful to bridge's maintenance and life

1.2. Objective

a. Sort models regarding how to estimate life cycle cost of the bridge
b. Discuss the details of the module
c. Try to find a suitable choice for Taiwan's future development

1.3. Methods and procedures

Literature review is used to understand the proceeding situations of estimation system of life cycle cost. Performance-based life cycle cost evaluation system is used to generate life cycle cost estimation model. Combine life cycle cost estimation model and history into a systematic module.

2. Methodology

2.1. Performance-based life cycle cost evaluation system

The main difference between this module and conventional way is in budget items. Here, we divided all items into single cost, regularly preventive maintenance cost, predictable uncertainty cost and unpredictable uncertainty cost.

We calculate all items; the results are showed in Table 1.

Table 1 classification of life cycle cost

Cost type	Description
Single cost	Used only once, e.g. New construction cost, recycle cost
regularly preventive maintenance cost	Periodical maintenance to improve deterioration of bridge constitution due to environmental conditions. Its period will be decided by engineers' experience and the environmental conditions. e.g. inspection, cleaning and oil.
predictable uncertainty cost	Gap, erosions or fatigues may happen on bridges' constitutions due to environment conditions and its life This is the cost used to enhance or recover the constitutions.
unpredictable uncertainty cost	Bridges may be damaged by unpredictable source, such as earthquakes, typhoon, earth flow or terror operations. However, the time of this item is not predicable, we ignore this in our discussion

Among these items, we mainly discuss two items: regularly preventive maintenance cost and predictable uncertainty cost

Regularly preventive maintenance cost

It's hard for the government to make a budget for maintenance cost since the speed of deterioration of the bridge constitution differs from area to area. Usually, it takes several inspections to get it thoroughly. After these, we can evaluate the necessary cost. However, we are now facing a problem that we don't have enough people to do inspections. According to the model(s), it is suggested that the concept regularly preventive maintenance should be used here.

Regularly preventive maintenance cost belongs to active bridge maintenance. With regular but less cost, it diminishes the speed of deterioration of bridges' constitution by improving the environment of bridges. Besides, it enhances the control of manager to the deterioration and decrease the maintenance cost of the life cycle of the bridge. Moreover, we can assume that it cause ignorable influence to passenger during the period of regularly predictive maintenance. We listed items regarding regularly preventive maintenance cost bases on the bridge components maintenance method list of the bridge management system in Taiwan, In order to understand the existing maintenance job regarding Taiwan's bridges, we discuss this with some experts and get a table concerning regularly preventive maintenance. This table includes how to maintain each components regularly, how much does it cost and its frequency.

The formula listed below shows the executive degree of regularly preventive maintenance (M%). It's ratio between realistic cost and ideal cost. The price, frequency and amounts needed in this formula can be found in Table and data of the bridge.

$$M\% = \frac{\left(\sum_{i=1}^{21} \sum_{j=1}^{n} IPij \times f - \sum_{i=1}^{21} \sum_{j=1}^{n} IPij \times F \right)}{\sum_{i=1}^{21} \sum_{j=1}^{n} IPij \times F} \times 100\% + 80\% \quad (1)$$

M(%)：The executive degree of regularly preventive maintenance.
IPi：The number of bridge component.
J：Regularly preventive maintenance project of bridge component.
n：The quantity of J.
f：Regularly preventive maintenance cost each year.
F：Regularly preventive maintenance budget each year.

This formula can be used to express the execution of the maintenance work and decide the deterioration curve of the components

If there is no regularly preventive maintenance, the slope of the deterioration curve is will be worst, however, with fully execution of regularly preventive maintenance job, we can get better results.

2.2. Predictable uncertainty cost

To this item, we first analyze the data regarding the bridge, such as its environment and constitutions.

Furthermore, we get the shortest life (L0) and longest life (L1) of the components by the use of historical data and discussion from experts. And we decide the real deterioration curve of this component by the executive degree of regularly preventive maintenance (M%).

Deterioration rate R = -dR/dt = (r1 – r0) X M(%) + r0 (2)

Compared to regularly preventive maintenance, predicative uncertainty method is a passive method since it only operates when the components of the bridge are broken. If the deterioration of the element reaches the criteria, it needs to be fixed or repaired. Here, depends of the situations of deterioration, we can divide the Predictable uncertainty cost into repairing cost and exchanging cost:

Repairing cost: when the situations of the element reached the designed standard, we have to take actions to repair the damaged part of the element. Although this situation can be repaired by this, it cannot be recovered to the best situation. Besides, it causes bigger influence to the passengers than regularly predictive maintenance.

Exchange cost: if the components cannot be repaired to the designed standard, for the safety, the element should be exchanged. This cost is a new cost to the element. Also, it causes bigger influence to the passengers than regularly predictive maintenance.

After repairing or exchanging, deteriorated components can be improved. However, since they are different, their cost and influence are also different. Repairing can only recover to a certain degree. As to exchanging, the new element can be viewed as a new one. Therefore, it can reach the best situation.

The flow chart regarding how to use performance-based life cycle cost evaluation system to evaluate the budget of bridge life cycle can be seen in Fig. 1

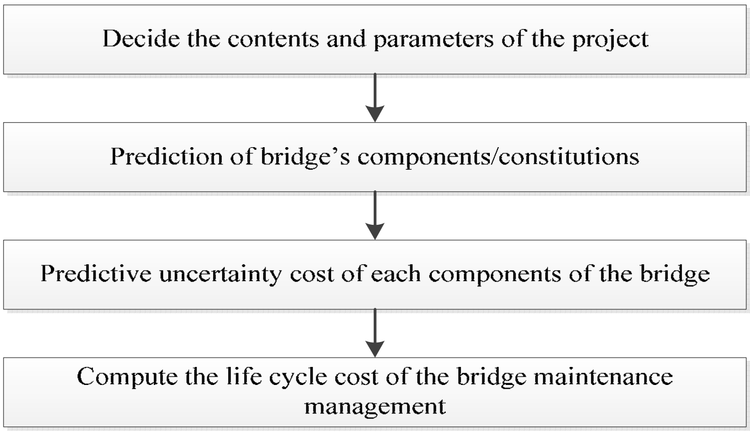

Figure 1. The process of bridge life cycle cost estimating

3. The bridge historical cost module

This is the sum of all necessary costs when a bridge is "alive". It includes construction costs and maintenance cost. Besides, price index also needed to be considered.

According to the concept of the life cycle, we cannot only concern about the construction cost. We have to take the following maintenance cost and demolition cost into consideration.

The module can help the decider to make efficient decisions. There are two results showed in the final results, the first one is the budget cost, which is the realistic cost. The other is the cost adjusted by price index. The results can be seen in Fig 2.

Figure 2. The screenshot of historical cost module

4. Life cycle cost estimating module

This module is an implementation of performance-based life cycle cost evaluation system. The user need to find parameters regarding life cycle cost in analytical parameters setting, which belongs to analytical estimation module. Here, we can set the maintenance threshold. It means the limitation of the deterioration of the element, when the element reaches it, it need to be repaired. We can set 20 components individually.

After setting these parameters, we have to input the amounts of the project which we are going to evaluate. These actions can be done by entering project cost comparison evaluation, which belongs to the life cycle cost module of the analytical estimation module.

Now, we have to choose the way for estimation, if we choose a element only, the system will only evaluate the life cycle cost of the element.

If we choose the whole bridge, we will evaluate the life cycle cost of the bridge thoroughly.

The final result is the life cycle cost of the element (refer to Fig. 3).

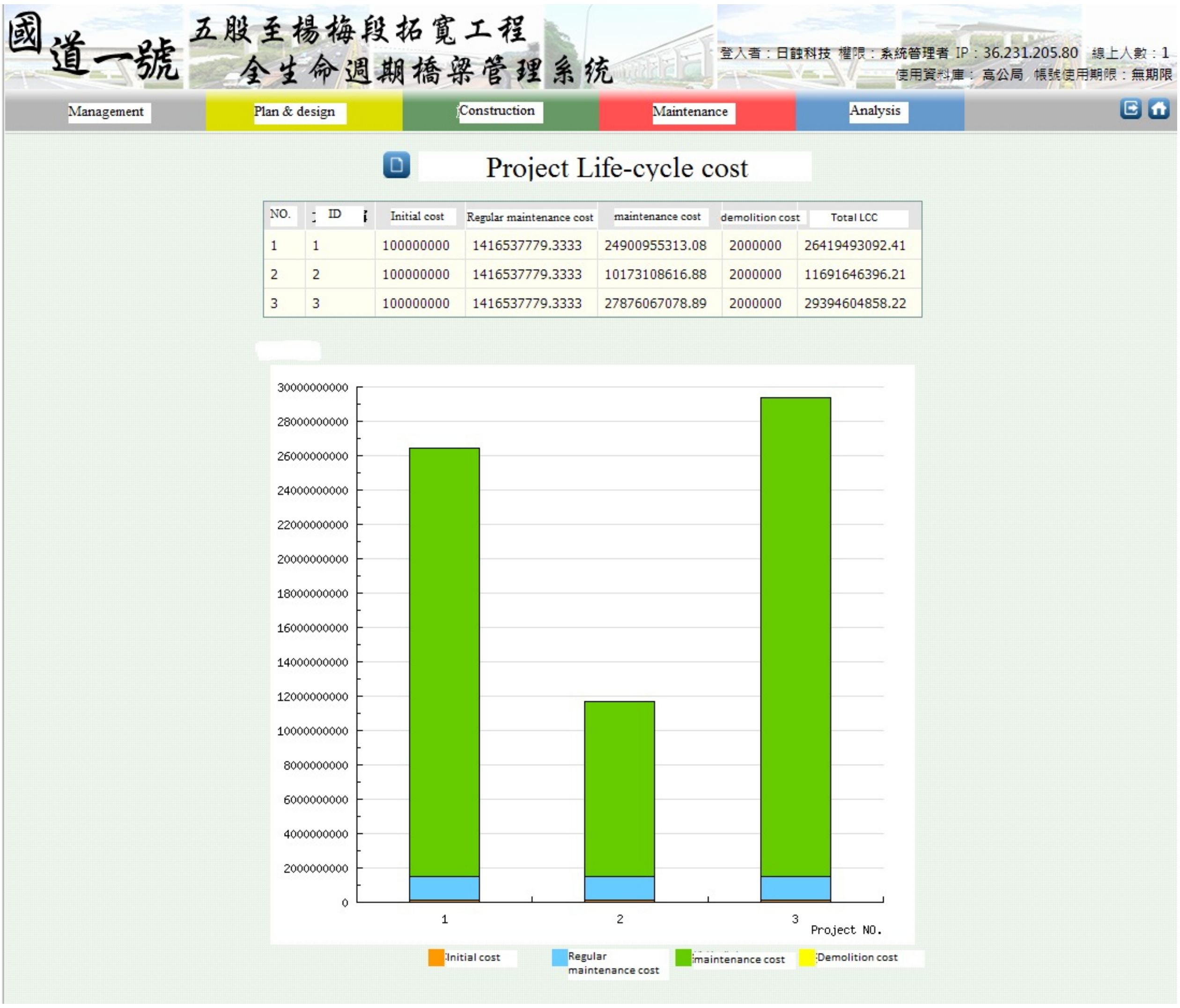

Figure 3. The screenshot of life cycle cost estimating module

5. Conclusions

The objective of this research is to build the life cycle cost module of Taiwan bridge management system. This module can be used to get all historical costs of the bridge and estimate all possible costs need for new or existing bridges in the next few years.

We try to make this system become a powerful tool for users to consider the life cycle cost of the bridge when they design, operate and maintenance a bridge. Eventually, the user can make the most efficient strategy by using the system.

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Creative Construction Conference 2014

The impact of the additional workload on the productivity in construction projects

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Abstract

Additional works are not rare in construction projects. Their occurrence is often not anticipated on time. Practice usually only considers the direct impact on the organizational and technological aspect of them when planning the project, although it is known that they reduce the productivity and motivation as well. These hidden effects can reduce the dynamics of labour and thereby cause additional problems to managing the project. Moreover, constraints typically increase or are constant on projects through project phases and thus are completely maladjusted to the new conditions of increasing workload. Conducted research includes detail analysis and simulation of performance of 3 business residential building projects in Croatia, considering the relationship between the workload, time pressure and the work productivity. The technical, organizational and human component is considered. The paper proves the occurrence of productivity reduction in the case of additional work, no matter if the additional work is required or is consequence of prior poor performance. Based on the research results, the paper give the recommendation for reduced productivity compensation, which has direct impact on cost, time and resources and should be taken into account when deciding on additional work, if the project success is the main objective of project activities.

Keywords: additional work, impact of additional workload, productivity

1. Introduction

The additional workload is usually the consequence of required additional work which is more practice than exception in construction projects. Disadvantages of project documentation, too late perceived needs and technology conditions and later investor's requests are some of the common reasons for additional works in construction projects. The research results all over the world prove that the each key project participant could be the initiator of additional work. In other words, client, consultant, contractor or any other can be responsible for rework orders (Arain and Low, 2006). Researchers confirmed that the client contributed most to rework (Hwang et al, 2013). Regardless the initiating participant, the negative impact of rework on project performance is in the focus of many researching in today's construction projects (Love et al, 2002; Palaneswaran et al, 2007; Thyssen et al, 2010). In this study, the term of additional workload means additional work or rework, despite of root cause and the contractual conditions and settings. In other words, regardless if it is consequence of accepted change or its time/cost or other constraint overrun that has to be overcome during the project performance, it is always the unpredictable event on which is necessary that project manager react. The research question is: Is there relationship between additional workload and the productivity in construction projects? If this relationship is significant, it has to be calculated in plan revising, whenever it includes additional work, which is not case in the practice. No doubt, this could be one of the drops in the bucket of reasons why 68-97% of projects don’t achieve their determined goals.

2. Background

The impact of additional work on construction projects is well recognized. It is one of the most common concerns in construction projects (Hwang et al, 2013). The researchers agree that it has significantly contribution to project cost and schedule overrun (Love and Edwards, 2005; Hwang et al, 2013). Rework, as one of the main its manifestation, is a form of waste and is a non-value adding activity. (Love et al, 1999). It is believed that it appears in every project management dynamic model with varying degree of complexity, especially after developing community of system dynamics in 1970s. (Lyneis and Ford, 2007). Each project that is to be modelled—a project is defined here as a series of tasks that have a specific objective, start and end dates, and funding limits. It assumed to be comprised of a certain number of tasks or “original work to do”. The tasks can either be completed fully and correctly (i.e. they can become “work done”) or they can be mistakenly classified as completed fully and correctly (i.e. they can become “undiscovered rework”), until it is discovered that they were flawed and need to be redone (i.e. they can go from being “undiscovered rework” to “rework to do”). Thus the stocks or state variables of the system, as shown in Figure 1, are: original work to do, undiscovered rework, rework to do, and work done. The rates at which work is being completed correctly and incorrectly are affected by the value of original work to do and the workforce size, productivity, and error fraction. Similarly, the rate at which rework is discovered and reclassified as work to do is affected by the undiscovered rework and the time to discover rework, which can also be affected by the workforce size and productivity. In Figure 2, workforce size, productivity, error fraction, and time to discover rework are treated as constants (or parameters). However, in reality, the parameters in Figure 1 are state variables that are controllable by organizations and thus they represent the control authority of the organization over the states of work to do, undiscovered rework, and work done. (see figure 1).

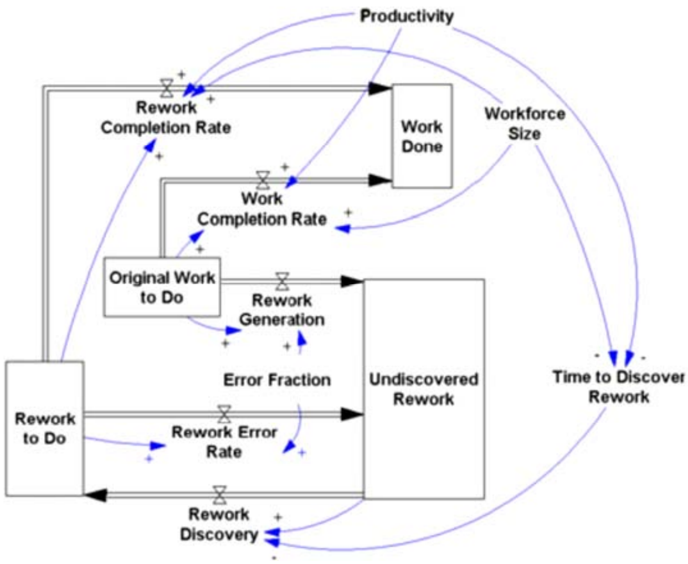

Figure 1. Rework cycle dynamic structure (Owens et al, 2011; Lyneis and Ford 2007)

This is only one of the recognized models for additional work on projects. Every variable could have specific part of its behavioural, depending on type of the project, which also must be concerned. In the most cases in construction industry, additional work arises from changes, damages, defects, errors, omissions and other non-conformances (Palaneeswaran et al, 2007). It is proven that the cause of rework in a construction supply-chain is poor information flow and the absence of a quality focus (Love et al, 1999).

Concerning the participants in projects that contribute to the additional work, it is known that there are four project players responsible for rework orders, i.e. the client, consultant, contractor and others, and found that these project players were the sources of design change, design error, design omission, construction error and construction omission, which caused rework in construction projects (Hwang et al, 2009).

3. Methodology

Conducted research aims to find a relationship between workers' productivity and the additional work that is being introduced in the project. It is about connecting workers' productivity with project performance, which is not easy to do. Productivity involves a series of complex processes that workers perform.

If the legality could be found on the significant set of projects or on several projects of best practice, based on the average productivity of workers on projects that are analogue by its nature, then the conclusion could be performed.

Considering the average productivity of workers per day and performed activities, based on applied monitoring and control methods, the conducted research prove the relationship between additional work, motivation and time pressure in projects. The additional work is therefore defined as rework or set of unplanned activities that should be carried out within the previous determined plan. The workers' productivity is measured by relative (%) difference between average workers' productivity before, during and after applying the additional work on project.

A case study is chosen as the main research method, which allows a deep analysis of some of the best practice projects in Croatia.

It is very important to taking into account the various possible causes that have the identical effect as additional work, but still doesn't derives from it and are not relevant for this research.

The figure 2 show the resume of additional work sources and analyze of it into three main components: organizational, technical and human component. The each component is further analysed into its parts. It is the framework for conducted research.

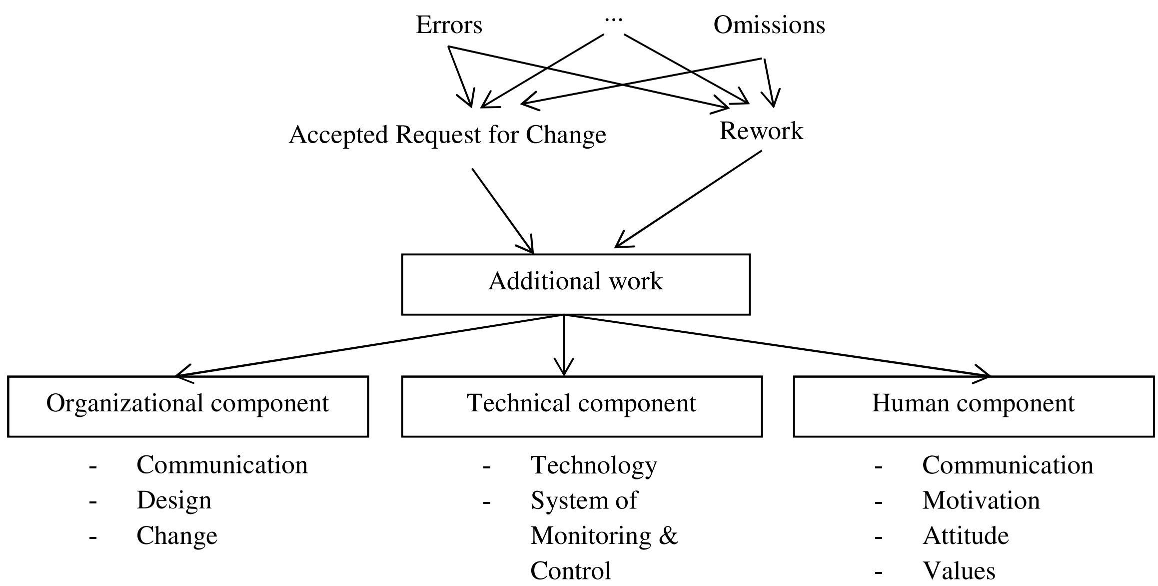

Figure 2. The source and components of additional work on construction projects

4. Case studies

The research included case studies of three construction projects in Croatia. The projects are chosen by criteria of Croatian construction industry best practice in the mean of applying project management procedures and methods as well as achieving the project management success. Two of them had private and one of them (Case study 2) had public investor. All of them are finished and achieved project management success.

It was very important to analyse all planned and performed information on projects and to ensure the research relevance for answering the research question.

4.1. Case study 1: Business building construction, Business Complex Radnička

The construction project which is observed here planned to last for 137 working days and had MS Project plan which was contracted. The monitoring and control system consisted of monitoring planned and realized amount of concrete (in m^3), gross area that was closed and ready for installers and other experts who follow the completion of construction structure (in m^2), as well as number of workers and performance in overall. After several weeks of realization within the planed one, the time delay occurred (at the first third of construction performance, see figure 1 and 2). It lasted until the number of workers had been increased for 77%. So there was additional work because of time pressure that had to be done. By the plan, during this time the workforce should increase for 40%. If we engage the increased (actual) number of workforce in the simulation of plan, it turns out that reaching the plan should come 10 days before it really happened. The results of analysis showed that the labour productivity, measured according to the average performance of workers, were about 10% weaker than at the period of realization according plan. Moreover, after the realization exceeded the planned performance, labour productivity slightly increased as well (for about 8%). Finally, the project was completed on time and achieved project management success.

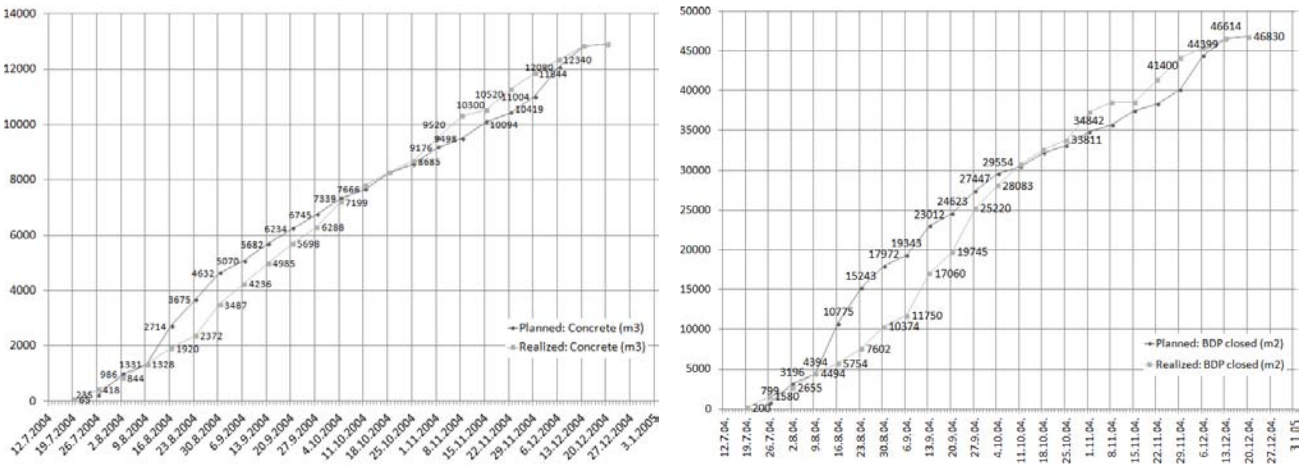

Figure 1. The S-curve of planned and realized amount of concrete (case study 1) and closed gross area (BDP) in case study 1

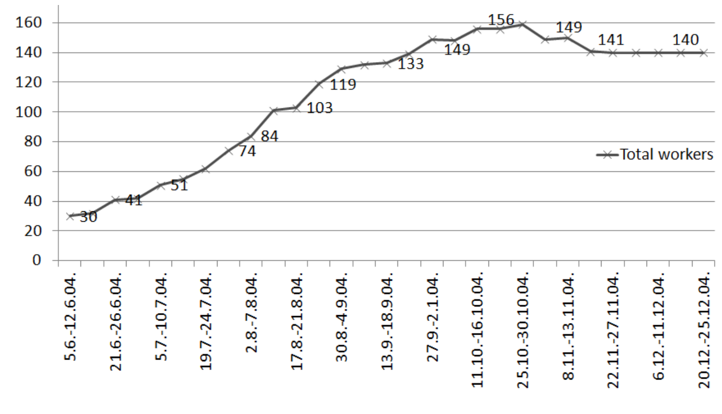

Figure 2. The number of workers during the considering construction performance in case study 1

4.2. Case study 2: Construction of Emergency medical services

The considering building has finished with construction phase on 2009. It has about 14.000 m2 and is consisted of eight floors. There is an emergency ambulance with reanimation, emergency alarming service for the whole city, patient injury clinic and medical educational centre with multi-storey garage for 170 ambulance vehicles. The Investor was the City of Zagreb.

There was an additional work for ensuring the stopping a possible rush of emergency vehicles under high speed, when exiting the multi-storey garage, in the case of failure of its breaks.

There was plan schedule in MS Project for the construction phase of project and monitoring and control system, which gave the weekly information about distinction of realization from planned ones. The realization was mainly followed planned schedule. There was slightly standstill because the required additional work demanded additional calculations and designing auxiliary steel structure, but the difference between planned and realized was only about 2%. From the time that this problem was recognized to the time that planned and realized had maximum deviation, the impact of this additional work increased this deviation to 5%. As the additional work was not in the initial plan, the plan had to be revised. At the time of revising the plan, which happened after finishing the whole preparation for building the auxiliary steel structure, the labour productivity, measured according to the average performance of workers, were about 8% weaker that at the period of realization according plan. After revising the plan, there was impossible to compare new productivity with earlier one because the reference point for comparing was the initial plan which has been changed. The project had one external time pressure requirement, which came from investors. It contained a request to shorten the construction phase period for 2 months. The key participants argued about it, especially contractor, but the importance and authority of investor is enabled that the project had achieved the new deadline, after the second revision of the plan. The contractor had to engage 15% more workers on the site, but the motivation was the award for earlier completion of work. The detailed analysis of performance and schedule was done for this situation. It appears that there was no decreasing productivity after shorting the deadline, which can be explained by motivation to get award of earlier completion of work.

4.3. Case study 3: Hotel Eden

Construction phase of Hotel Eden planned to last for 110 days. It consists of three parts: restaurant Oleandar, external swimming pool and wellness with additional facilities. In this project the plan was not designed in the detailed way. The monitoring and control system was applied after contracting the whole project and after the final plan approval.

The defects of plan were revealed very soon. The monitoring plan compared the planned and realized activities of main work groups, which were divided in the three main parts: restaurant Oleandar, external swimming pool and wellness with additional facilities. The work groups included earthworks, masonry, reinforced concrete works, electrical installations, and mechanical installations etc., for the each part of it. The greatest defects of the plan were done because the contractor put the start of activities towards the beginning of the project, so that they overlapped unrealistically. It caused the apparent delay in starting of the majority of group works, while activities were not even supposed to start practically. During the works the delay seemed to be decreased, while the plan was caught up the project realization. As the project was coming to the end, the delay was reduced. At the time of two weeks before planned end of the project, it was clear that the project would possibly be delayed for 2-3 days, which was acceptable for achieving the project’s success. Since the plan defects were noted at the beginning of the monitoring and control system applying, the project was monitored by two parallel systems: one by existing contract documentation and the other one by expert adjustment of existing plan, which complemented the measurable project parameters and gave the expert explanation of state of the project.

Without detailed analysis of plan, one could conclude that there is a time pressure and overrun in the early beginning of the project realization, which was not true.

Analysis of this project suggested that case study is the right research method for researching an impact of additional work on project success and that there are many preconditions that have to be clarify before any conclusions. This case study research resulted with list of concerning things to control the appropriateness of project choice.

5. Conclusions and future work

Exploring the impact of the additional workload to productivity is very challenging because the overlap with other similar issues in project management is significant. Precision, accuracy, reality and applicability of plan are limitation of research and the main reason why it is conducted only on 2 case studies. In other words, the quality of planning phase is crucial because it is impossible to make any conclusion if the plan has no listed properties (see 4.3.). Research has shown reduced performance productivity in applying additional work on projects (about 8-10 % weaker then at the time of realization according plan). The answer to the research question is: there is relationship between additional workload and productivity in the construction projects.

Creating a database with a large number of projects would provide more relevant results and enable wider conclusions. Moreover, further research could find the amount of organizational, technical and human component as parts of this impact. There was also increased productivity with reduced time pressure or extra motivation to complete the project, from which can be assumed that there is a relationship between motivation and productivity as well. Further researches include testing this relationship on greater number of projects before further conclusions.

For larger projects, a 10% decrease in productivity can certainly contribute to achieving the success of the project and this percentage should not be ignored. In other words, if additional work is applied in the project, the workers' productivity should be calculated with 10% weaker than average or it could be compensate with more time needed than expected after revising the original one with new activities of additional work.

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Mechatronics systems and logistic service for ensuring the smooth construction process

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Abstract

The article considers possible structures to integrate ERP [1] systems at a building enterprise with low - end information and mechatronic systems – AMS (automated management systems) and MES (Manufacturing Executive System) which handle technological divisions as well as read necessary information. To achieve the information integrity of the construction process a multiagent control system of information and resource flows of industrial divisions together with a mathematical model of the operation is suggested.

Keywords: ERP-system; MES-system; logistic service; TIA technology; intelligent agent; mechatronic systems.

1. Introduction

Features of the robotization and automation:

- Tele-existence system

The remote operation system utilizing stereoscopic image and other virtual reality (VR) technologies allows the operator in the control room to remotely control operations at the site feeling.

- Bidirectional vehicle control system

The bidirectional vehicle control system controls vehicles by bidirectional control and vehicle information.

- Audio video transmission system

The audio video transmission system provides the operator with audio image information required for remote control.

- Remote survey system

The remote survey system uses a global positioning system (GPS) and an automatic tracking total station (three-dimensional laser positioning machine)

- Vehicular operation and work progress system

These systems output and display the survey information obtained by using the remote survey system through printers and monitoring screens.

- Excavation support system

The survey information obtained through the remote survey system is automatically processed and linked with information on vehicles (posture and inclination) as well as information on the planned excavation profile, before it is provided as stereoscopic visual information for excavation.

The main challenge in designing mechatronic systems (MS) is developing such MS configurations which main function is control maneuverability.

At present this trend is connected with the realization of the decentralized control of technological divisions. In this case the industrial system is thought to be a conductor of basic information and resource flows of the system(fig. 1), which means it should ensure a high control maneuverability.

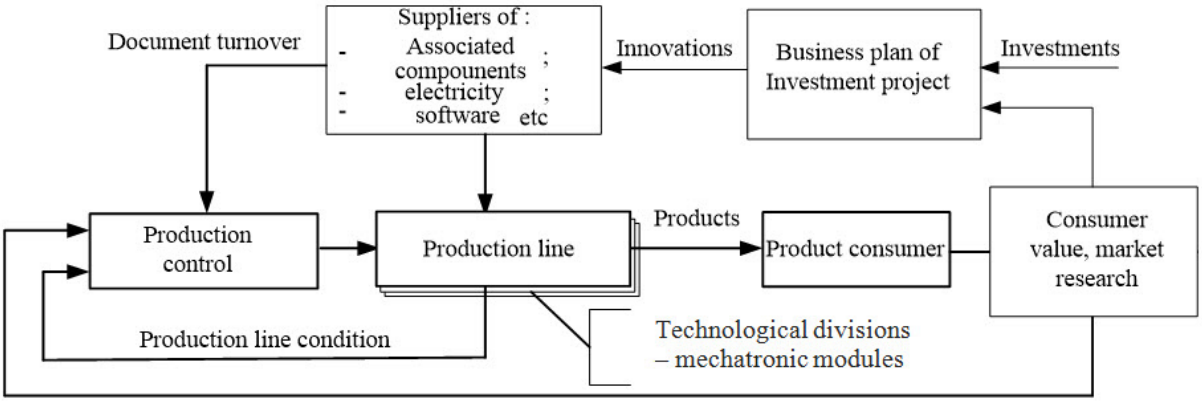

Figure 1. Basic information and resource flows of production system

For the last 20-30 years the integration of such production systems has reduced the production - related costs to an extent which the present stage of science and technology development makes it possible. The intensification of specialization as an indispensable factor of the phenomenon in its turn implied an adequate development of cooperation and integration of managing subjects.

Marketing goods with relatively short life spans accompanied by increasing consumer demands on the product quality has led to substantial changes of both goals and logistic service technology The conventional supply chain despite introducing logistics as functional management responsible for material flow control and corresponding information and finance within the cycle of some companies could not ensure the level similar to the production field.

2. Enterprise resource planning

Enterprise resource planning (ERP) integrates internal and external management information across an entire organization, embracing finance/accounting, manufacturing, sales and service, customer relationship management, etc. ERP systems automate this activity with an integrated software application. Its purpose is to facilitate the flow of information between all business functions inside the boundaries of the organization and manage the connections to outside stakeholders.[1]

ERP systems can run on a variety of hardware and network configurations, typically employing a database as a repository for information.[2] ERP systems typically include the following characteristics:

- An integrated system that operates in real time (or next to real time), without relying on periodic updates.
- A common database, which supports all applications.
- A consistent look and feel throughout each module.
- Installation of the system without elaborate application/data integration by the Information Technology (IT) department.[3]

3. Supply chain management

Supply chain management (SCM) is the management of a network of interconnected businesses involved in the ultimate provision of product and service packages required by end customers (Harland, 1996).[4] Supply chain management spans all movement and storage of raw materials, work-in-process inventory, and finished goods from point of origin to point of consumption (supply chain).

Another definition is provided by the APICS Dictionary when it defines SCM as the "design, planning, execution, control, and monitoring of supply chain activities with the objective of creating net value, building a competitive infrastructure, leveraging worldwide logistics, synchronizing supply with demand and measuring performance globally."

This is why the development of such logistic concept as Lean Production(LP) and the Just -in-time principle in 1990s was further shaped into the concept of Supply Chain Management(SCM) which is defined as the integration of key business processes starting with the final consumer and embracing all suppliers of goods, services and information thus adding value for consumers and other interested individuals.

When the term SCM was first introduced it was used as synonym to "logistics" and "logistic management". In recent years the meaning of the SCM category has changed and is now considered a new business concept. Positive attitude to the SCM concept has resulted in reconsidering the definition of logistics as it is. According to the definition given by the Logistic Management Council (USA) in 1998 logistics is part of the process in supply chains wherein an effective and efficient flow of goods their supplies, service and related information is planned, implemented and controlled from the point of their originating to the point of their consumption in order to meet the consumer demands [1].

So the supply chain management tends to be a more global category than logistics. It is the network which prevails as an organizational structure rather than the hierarchy. The network of small systems is far more sensitive to market changes than large bureaucratic structures. Specialists no longer argue about key business processes of SCM related to different levels of the control system which interaction is realized in the network structure of the industrial communication system.

The components of such systems implementing TIA technology [6] in the SIMANTIC NET [7,8], shown in fig 2, serve as the fundamentals to provide industrial communication in case of large scale construction projects, within the frame of a construction object, in the technological process. There have been suggested ways to solve control problems which make the most of all the advantages of the Ethernet and imply vertical data communication from the field level to the corporate management level with a wide use of information technologies.

The development of information integrity is progressing from connecting separate automated areas to programmed cooperation of all offices, design departments and technological divisions. With soft web-technologies such integration can be realized through online channels of several enterprises, suppliers and even consumers. The ways of integration of multiple functions at the plant as well as outside it are as varied as the ways of local automation and construction production control. The advantages of such programmed integration being advertised or as countless as the quantity of different exact customer conditions.

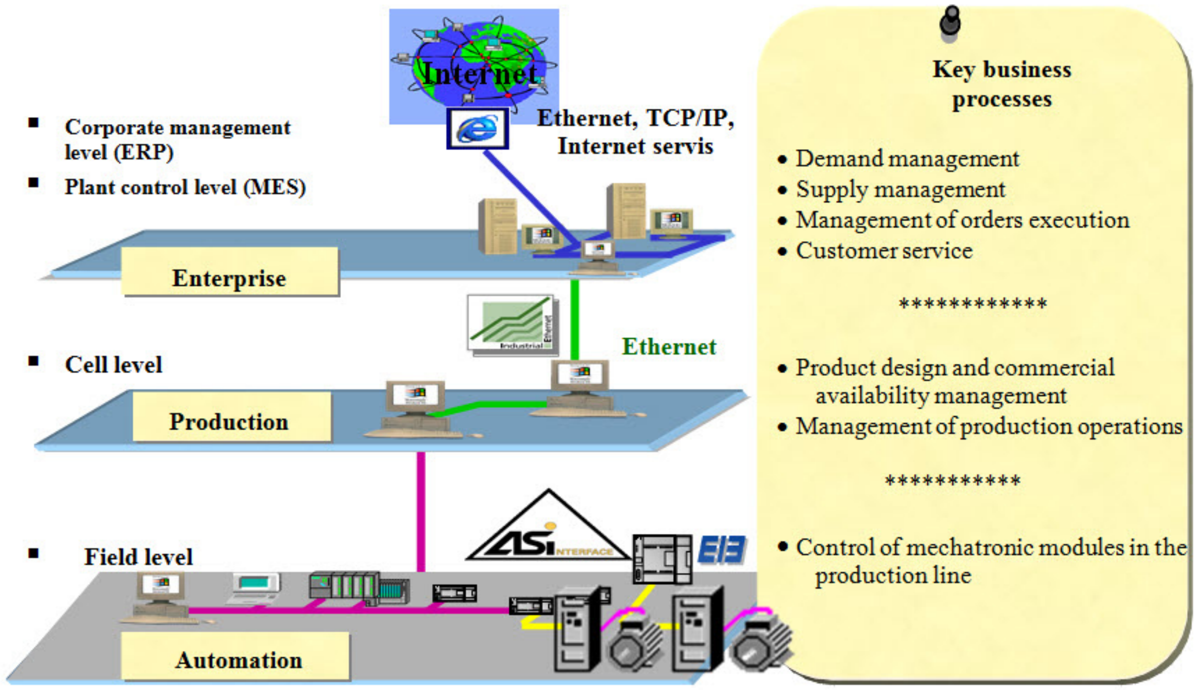

Figure 2. Network communications in TIA-technology

The research made by many authors and consumer data speak of the fact that the effective interaction of different levels increases the production growth rate without plant refurbishing by 10-25%. The set of the function performed can be implemented by way of specific intelligent modules or increasingly as off-the-shelf software packages of one or several suppliers. I due time software manufactures divided the market and found their own areas corresponding to different plant levels: systems of regulation execution production systems, cooperate management systems as well as CAD and office systems. However within the time the borders between them are beginning to smooth over. The customers' need of greater availability and cheaper ways of connecting systems to make information obtained from different divisions compatible appeared.

The influence of the Internet on the efficiency of business activity has resulted in making selling goods with decision making concerning planning projects, their implementation, material shipping and handling all the supply chain through the "Portals of Intelligent Logistics". The key to understanding the "Intelligent Logistics" is the "Intelligent Agent Concept".

The basic feature of the second generation multiagent logistics is replacing the bar code with electronic markers, each of them containing an agent.

This kind of commodity coding will enable to develop mechatronic systems for monitoring and material handling through the delivery process from the supplier to the construction site. These mechatronic systems based on the multiagent structure to control business processes within the ERP system will incorporate the following elements:

- Intelligent distribution of goods on the shelves (in warehouses).
- Intelligent robots capable of searching goods according to the data read from the intelligent codes, unlike conventional robots which can just deliver a commodity to a definite point.
- Intelligent transport systems (lorries, stand-alone means of transport, conveyors) capable of determining the kind of goods contained in them and transmitting this information further along the system if necessary.
- Intelligent systems designed to control the environment of storing goods and which a capable of detecting the proper conditions for storing each of the commodities.
- Intelligent commodity sorting systems that can sort out commodities in accordance with the data recorded in their codes.

4. Intelligent agent for the operation

Last years at the area of mechatronics, robotics and artificial intelligence multi-agent technologies and multi-agent robotic systems are actively developed [5]. At this case robots or mechatronic machines are considered as intelligent agents having own databases and knowledge bases and communication channels for information exchange between themselves at global task solving process.

Multi-agent robot system (MARS) represents a group of autonomous robots, which corporately solve common task in real time in dynamic environment. The paper describes methods of multi-agent control of MARS and neurocontrol of mobile robots-agents. To solve the problem of MARS control in real time, it is proposed to combine methods of artificial intelligence (AI) and neurocontrol. Multi-agent control system has a hierarchical structure with parallel processing features. It includes strategic and tactical levels of control. At the strategic control level a number of problems is solved: common MARS task decomposition into series of local sub-tasks of robots-agents, optimal sub-task distribution between robots-agents, global environment modelling and avoidance of robot collisions.

Agents operate as distributed problem solvers and work together to accomplish the tasks in the system. Various control frameworks have been developed for execution of tasks by agents in the system. Control frameworks consider that the agents are aware of their tasks and provide for the controls to complete the tasks in the dynamic, changing and uncertain environment of the system. But tasks in multi agent systems are not always predetermined and may evolve over time requiring dynamic planning for not only the controls but also the determination of tasks for the agents.

In order to control information and resource flows of mechtronic production system considered above (fig. 1) a team of five agents can be organized responsible for planning, maintenance, operation, safety and administration, each of them being a miniature system with knowledge base which functioning can be represented by three stages: setting a goal, receiving results, evaluating operation effectiveness.

Each agent performs one operation in S_0-system, that is the production line making this operation and that is why the execution of the operation can be thought to be a process of changing its states in the multitude (Z) of all possible states of S_0-system. In this case an intelligent agent of S_0-system is a mathematical model of the operation (Ψ) designed to solve the problem of quantitative evaluation of effectiveness (W) as the criterion of the rate of the correspondence of an actual (predicted) result (Y) of the operation to the result desired (Y^d) or the goal achievement rate (A_0) of the operation, expressed by the result desired (Y^d).

Quantitative and generally vector numerical values (W(u)) are obtained for all strategies (u) from the multitude of possible strategies considered. Each of these values (W(u)) characterizes a level of effectiveness(goal achievement rate) of the operation in use of the strategy given ($u \in U$).

In general the problem of evaluation of operation effectiveness can be represented by a formal equation of the following kind:

$$W(u)=M[\rho(Y(u),Y^d)]; \tag{1}$$

$$\Psi : \{Y \mid H : U \times \Lambda \xrightarrow{\theta} Y(G)\} \xrightarrow{\theta} W \tag{2}$$

where Λ - multitude of definite and indefinite factors forming the environment of the operation; Y^d - operation result desired; Y - operation result that is the vector of characteristics of the outcome ($g \in G$) of the operations significant for achieving the goal (A_0) of the operation, expressed by the result desired (Y^d); M - a sign of mathematical expectation; ρ – a function of correspondence; H - a model of the operation result enabling to calculate the values (Y(u)) of the operation result (Y) for each strategy ($u \in U$) Ψ in (2) is the reflection of the multitude (U) of possible strategies into the multitude of values of effectiveness indicator (W) with consideration of (1) and is usually given in the form of a definite mathematical model of the operation.

In the multiagent control system of information and resource by (1, 2) can be used to create a structure of programmed genes suitable for all five agents. Such structure shown in fig. 3 enable us to evaluate the effectiveness of operations, for example, planning and maintenance. The agent of planning has a goal to reduce the cost of products (A_0) and to determine a rational volume and types of orders for manufacturing this or that product on the basis of the business plan (Λ) and the results of market research. To be able to choose the best marketing steps (U* - strategies) the agent "holds the negotiations" with suppliers in the form of an auction using submodels (P_u, P_Λ) which are models of preferences (P). Similarly on the basis of submodels of preferences (P_G, P_Y) and with consideration of the data (θ_H) of available means to build the models (H) the characteristics (Y) of the outcome (G) are chosen, the kind of correspondence ($H : U \times \Lambda \rightarrow Y(G)$) is set and the value of the result desired (Y^d) is estimated.

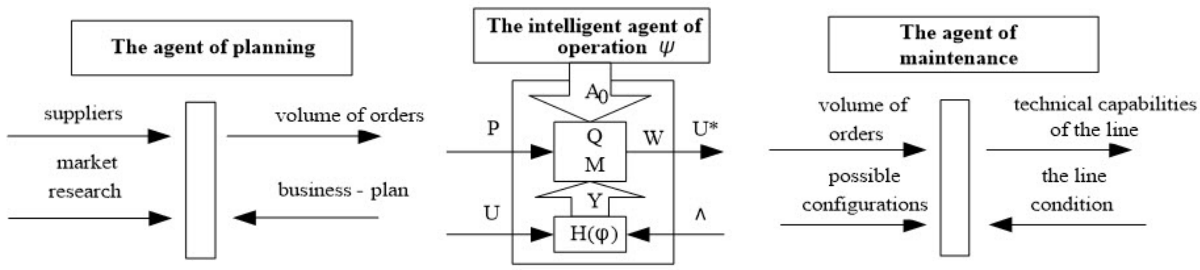

Figure 3. The structure of the intelligent agent for the operation

Then based on the data (Y, Y^d) and preferences (P_w) concerning the type of the effectiveness indicator one of the possible kinds of the parameters ($\rho(Y,Y^d)$) is set and the model "result-indicator" is formed. At the same time the criterion (K) based on the data and submodel (P_K) can offer a criterion in the form of the decisive rule. Based on the consideration about the goal achievement rate of the operation the best option from the multitude ($U^* \in U$) is picked up or some elements of the model of the problem situation are returned and corrected.

Thus in the process of receiving results the correlation (2) is obtained while analyzing the results leads to the following correlation:

$$P \xrightarrow{\theta} K : U \xrightarrow{W} U^*. \tag{3}$$

The goal of the agent of maintenance is to minimize time and energy consumption necessary to produce a product. A great deal of factors (Λ) form the agent knowledge base of the technical state of the line, which possible configurations (U) make it possible to estimate its technical capabilities considering the models of preferences for the best marketing steps of the agent of planning.

The parameters (Q, M) reflect the multitude of the operation results (Y) into the multitude of the effectiveness indicator (W). Under this circumstance the multitude (Y) together with the parameter of the correspondence ($Q: Y\times Y^d$) is reflected into the multitude of the function of the correspondence (ρ), while the operator for averaging out transform the multitude of the values of the function of the correspondence (ρ) into the multitude of the values of the effectiveness indicator (W) i.e. $Q \bigcirc M : Y \rightarrow W$. The superposition of the parameters $Q \bigcirc M$ determines the correlation of given effectiveness indicator to the operation goal (A_0) expressed by the result desired (Y^d). A certain type of the parameter depends on the behavior of numerous factors and relations between them which must be considered while evaluating effectiveness.

When certain properties of the operation are not given the agent has a possibility to determine the trajectories of functioning of the system (Z_T, Y_T), whereas the data of input effects ($U\times\Lambda$) can be used to predict both the operation result (Y) and the state of the S_0-system. In this case the parameters (φ, H) called transform and output parameters correspondingly can be introduced and recorded in the following:

$$\varphi : Z\times U\times T\times\Lambda\rightarrow Z; \quad (4)$$

$$H : Z\times U\times T\times\Lambda\rightarrow Y(G). \quad (5)$$

Each point in the trajectory (Z_T) of the states of the S_0-systems and in the trajectory (Y_T) of the operation results found with the help of the parameters (4) and (5), characterizes the state of the system (Z_t) and the value of the operation result (Y_t) at a definite moment of the time.

The main aim of control for global telecommunication and computer networks (TCN) is a fast search and delivery (transportation) of necessary information to TCN users-agents with high quality of submitted services.

So the general problem of control and multi-agent processing of information in TCN may be divided on four interconnected sub problems:

- control for data flows between TCN agents with adaptation to different kinds of heterogeneous traffic;
- organization for multi-agent dialogue between TCN agents;
- telecommunication equipment control;
- administrative control for productivity and configuration of TCN.

In global TCN (for example, Internet) [10] control for transfer and distribution (routing) of data flows between agents should be done not on severe program but “in loose” on changing unpredictably users or nodal TCN components requests.

Traditional approach to TCN control does not provide interactivity in real time (for example, speech dialogue without relays) often. The other disadvantages are non-adaptively (by relation to changing traffic) of control for data flows, impossibility for automatic avoiding of network conflicts, fault recognition and TCN reconfiguration without human (administrator or network operators) participation.

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Errors in the preparation of design documentation in public procurement in Poland

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Abstract

The system of construction design completion most frequently used in Poland is the traditional one. In this system, the client describes the subject of the order by means of design documentation and technical specifications of construction and commissioning of building works. The article analyses the most frequent errors that appear in design documentation, discusses the reasons for their occurrence and specifies their possible consequences.

Keywords: design documentation, public procurement, constraction

1. Introduction

The basis of an appropriate bidding procedure concerning construction works is the correct preparation of documents describing the subject of the order. In the case of orders involving public funds, the client must obey the relevant regulations, especially ones specified in the Public Procurement Law. Although the regulations came into force years ago and even though there exist numerous master documents, clients continue having problems with an appropriate preparation of design documentation describing the subject of the order. As a result, a number of issues ensue on both the bid preparation and project completion stage. In many countries extensive researches on problems with an appropriate preparation of design documentation were carried out (Love, Lopez & Kim, 2014; Lopez & Love, 2012; Dosumu & Adenuga, 2013).

The aim of the article is to analyse the errors that occur most often in describing the subject of the construction order when the client separates the design contract from the construction works contract.

2. The scope of design documentation

Construction works consist of two stages. The first involves designing the building, while the second embraces works execution on the basis of design documentation.

In the traditional form of construction works completion, the design stage is separated from the construction one. In this case, the investor first orders designing a project and then, when the design is ready, execution of works. In the other form, one contractor is entrusted with both design preparation and construction completion (Design & Build). Both systems are described in the Polish law (Act on Public Procurement Law of 29th January 2004, as amended), as the possible ways of contracting construction designs in the public sector.

The traditional system of completing construction works designs is the most popular and most commonly implemented one (Harris, McCaffer & Edum-Fotwe, 2006). In Poland as many as 99% of public investments are done within this system. Here the client describes the subject of the order by means of design documentation and technical specification of construction and commissioning of building works.

The scope and form of design documentation are regulated by the Regulation of the Minister of Infrastructure from 2nd September 2004, concerning the detailed scope and form of design documentation, technical specifications of construction and commissioning of building works and the functional-utility program (Journal of Laws No. 202, pos. 2072) as amended (subsequent amendments of 22nd April 2005, Journal of Laws No. 75, pos. 2075, of 23rd April 2010; Journal of Laws No. 72, pos. 464 and of 18th February 2011, Journal of Laws No. 42, pos. 217).

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The scope of design documentation differs depending on whether or not it is necessary to obtain a building permit. In the case of the necessity of a building permit, design documentation consists of a construction design which includes the specificity of construction works, detailed designs, bill of quantities of the works, as well as the information about safety and health protection, when its compilation is required by separate regulations.

3. Errors in construction and detailed design projects

The content of a construction design, as it is required in Poland, was defined by the Act on the Construction Law. The Act mentions only the construction design, which is necessary to prepare when one needs to obtain a building permit. The construction design should contain the following: land or plot development plan, architectural and construction plan, specifying the function, form and construction of works in question, their energy and ecology performance, also including suggested technical and material solutions.

In accordance with the needs, the design may also contain declarations about ensuring a supply of energy, water, heating and gas, sewerage; statements about the conditions of connecting the building object to systems of water supply, sewerage, heating, gas, electroenergetic, telecommunication and roads; a declaration about the possibility to connect the plot to a public road; a geology engineering report and geotechnical conditions of foundation of a building object.

The aim of the detailed design is to complement and provide details to the construction design to the degree necessary to formulate the bill of quantities of the construction works, an investment cost estimate, to prepare a bid by the contractor (in the form of a tender cost estimate) and to facilitate the subsequent execution of the construction works. In sum, the detailed design is prepared in order to complete the works.

Errors in the preparation of designs, in both the construction design and the detailed design, are an inseparable part of preparing a construction investment and, unfortunately, they tend to occur frequently. A simple definition of a design error is "a deviation from the plans and specifications" (Suther, 1998).

An analysis of errors committed in designs reveals a possibility of dividing them into categories according to the place of their occurrence: technical description, engineering drawings, calculations. Another categorisation is one according to the person: investor, architect, discipline-specific designer. Categorisation according to the type of error includes: discrepancy in the design, discrepancy within design documentation, lack of information, incorrect or incomplete information, errors in designing. The most frequent errors in construction and detailed designs in public procurement in Poland were included in Table 1. All the errors were categorised in accordance with the type of error, its place of occurrence and the person responsible for the appearance of the error.

Table 1. The most frequent errors in designs.

Error groups	**Person responsible**			**Place of error in a design**
	Investor	**Architect**	**Discipline-specific designer**	
Discrepancy in the design		Discrepancy between technical description with drawings		*Technical description*
		Discrepant information in individual design disciplines		*Technical description, drawings*
Discrepancy within design documentation	Discrepancy between the design's bill of quantities			*Drawings*
	Discrepancy between the design's technical specifications			*Drawings*
No information		No information required		*Technical description*
		No dimensions in drawings		*Drawings*
		No detailed information about technology or materials		*Technical description, drawings*
	No design assumptions	Excluding data, i.e. load, ground conditions		*Drawings, Calculations*
Incorrect or incomplete information		Incorrect or incomplete description of elements		*Technical description*
		Incorrect dimensions in drawings		*Drawings*
	Incorrect design assumptions			*Drawings, Calculations*
		Incorrect description of materials		*Technical description, drawings*
Errors in designing		Discontinuity of the elements designed		*Drawings*
		Lack of required elements		*Drawings*
		Discrepancy between elements designed and law,		*Drawings, Calculations*

standards, rules of art		
	Errors in calculations	*Calculations*

There exist a few main factors which cause errors to occur in designs. They include the following: designers' lack of construction knowledge or experience, lack of time to prepare a high-quality design documentation, working on two-dimensional documentation which hinders design verification, lack of coordination between subjects, wrongly defined or imprecise scope of duties, human errors.

4. Errors in bill of quantities

The requirements concerning the bill of quantities, which constitutes the description of the subject of a public procurement on construction works, are specified in the Regulation of the Minister of Infrastructure of 2nd September 2004 on the detailed scope and form of design documentation, technical specifications of construction and commissioning of building works and the functional-utility program (Journal of Laws No. 202, pos. 2072 as amended). According to article 6, section 1, "A bill of quantities of construction works should contain a list of basic works predicted to be completed in the technical order of their completion together with their detailed description or indication of the basis establishing a detailed description and indication of appropriate technical specifications of construction and commissioning of building works, with the calculated and listed bill of quantities items of basic works". As the article states, the bill of quantities of construction works should include the following: the title page, an index of the sections of the bill of quantities and a table of the bill of quantities. The information that should be included in the individual sections of such a compilation is listed in Table 2.

Table 2. The contents of the bill of quantities (BOQ) of construction works

elements of BOQ	**Information required in the given element of the bill of quantities (BOQ)**
Title page of BOQ	1) name of the order given by the client; 2) depending on the scope of construction works specified by the subject of the order – names and codes: a) works groups, b) works classes, c) works categories; 3) address of the construction object; 4) name and address of the client; 5) date of the BOQ completion.
List of BOQ sections	1) division of all works in a given construction object into work groups according to CPV; 2) further division of the BOQ according to the taxonomy established individually or taxonomy employed in publications concerning standard cost-estimates of non-cash outlays; 3) in the case of works involving multiple construction objects, the list of sections should additionally include the division of the whole investment into construction objects – the work group concerning ground preparation should constitute a separate section of the BOQ for all of the objects.
Table of BOQ	1) BOQ items related to basic works; 2) numbers of the BOQ items; 3) codes of BOQ items, specified according to the taxonomy of works established individually or on the basis of publications concerning standard cost-estimates of non-cash outlays; 4) numbers of technical specifications of construction and commissioning of building works including the requirements for individual BOQ items; 5) names and descriptions of BOQ items, and calculations of the number of units of measure for BOQ items; 6) units of measure concerning the particular BOQ items; 7) number of units of measure for the particular BOQ items.

Errors committed in the bill of quantities can be classified as follows: formal errors and calculation errors. Formal errors – relating to the discrepancy between the bill of quantities as part of the design documentation describing the subject of the public procurement for construction works and the requirements of the Regulation mentioned above. A synthetic compilation of formal errors that occur in the bill of quantities are presented in Table 3.

When considering the reasons for which formal errors occur, one needs to take into account such aspects as: lack of knowledge or experience of the people preparing the bill of quantities documentation, especially their poor knowledge of public procurement laws and regulations concerning the bill of quantities of construction works; incoherency of construction designs, detailed designs and technical specifications of construction and commissioning of building works.

Table 3. The content of the bill of quantities (BOQ) of construction works

Elements of BOQ	Formal mistakes
Title page of BOQ	1) providing erroneous CPV codes of works;
List of BOQ sections	1) a free division of all construction works into BOQ sections, failing to divide works into groups according to CPV;
Table of BOQ	1) no reference to technical specifications of construction and commissioning of building works containing requirements for the particular BOQ items; 2) erroneous reference to technical specifications of construction and commissioning of building works containing requirements for the particular BOQ items; 3) lack of calculation formulas – providing only the final numbers of BOQ units of works.

Calculation errors occur in the discrepancy between the number of works calculated and included in the bill of quantities and the actual numbers that result from the technical documentation. When considering the reasons for which calculation errors occur, one may distinguish the following factors: the quality of construction designs and detailed designs – design errors are transferred to the bill of quantities; human errors – resulting from a large number of necessary calculations, the complexity of the calculation formulas and their laboriousness.

The bill of quantities should be in the form of a document that, to a large extent, facilitates the preparation of a bid compatible with the Regulation article 4 section 3, if the order for construction works "is granted as a single source procurement or, in the essential decisions of the contract, a lump-sum remuneration was agreed on, design documentation may not include the bill of quantities of the construction works". As a result, the risk involved in the preparation of the bill of quantities and the possibility of errors which may occur in the calculation of the number of works is taken by the potential contractors, not the client.

5. Errors in the information about safety and health protection

The duties of the designer involve, according to the Act of 7th July 1994, Art. 20, sec. 1, pt. 1b of the Construction Law, Journal of Laws of 2003 No. 80, pos. 718, preparation of the information concerning safety and health protection (referred to as "information") related to the specificity of the building object's design which will be included in the safety and health protection plan. Thus the information in question is essential to prepare such a plan by the construction manager, whose duty is to prepare it himself or to have it prepared in such a way that the plan contains the specificity of the building object and the conditions of conducting the construction works, including the planned simultaneous construction works and industrial production.

The designer's duty also includes the preparation of information for each investment for which a construction design is done. The safety and health protection plan is indispensable to be granted a building permit or a separate decision approving a construction design (Art. of 35 sec. 1 pt. 3 of the Construction Law). In addition, information concerning safety and health protection must be prepared in the case of the need to obtain the final decision about a demolition plan when the application includes a plan of the building object demolition.

The relevant authority that issues building permits, before granting permission or approving on a construction design, has to verify the completeness of the design, the required opinions, agreements, permits, verifications and the information about safety and health protection.

To preparation of the information is based on the construction design. The scope of the information is specified by article 2 of the Regulation of the Minister of Infrastructure of 23rd June 2003 on the information about safety and health protection, as well as the safety and health protection plan (Journal of Laws of 2003 No. 120, pos. 1126). The information about safety and health protection consists of the above-mentioned Regulation, a title page and a descriptive section.

The descriptive section, contains the following.

- the scope of the works for the whole construction project and the order of completing individual objects;
- a list of the existing building objects;
- indication of the elements of land or plot development that may pose a danger to people's safety and health;
- indication of possible danger existing during works completion, specifying the degree and types of danger, its place and time of occurrence;
- indication of the way employees are instructed before the beginning of particularly dangerous works.
- Indication of technical and organizational means preventing the risks that result from the conduction of construction works in places posing particular danger or in their neighbourhood, including those that ensure safe and efficient communication facilitating quick evacuation in case of fire, breakdown or other dangers.

The lack of knowledge of the health and safety regulations, lack of experience and inaccuracy may be the source of errors in the prepared safety and health protection information. The particular errors that may occur include the following:

- failure to indicate all the elements of land development which may endanger people's health and safety;
- incomplete specification of possible risks which may arise during construction works;
- incorrect specification of the degree and types of danger, or the place and time of its occurrence;
- incomplete specification of technical and organizational means preventing risks that result from the construction works in places posing particular danger or in their neighbourhood.

6. Consequences of errors in the subject of the order

The consequences of errors in the description of the subject of the order are taken by the client as early as at the bidding procedure stage. Contractors willing to prepare their bid correctly ask many of questions. Therefore, in order to receive an insight into the problems associated with the preparation of the bid, the results of construction works contracts announced by the authorities of chosen cities in 2010-2011 were analysed (Kozik & Plebankiewicz, 2013). The analysis involved the structure of questions based on the proceedings conducted in Krakow and Szczecin (in total 270 questions). Figure 1 presents the structure of the questions.

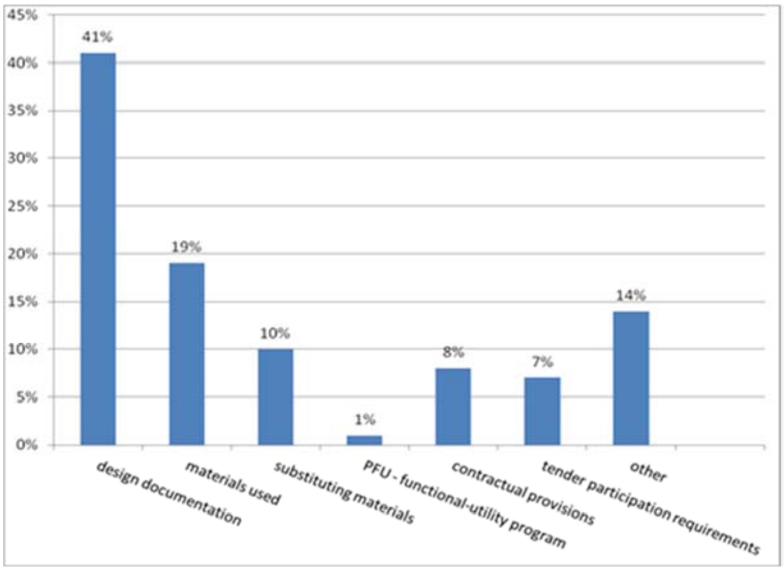

Figure 1. The structure of the questions (proceedings conducted by the Municipality of Krakow and the Municipality of Szczecin)

A significant number of questions involved project designs (41% of questions). Many of them asked about the building materials to be used. They included requests for more precise statements about the client's requirements concerning materials and questions about possibilities of using substitutes, which may be seen as the consequence of imprecise descriptions of these elements in the documentation.

Since the majority of questions were connected with design documentation, Figure 2 presents the scope of bidders' most frequent doubts associated with the design.

The greatest number of doubts found in questions concerning design documentation occurred in relation to the differences between the design and the bill of quantities of construction works. Bidders also noticed differences between technical specifications and the design. In some cases, the lack of dimensions in the design documentation hindered appropriate pricing and caused bidders' doubts whether the pricing should include those elements. Moreover, bidders indicated the lack of a particular item in the bill of quantities or the lack technical specifications, as well as incomplete information in the detailed design.

It must be emphasised, though, that questions do not necessarily mean gaps or improperly prepared documentation. Questions may just as well result from contractor's ignorance or the willingness to enforce the postponement of tender submission. What indicates that contractors' questions are valid and that the proceedings have been correctly prepared is, to a large extent, the necessity to introduce changes to the documentation. On the other hand, the need to introduce numerous changes to the documentation may cause tender submission postponement or, in extreme situations, cancelling the proceedings.

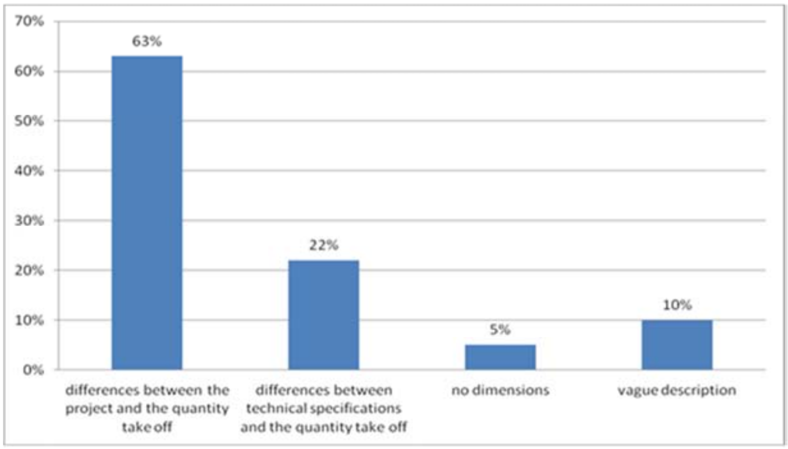

Figure 2. The structure of questions concerning design documentation

Changing or complementation of documents took place in about 31% of all proceedings and in about 90% of those in which questions were asked. This indicates that contractors' questions almost always lead to the introduction of changes. Changes in tender documentation involved completing the bill of quantities, adding drawings, changing and completing technical specifications, changing and completing significant terms and conditions of the tender, and changes in contractual provisions.

The most frequent and the most serious consequences of mistakes in design documentation at the stage of completion of the investment include the following:

- suspension of works until design changes are ready or discrepancies in technical documentation are clarified;
- increase in the contract value due to additional and complementary works when the scope and type of works have changed;
- a threat to workers' health and life.

7. Summary

A correctly prepared documentation that bidders receive in tender proceedings is a condition of the contractor's submission of a tender that fulfils the client's requirements.

The article indicates the errors that appear most frequently in design documentation and technical specifications of construction and commissioning of building works. An attempt has been made to evaluate the reasons of error occurrence and enumerate their possible consequences. When more attention is paid to the preparation of the documents by reliable designers, the client may avoid spending time and resources on the introduction of necessary corrections.

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Analysis of the "Design & Build" project delivery method in case of public construction project

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Abstract

Conceptual and design stages are two of most important stages that decide how the construction project is realized. However, theses stages are commonly underestimated, especially as investment budget factors. Furthermore, these stages are crucial for design companies and their strategic and operational decisions taking into account financial factors such as profitability, costs, cashflow etc. The evaluation of design works could be much more complicated than the evaluation of construction works based on design. The specific example is optimisation of tendering within contracts in the Design & Build formula where a design company becomes a subcontractor and depends on General Contractor whose aim is to cut costs on its subcontractors. Such situation is much more risky and uncomfortable than cooperation with public or private investor. Furthermore, the authors diagnosed and described the reasons of the problems connected with the implementation of the "Design and Build" formula within realisation stage of the contract. One of the main aims of that paper is to present and analyze the typical problems within the lump sum contracts.

Keywords: construction, costs, design and build, design stage, optimisation, tendering.

1. Conceptual and design stages of the construction investment

Investor (Client) requires optimization of the design and construction processes and products, appropriately from the Design Company and the General Contractor. This applies to conceptual stage, basic design as well as complex detailed design including structural, architectural, multi-trade and material solutions.

The typical structure of the investment project could be described as on following diagram:

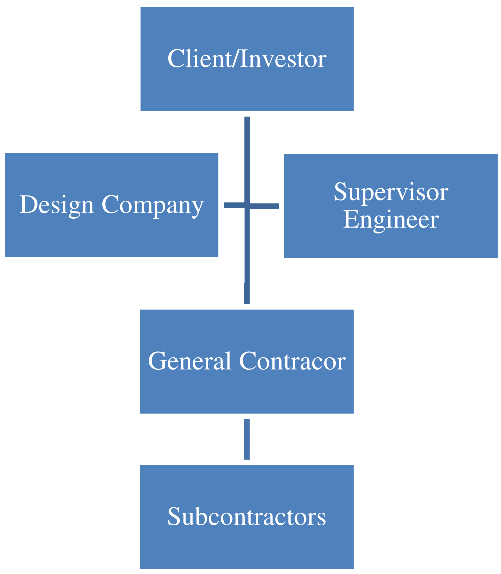

Figure 1. A diagram for a typical structure of the construction investment.

The example

Client (large airline company) signs an agreement for 20 year supply of aeroplanes to operate the air connection on a higher standard. In the tender, there participate the aeroplane manufacturers. The contract is valid for 20 years because it consists not only of supply and warranty but also of technical support and constant service. As a result, the potential supplier is obliged to provide the service (preferably at home airport). Therefore the component of the contract is the construction of the technical maintenance hangars. The following diagram illustrates the structure of the contract according to the "Design and Build" formula.

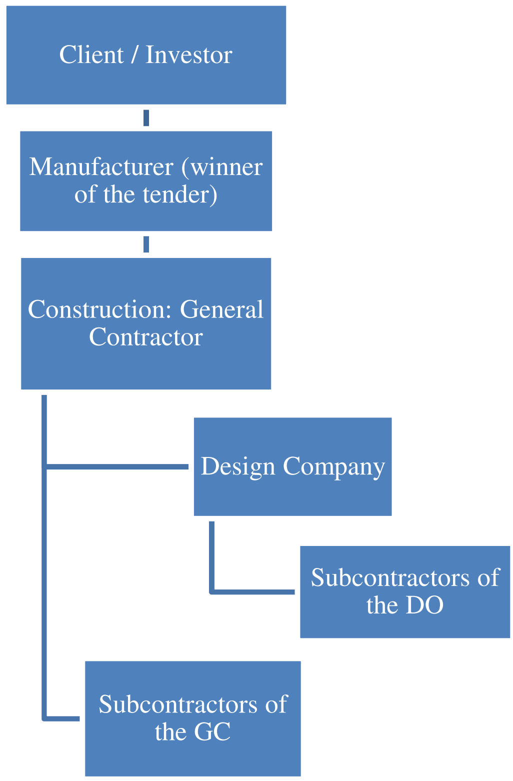

Figure 2. A diagram for a structure of the contract and Design & Build formula of the construction investment.

According to the "D&B" formula, the General Contractors employ design companies as designers. Thus, the design company becomes a subcontractor of the General Contractor instead of the Investor (Client), but depends on the Investor as the last one who still has its own requirements. This example illustrates that not only the Construction Contractor (e.g. a company specializing in earthworks or installation) can experience the "flavor" of cooperation with the General Contractor. On the other hand, the GC is dependent on the Manufacturer who won the tender and also from the Main Client (Investor). Each of these companies may be dependent on other companies (including international ones) or The State Treasury. The described situation shows how poor is the negotiating and business position of design companies in a new formula of contracts.

Each of the above-mentioned companies or institutions require at some stage of the project to be "good and cheap". The contract requires the above arrangements from the Manufacturer and General Contractor and GC, usually employed under the lump sum, demands that from its subcontractors, including the Design Company. This is despite the fact that GC often does not have staff with the required licenses, however holds wider knowledge of investment and construction than the Client.

Negotiating position of the Design Company, especially after a careless signing the agreement without adequate records, is weak and at best brings about poor financial results. The above-mentioned example proves that the General Contractor is in charge of finding the optimal technical solutions as well as the choice of the so-called compliant materials. As described above, the optimizing endeavors are generated in order to lower the costs while maintaining the highest possible quality and in the worst-case scenario - by meeting the minimum mandatory standards (under existing law requirements such as: urban architectural, structural and usable provisions, as well as industrial safety and fire regulations).

As described above, no attention is paid to the involvement of the Design Company because of the mutual agreement with the GC (usually a lump sum contract). One may say that since the Design Company signed a contract (similar to the contract for natural persons), people in charge of signing the agreement were aware of the resources and involvement needed to proceed. Is that true?

It turns out not to be easy to estimate. Experienced authors prove that it is even more difficult than to estimate the scope and expenses of the construction works. There is no universal method for calculating the value of design works. In Poland, the valuation of the design work in the construction industry has been unregulated since 1982. Instead of that there are rules developed by Professional Chambers: IPB (The Polish Chamber of Construction Design) and SARP (The Association of Architects of Poland). The document contains basic rules for calculating the value of the design works at different stages, depending on investment category, its value or size.

The difficulties in estimating the value of these works concern in particular investments which are innovative, unique, of complex function or infrastructure, i.e.:

- specialized industrial facilities,
- specialized infrastructure & communication facilities,
- scientific and technical facilities, health services, cultural institutions.

2. Realization stage of the construction investment connected with the “D&B” formula according to the lump sum

The basic element which allows the execution of a construction project is a contract description. Within "Design and Build" formula, the basic document describing the object of the contract is the Functional & Usable Program. The value of the contract at the stage of the announcement is determined on the basis of the planned design and construction works costs (in accordance with the Regulation of the Minister of Infrastructure of 18.05.2004 Journal of Laws No. 130, item. 1369). The Client may also present a conceptual design that is also a part of the order description. When it comes to large and complex projects within public procurement (mainly infrastructure) the preparation of relevant documents describing the object of the contract is extremely difficult and time-consuming. It requires multi-disciplinary knowledge as well as the involvement of the appropriate team of designers and experts. Unfortunately, very often the Public Client presents documents that show obvious shortcomings, mistakes and discrepancies between the documents describing the object of the contract. The example might be the assumption in the Functional & Usable Program description the technical equipment in defined numbers and parameters without necessary space for devices of this size in the conceptual drawings. Time pressure is also a significant factor. In the case of Public Client, time pressure is especially essential due to political reasons as the Client wants to show the earliest start of construction works. Preparing the contract and project design is also time-consuming but not as much visible as construction works. The Contractor participating in the tender is responsible for calculation of the order costs (required to make an offer) to which it is necessary to understand properly the scope of the project and works. The Contractor should carefully examine all aspects presented in the specification order and explain all doubts and questions with the Client. On the other hand, it requires large financial effort and time which often results in estimated costs. The above-mentioned expenses are not reimbursed. It can be assumed that some companies make an offer using lower prices on purpose knowing that they would be able to obtain the additional remuneration for additional work or by proving high loss.

The participants in the construction process are not always responsible for problems in the implementation of investment projects. It may happen that independent causes occur that significantly delay and / or increase the implementation cost. For instance: a disturbance with earthworks (unexploded bombs, archaeological discoveries, installation network) or simply bad weather. An excellent example of such infrastructure implementation is the construction of the second line of the underground in Warsaw.

For large infrastructure projects such as roads and railways, there is often a problem with insufficient or incorrect documentation on existing underground installations. In addition, it happens that the owner and administrator of the network runs an aggressive policy in order to replace or renovate their old facilities at the expense of the new investment. Such situation is extremely difficult for the Client as his refusal could be worse in consequences than an acceptance of the reconstruction suggested by the administrator. It is very likely that construction works carried out next to the old networks and devices may cause damage and interruptions in deliveries. The effects of these failures and interruptions in supply can significantly disrupt the implementation by extending the time of construction works, requiring additional works as well as increasing construction costs

[2] [3]. The optimization of the tender in the "Design and Build" formula should take into account both materially and financially all risks connected with these causes.

3. The effects of the problems connected with the implementation of the "Design and Build" formula of a lump sum settlement

It should be noted that in case of valuable and large investments in public procurement the Design & Build formula has become a dominant method of realization. The most common form of settlement, which is chosen by the Public Client, is a lump-sum fee, however there are exceptions to this rule, such as changes in tax rates. Moreover, construction contracts tend to be structured in a way that is not fair between the Client, Contractor and Designer, when it comes to rights and obligations. In many cases, there is a total loss of balance resulting in almost complete transfer of responsibility and risk to the Contractors. A common practice is the use of standard FIDIC contracts and modifying them in order to achieve the favorable meaning. Deleting the clauses of Contractor's claims makes the process much more disordered and unpredictable. The Client seems to believe that the lack of such entry in construction contracts releases him from the liability of those demands. Nothing of the kind. Each part may pursue their claims on the basis of the Civil Code.

The result of incorrect handling both tenders and offers for public procurement in the "Design and Build" formula are disturbances during the process and the disruption during the further implementation of the projects. Errors and inconsistencies in documents prepared by the Client are the source of many questions put by the bidders and as a consequence may cause a protest and result in re-announcement of the tender. The above interferences result in extending the time of construction works, requiring additional works as well as increasing the project costs. As regards the lump sum, the contractors meet difficulties with obtaining additional remuneration. On the other hand, it can be assumed that certain contractors decide to make an offer on a low price level, hoping that later on, by using aggressive policy, they would be able to obtain additional remuneration or to increase the implementation time . The scope of the problems shows the following chart with values of claims from State Tresaury within road infrastructure contracts in Poland.

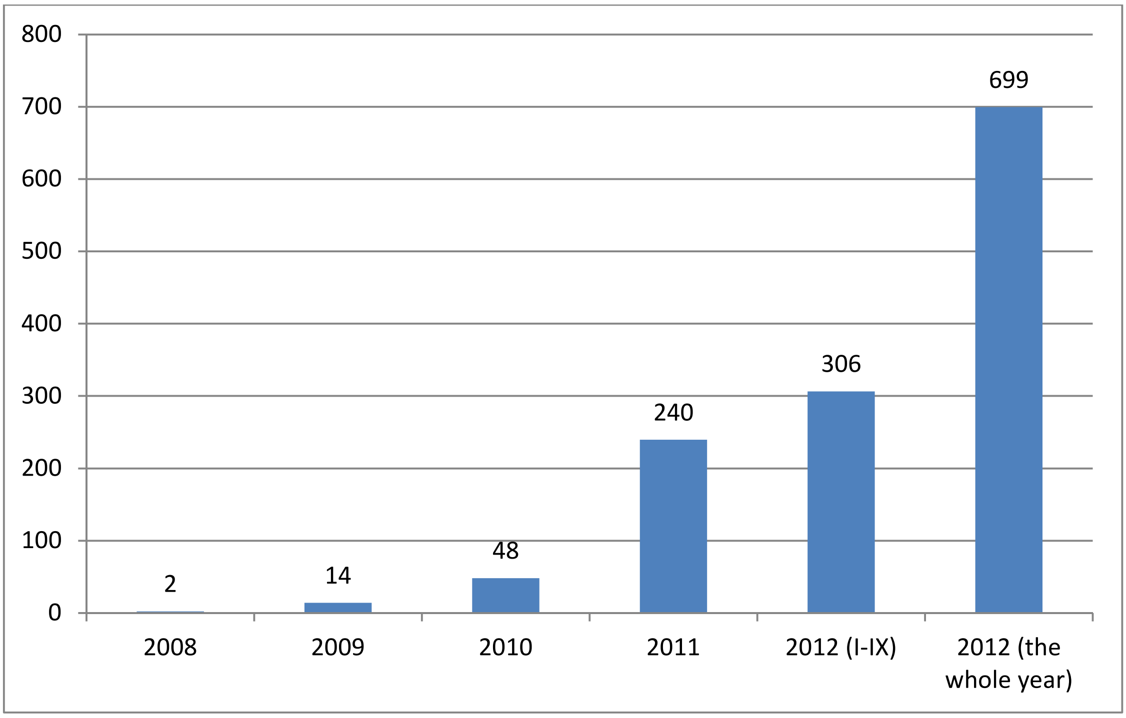

Figure 3. The value of claims from State Treasury within road infrastructure contracts in Poland (in MLN EUR) [6]

4. **Summary and suggested solutions**

In order to improve the quality of construction processes implemented in the "Design and Build" formula, it is necessary to introduce some changes in the existing state. First of all it is mandatory to change the mutual relationship between the participants. Cooperation and partnership are the key words. While the rivalry between the tenderers increases the quality of the project, the rivalry between a Client and a Contractor or a designer brings more harm.

The solution to some of these problems may be the use of existing standards in preparation and implementation of investment projects such as FIDIC. It should be noted, however, that this action makes sense only if the standards are similar. It is mandatory to maintain the balance of rights and obligations of the parties, that is the cessation of making changes of contractor's rights. Clients seem to forget about the balance and during the preparation of the agreements, often change the clauses relating to contractors' claims. As a consequence, orderly and defined process becomes chaotic.

Another solution is to prepare the tender carefully, taking into consideration the understanding of the subject, supported by the dialogue with the Client. When it comes to infrastructure projects in highly urbanized areas, the bidder during optimization should pay special attention to all the risks and take them into account while creating the offer. A particularly important issue should be discrepancies between tender documents as well as geotechnical conditions and underground installations inventory.

The answer to the optimization of the entire tendering process seems to be the BIM concept (Building Information Modeling), which allows new communication quality between the participants and also increases quality and compatibility of the documentation.

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Creative Construction Conference 2014

A meta classification and analysis of contractor selection and prequalification

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Abstract

In order to achieve the objectives of a construction project all of the resources are needed to be used effectively and efficiently. Therefore, the success and accomplishment of a construction project is directly related to the accurate and proper identification of the building production process participants who will use these resources. The selection of the contractor, who is one of the main participants of a construction project, is the most important and difficult decision processes for the clients. Considering the constant delay in the process, quality, and cost estimations that have been planned at the beginning of most construction projects, making the right decision for the evaluation of the bids and selection of the right contractor seem to be important.

The objectives of this study are (1) general analysis of the contractor selection and pre-qualification models and systems which are set out after the examination of relevant literature study in the subject area (2) and the classification and analysis of academic studies with a meta classification method in certain contexts regarding the selection, pre-qualification and criteria of contractors in between the years 1992 – 2013. In this paper, 133 peer-reviewed studies covering the topics of contractor selection, contractor pre-qualification and weighting criteria, in the last 20-year period have been classified and analyzed. A Meta-classification system is adapted and used in order to examine state of the art for contractor selection problem for all procurement systems. Furthermore, based on the findings in this study, supporting the existing models in terms of updated information technologies and/or discussing them for the creation of new models are aimed and discussed.

Keywords: contractor selection, contractor pre-qualification, meta-classification, meta-analysis, weighting criteria.

1. Introduction

The relationship and integration between the client and the contractor appears to be the most important elements in achieving the objectives of construction projects. Even though it is intended to build a robust relationship between the client and the contractor at the beginning of the project, in most cases it is observed that no solid foundation could be built for the relationship in question. Therefore, the optimal evaluation of the bids by the contractors and the selection of the right contractor accordingly constitute an important decision stage.

The main tool used in the selection of the contractor is often called the "bidding price". However the details such as the bidders and the type of tender reveal the situations for questioning the dominance of the price criterion. If the bidder is a public institution, then the evaluation process is surrounded by the sharp boundaries of various laws, regulations and procedures, and a price based evaluation system comes into the picture. On the other hand, if the client is the private sector, then this brings certain flexibility to the process and it creates an environment for the rational evaluation of other criteria which are or will be present except the prices within the scope of the process.

In this study, the criteria which form the basis for the selection of the contractors by the clients and also the existing models and systems that are used for the evaluation of the contractor qualifications have been examined. It focuses on the problem of selecting the contractor and provides updated information about current studies. Recent studies covering the topics of contractor pre-qualification (CP), contractor criteria weighting and contractor selection (CS) in the last 20-year period have been classified and analyzed statistically. This paper is structured as follows: the problem and the objectives of the study are clarified and the background of study from literature is expressed in next sections. Research methodology and classification study is overviewed in Approach section. Result section sets out the preliminary findings of the study in order to analyze Meta-classification of recent studies. The results are discussed in next section and the paper is concluded with the suggestions of further studies.

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2. Problem

Findings and interpretations, which are carried out by scientific researches, states acquired knowledge (Gilbert, 1976). However, this knowledge can appreciate, when it is shared. Scientific publications are important instruments in order to share this knowledge and to provide a basis for new researches. Although developing communication age makes it easier to reach scientific resources in related fields, it is observed that different factors of reachable publications such as counts, content's differences, application fields, etc. make it complicated to reach essential resources. In addition, the usage of different type of statements by researchers, who are working in different disciplines but in similar issues, is an inevitable situation.

Literature survey studies are provided to reveal scientific productivity, tendency, research emphasis and researcher's preferences by the evaluation of scientific publications of related subject (Ilter, Dikbas & Ilter, 2008). In literature survey studies, it is very important to determine an effective classification methodology in order to increase scientific productivity, to observe intensified and unexamined points and to state similar findings of researchers with a common language. The same situation holds also for the CS and prequalification studies, which are conducted in construction sector. Studies regarding the problems of CP and CS have been carried out for many years. As a result of these studies, several researches are conducted on CS and pre-qualification and several methods have emerged. According to the scientific publications of CS and CP, it is observed that the researches are interdisciplinary and situated at international level. The CP and CS problems are still an ongoing issue that is updated constantly. However, an in-depth examination of the ongoing research is required, which is based on the scientific publications of CS and CP. Some deficiencies emerged since these studies have not been classified in any form and no collaborative studies have been carried out based on cause-effect relationship. Also it should not be ignored that the researchers are willing to reach the most important information during all existing studies in a quick and easy way.

3. Background

The selection of the contractor constitutes one of the most important decision-making stages of a construction project. Making the right decision is one of the most important factors that affect the success of the project. In other words, to achieve the optimum result in cost, time and quality triangle for the project management.

The bidding price has been the most important criterion affecting the course of the bidding process and the selection of the contractor. In terms of general practices in public tenders, providing the most convenient way is usually based on the decisions made on the prices. However, according to McCanlis (1967), the client shouldn't be carried away by the attractant effect of the low prices and should behave cautiously. Otherwise the decisions that are made based on the prices might cause greater losses in terms of other goals, such as quality and time. Similarly, Latham (1994) referred to the necessity of a fundamental evaluation given appropriate weights on the criteria of skills, experience and past performance, rather than choosing the lowest price in all cases automatically for the consultant or CS. In other words, he emphasized on the consideration of other criteria in addition to the price, and that they should be evaluated given appropriate weights for the CS. In their studies, Holt, Olomolaiye & Harris (1995) emphasized on the need of encouraging the contractors for the quality and performance-oriented qualities rather than offering the lowest price. For example, he declared that in case the client is a public institution, the lowest price offer is taken into account and expressed the idea that this is an effective solution in the long term process. Kumaraswamy (1996), who promotes the same idea, stated that public company clients are required to choose the lowest bidder most of the time except in some circumstances, but also noted that the lowest bid is not the most economical solution in the long term. Considering the price based criticisms in the public sector, a wide variety of ideas regarding CS criteria (Russell, 1992) and CS models have been developed that would accommodate better to the flexible structure of the private sector.

It is observed that one of the most comprehensive studies on CS is conducted by Russell (1992). Russell proposes a decision support system, which consists of financial model, linear model, fuzzy set model, statistical model, knowledge-based model and hybrid model, in order to evaluate contractors. Similarly studies of Kumaraswamy (1996) and Holt (1998) are other important overview studies on the selection of contractor. El–Sawalhi, Eaton & Rustom (2007) compare contractor prequalification models and present the strengths and weaknesses of these models. In their study, it is referred that there are disadvantages as well as advantages of proposed models. Their study is aimed to propose a state of art model with the investigation of existing models in literature. However, the comprehensive and holistic study within the scope of literature survey is carried out by Holt (2009). Holt is examined the academic researches of CS in construction industry between 1990 – 2009 years. In this review study, 93 academic papers are analyzed in order to observe research focus and justification, methodological approaches, research tools and research results.

4. Methodology

The process of obtaining the data was performed on online scanning servers of Federal Republic of Germany – Saxon State and University Library (SLUB, 2013). SLUB provides licensed access to over 70 million files in national and international standards while providing the user an ease of use and reliability within its own classification tool. The obtained research results for different keyword queries that returned the same result have been accounted only for once during the evaluation on the subject area. Only the peer-reviewed journals have been evaluated in this study. This scan includes the access to all electronic databases for academic studies which is provided by the SLUB catalogue in between the years 1992 – 2013. The SLUB catalogue provides direct access to 169 databanks for the architecture and civil engineering disciplines such as Emerald Journals, SciVerse Science Direct, Taylor & Francis Online Archives and SpringerLink. Additionally it provides licensed access to the databanks which include the American Society of Civil Engineering (ASCE) magazines, also the indexes such as Academic Search Complete and Web of Science through reference servers of EBSCO Host and JSTOR. By these means, it provides access to a total number of 1465 electronic journals related to the disciplines of architecture and civil engineering. In general, 3650 internet accessible databanks out of a total of 9472 databanks have been accessed that cover all the branches of science.

For the purpose of confirming the accuracy of the keywords specified under the scope of this work with the numerical data of the publications resulting from the screening of these keywords in the title and keywords of the articles, similar queries with the same keywords have been carried out on the same databank servers and exactly the same results have been obtained. The surveying of "contractor selection" keyword achieved a total number of 72 publications where 67 out of 72 have been published after 1992. The query of "contractor criteria" achieved a total number of 44 results where 41 out of 44 have been published after 1992. The query of "Contractor Pre-qualification" achieved a total number of 29 results which have been published after 1992. A total number of 145 publications have been utilized, and it has been found out that 133 out of 145 have been published after 1992.

In study, a classification method is adapted from (Betts & Lensley, 1993) in order to classify scientific publications, which are conducted on CS and CP in construction sector between years 1992 – 2013. The classification method is developed and categorized according to the simplified knowledge hierarchy (Rowley, 2007). The classification method consists of 4 dimensions, which are categorized such as author, content, form / input-output and causation. Author information has 4 subcategories such as name, year, country and foundation, which are described in the table. In this dimension, it is aimed to examine studies according to researcher information. Year of publication is grouped as 1992 – 2002 and 2003 – 2013 in order to observe tendency of research field in last two decades and also country are grouped as continentals Europe, Asia and others. Content information has 3 subcategories such as sub-topics, project delivery method and level of analysis. Form / Input – Output consists of 4 subcategories such as sources of information, type of data, method / technique, contribution. Methods and techniques, which are used in the scope of studies by authors, are grouped into three main categories such as statistical methods, machine learning and artificial intelligent. Causation category is divided into three subcategories as origin / problem, result and opportunities / threads. The classification system is given in Table 1.

Table 1. A proposed classification system

Category	Subcategories	Enumerations (Abbreviations) or *Descriptions*
Author	Name	*Name of Authors*
	Year	*Year of Publication (Gr.)*
	Country	*Country of Author's Affiliation Institute (Gr.)*
	Foundation	*Affiliation Institute of Author*
Content	Sub-topics	Contractor Selection (CS), Contractor Prequalification (CP), Weighting Criteria (WC)
	Project Delivery Method	Traditional (TR), Design-Build (DB), Project Management (PM), N/A
	Level of Analysis	Private Sector (PrS), Public Sector (PuS), N/A
Form / Input-Output	Sources of Information	Review (Rw.), Case Studies (Case), Empirical Data (Emp.), N/A
	Type of Data	Quantitative (Qn.), Qualitative (Ql.), N/A
	Method / Technique	*Techniques and Methods that are used (Gr.)*
	Contribution	Overview (Ov.), Modeling (Md.), Statistical Findings (SF), System Development (SD)
Causation	Origin / Problem	*Main reason of the research (Gr.)*
	Result	*The result of the research (Gr.)*
	Opportunities / Threads	*Main opportunities and threads which are discussed by author (Gr.)*

(Gr.) denotes that there is a grouping study is conducted for given subcategory's results.

5. Result

As a result of literature survey 133 scientific publications (peer-reviewed) within the context of CS and CP until to the third quarter of 2013 was obtained.

5.1. Author

According to the scope of study years of publications are grouped into two parts as first ten years (1992 – 2002) and second ten years (2003 – 2013). Results of the analysis indicate that the studies are increased in second ten years period (Table 2).

Table 2. Distribution of studies according to the year periods

Year Period	N	%
1992-2002	55	41,4
2003-2013	78	58,6
Total	133	100,0

Another analysis result shows that the most of the studies are conducted in United Kingdom (32) and China (26). Table 3 indicates the group of countries as Europe, Asia and others and the distribution of studies.

Table 3. Distribution of studies according to the country groups

Country Groups	N	%
Europe	53	39,8
Asia	54	40,6
Others	26	19,5
Total	133	100,0

5.2. Content

Table 4 indicates the distribution of papers according to their sub-topics. Results show that the interest on CS studies is a bit more than CP studies, whereas %16 of studies contains both sub-topics.

Table 4. Distribution of studies according to the Sub-topics

Sub-topics	N	%
Contractor Selection	65	48,9
Contractor Prequalification	47	35,3
Both	21	15,8
Total	133	100,0

Level of analysis reflects the sector preferences of the papers as public or private sector. Results express that there is a significant difference between only PrS studies and PuS studies. However, %25 of studies contains both analysis levels. Another important result shows that %26 of papers does not contain any information about sectors, which is indicated in Table 5 with “N/A”.

Table 5. Distribution of studies according to the sectors

Sector	N	%
Public Sector	51	38,3
Private Sector	14	10,5
Both	33	24,8
N/A	35	26,3
Total	133	100,0

5.3. Form / Input-Output

In this classification study, it is observed that 59 different methods and techniques are used 220 times in papers. Statistical Methods, Decision Support Systems and Fuzzy Set Theory are seen as the most preferred methods. Table 6 indicates the distribution of grouped methods such as decision theory, statistical methods, neural networks, machine learning and hybrid. This grouping approach is adapted from (Michie, Spiegelhalter & Taylor, 1994).

Table 6. Distribution of studies according to the used Methods (grouped)

Methods	N	%
Decision Theory	47	35,3
Statistical Methods	31	23,3
Neural Networks	5	3,8
Machine Learning	6	4,5
Hybrid	30	22,6
N/A	14	10,5
Total	133	100,0

According to the Meta-classification it is aimed to observe contribution of papers to the literature as overview, statistical findings, modeling and system development. However, results show that some papers have more than one contribution with different combinations. Therefore contribution of paper is analyzed according to the observations independently from sample size. As seen in the Table 7, overview is the dominant contribution choice CS and CP studies, whereas modeling, statistical finding and system development follow each other in this order.

Table 7. Contributions of papers

Contribution	No. Of Observation[a]	Sample Size	%[b]
Overview	121	133	91,0
Statistical Finding	51	133	38,3
Modeling	69	133	51,9
System Development	14	133	10,5

[a]Total of No. of Observation differ from sample size due to the occurrence of more than one contributions in a paper.

[b] indicates the percentage of number of observed contribution in whole sample.

5.4. Causation

Results of the papers are classified in three groups such as analyze, proposal and determination. Analyze indicates that the paper states some analysis results. On the other hand proposal indicates that the paper proposes a model or system as a result of study. In addition, determination consists of identification and classification as a result of studies. Table 8 shows that the most of the papers are concluded with some proposals, whereas approximately quarters of papers are concluded with analyze or determination.

Table 8. Results of papers

Result	No. Of Observation[a]	Sample Size	%[b]
Analyze	35	133	26,3
Proposal	77	133	57,9
Determination	33	133	24,8

[a]Total of No. of Observation differ from sample size due to the occurrence of more than one contributions in a paper.

[b] indicates the percentage of number of observed contribution in whole sample

6. Discussion

Construction sector should be adapted to the developments in new technologies and business methods. The same situation is also hold for CS problem and the literature survey indicates that there is an increment in the relevant studies with the information utility.

The Meta-classification results show that CS is the major decision process, which effects directly to the results of projects as a kind of multi-criteria problem. Various methods and techniques are adapted to solve this problem. In this paper, 133 papers from 65 different institutions of 24 countries are examined. And preliminary findings of classification study, which is the basis of ongoing Ph.D. thesis, are given. The aim of future works will be the examination of relations between sub – categorized elements of related data in order to analyze CS and CP papers in detailed. This study set out to contribute to the CS studies and provide new solutions to the CS problem with simulation CS processes in an intelligent environment.

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Verification and validation approach of BPMN represented construction processes

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Abstract

Process configuration, is a smart method to integrate several business process variants into a single model, helps to omit unnecessary process parts and to give flexibility to the modeled business process. In the construction industry process configuration should support not only process sequence variants, but should also support ad hoc changes in the construction process at all stages. Moreover, construction projects consist of very complex and detailed processes, which are not easy to model or to integrate with each other. Therefore process modeling tools must support the process configuration with verification and validation knowledge, which supports the end users to identify and to avoid system errors like deadlocks, infinite loops, logical errors, etc. and determines the model coherence according to the real world. The objectives of this paper are (1) complementing the existing modeling methods and tools for verification of construction process models according to the behavioral and structural properties and (2) improving the verification and validation processes with modification patterns to diagnose and to restructure ill-behaved process models within knowledge-base.

The main focus of this paper is modeling a knowledge-based for construction process reengineering by templates, rules and patterns in order to verify, validate and modify configured process models. Petri Nets method is selected for the verification and validation purpose. Knowledge base consists of three main levels, which are knowledge level, information level and case level. Mapping templates, transformation rules, verification rules, validation rules and modification patterns constitute level of information. In this paper, mapping templates and transformation rules are explained briefly and verification rules and modification patterns are investigated mainly. In addition, validation rules are discussed comprehensively. New analysis methods are developed and existing methods are adapted in order to improve verification rules. Process patterns, which provide common or general solutions for the complexity, are adapted for the integration and simplification of the knowledge base as modification patterns. Modification patterns are defined in two main types, which are review and consequence patterns. Review patterns consist of diagnose patterns, error handling patterns and restructuring patterns and consequence patterns consist of decision patterns. In case of an ill-behaved model, the designer can diagnose the problem, handle error and restructure the model according to his experiences or provided through a knowledge base.

Keywords: bpmn, construction process reengineering, petri nets, process configuration, verification .

1. Introduction

Business Process Modeling (BPM) is supposed to be an instrument for coping with the complexity of process planning and control (Becker, Rosemann, & von Uthmann, 2000). In addition, it is a method for the managers or analysts to model their own business processes and to analyze or to improve their systems' performances (Kog, Scherer & Dikbas, 2012). The representation and analysis of alternative process designs by formal or semiformal process models indicate the main objective of BPM (Betz, Klink, Koschmider & Oberweis, 2006). BPM is the key point of the managers and analysts in the life cycle of Business Process Management (zur Muehlen, 2004). Business Process Modeling Notation (BPMN), which is a technique for modeling and analyzing business processes, has underlying capabilities such as simulation that helps business managers and analysts to understand the complex processes and to quantify the system's performance. BPMN is defined as a new standard for modeling business processes and web service processes by Business Process Management Initiative (White, 2004). It is used to support a nonredundant, flexible, integrable and adjustable visual environment for the business processes and it provides a graphical language with Business Process Diagrams, which is based on flowchart, activity diagrams and UML techniques.

Business Process Configuration (BPC), which is a method to integrate several business process variants into a single model, helps to omit unnecessary process parts and represents a family of process models. It provides flexible solutions to the modeled business process. In the construction industry, process modeling and configuration are used more and more to support simulation, estimate and plan required resources and costs (Benevolenskiy, Ross, Katranuschkov & Scherer., 2012).

2. Background

Process configuration, is a smart method to integrate several business process variants into a single model, helps to omit unnecessary process parts and to give flexibility to the modeled business process. In the construction industry process configuration should support not only process sequence variants, but should also support ad hoc changes in the construction process at all stages. Moreover, construction projects consist of very complex and detailed processes, which are not easy to model or to integrate with each other. Even if there is a configured process model or configured reference process model (Rosemann & van der Aalst, 2007) for a construction process, verification of the completeness and consistency system network is still a problem because of the complexity. Therefore process modeling tools must support the process configuration with verification and validation knowledge, which supports the end users to identify and to avoid system errors like deadlocks, infinite loops, logical errors, etc. and determines the model coherence according to the real world. BPMN is one of the most common and effective tools of BPM. In spite of BPMN's innovative approaches for business sectors, existing tools are not enough to model and simulate the construction projects because construction sector needs more sophisticated facilities to design and to control inherent uncertainties of their production systems due to one of kind product, production and project organization, due to the high complexity of the projects and due to the short lead time. A configurable process model represents a family of process models, that is, a model that through configuration can be customized for a particular setting (Van der Aalst, Lohmann, La Rosa & Xu, 2010a). Configuration is achieved by hiding (i. e., bypassing) or blocking (i. e., inhibiting) certain fragments of the configurable process model (Gottschalk, van der Aalst & Jansen-Vullers, 2007).

Process configuration become more of an issue in business industry and enterprise systems (Dreiling, Rosemann, van der Aalst, Sadiq & Khan, 2005), additionally in construction industry. Main process configuration methodologies in construction industry, which are based on knowledge based environment (Fischer & Aalami, 1995), graph theory (Huhnt, 2005), constraint/strategy-based methods (Beißert, König and Bargstädt, 2007), ontology-based process modeling (Benevolenskiy, Ross, Katranuschkov & Scherer., 2012), etc., are mostly concentrated on planning and scheduling activities. Although the general purpose of these researches is developing formal high level models for construction processes, verification and validation of the process models are not well examined. According to the Macal (2005), verification ensures that the specification is complete and mistakes have not been made in implementing the model and validation ensures that the model meets its intended requirements in terms of the methods employed and the results obtained. Miles & Moore (1994) identifies verification and validation as a subset of evaluation, which incorporates an analysis of such aspects as overall performance, feasibility of expansion and user acceptability too.

Van der Aalst, Dumas, Gottschalk, Hofstede, La Rosa & Mendling (2010b), have been focused on the verification of configurable executable process models to examine behavioral anomalies such as deadlocks and livelocks in the instances of a configured model. They stated that the verification of configurable process models is challenging and only few researchers have worked on this. Moreover, existing results impose restrictions on the structure of the configurable process model and fail to provide insights into the complex dependencies among different process model configuration decisions. There are several methodologies in order to improve or formalize existing tools. In this study, PN based process verification approach (Kog, Scherer & Dikbas, 2012) is used to improve deficiencies of existing tools (Fig. 1).

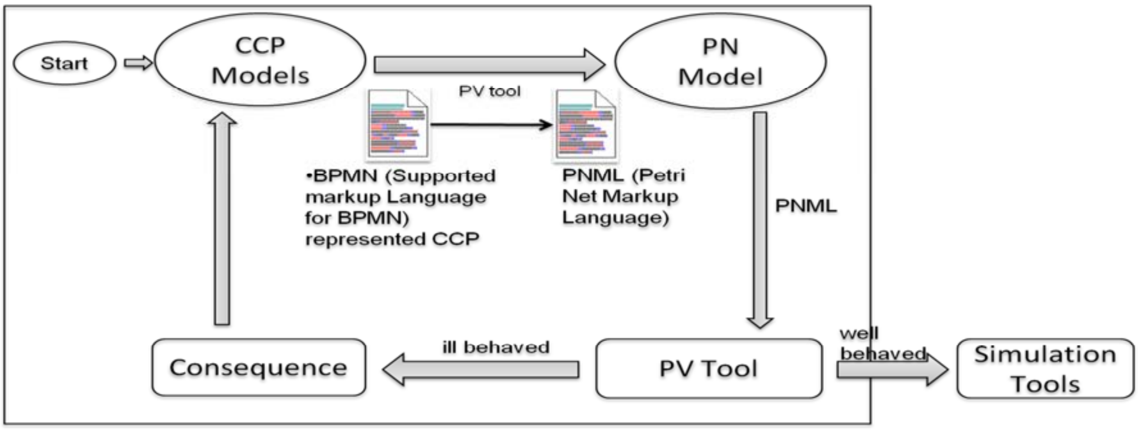

Figure 1. PN based Verification of BPMN represented CCP Model Approach.

3. Objective

The main focus of this paper is modeling a knowledge-based for construction process reengineering by templates, rules and patterns in order to verify, validate and modify configured process models. Petri Nets (PN) method is selected for the verification and validation purpose. PN, which was invented by Carl Adam Petri in 1962, is a mathematical and computational modeling language (Petri, 1962). It gives system designers a capability of analyzing the models with matrix representations, and it allows modeling of concurrency, synchronization, and resource sharing behavior of a system. It provides a uniform environment for modeling, formal analysis and meanwhile also verification and the design of discrete event simulation systems (Scherer & Kog, 2010). Several types of PN (timed, colored, hierarchy, attributed, etc.) were developed in order to satisfy the requirements of analysis and simulation of real world systems. Detailed information about PN can be found e.g. in (Murata, 1989).

The illustration of the main focus of this research is given as a simplified knowledge hierarchy (Rowley, 2007) in Figure 2. Knowledge base consists of three main levels, which are knowledge level, information level and case level. Mapping templates, transformation rules, verification rules, validation rules and modification patterns constitute level of information. In this paper, mapping templates and transformation rules are explained briefly and verification rules and modification patterns are investigated mainly. In addition, validation rules are discussed comprehensively. New analysis methods are developed and existing methods are adapted in order to improve verification rules. Process patterns, which provide common or general solutions for the complexity, are adapted for the integration and simplification of the knowledge base as modification patterns. Modification patterns are defined in two main types, which are review and consequence patterns. Review patterns consist of diagnose patterns, error handling patterns and restructuring patterns and consequence patterns consist of decision patterns. In case of an ill-behaved model, the designer can diagnose the problem, handle error and restructure the model according to his experiences or provided through a knowledge base. This paper represents the conceptually structured verification and validation rules with knowledge acquisition for improving the BPMN represented configured construction processes. In addition a prototype tool, which is developed for the verification of BPMN represented configured construction processes, is proposed with an illustrative case.

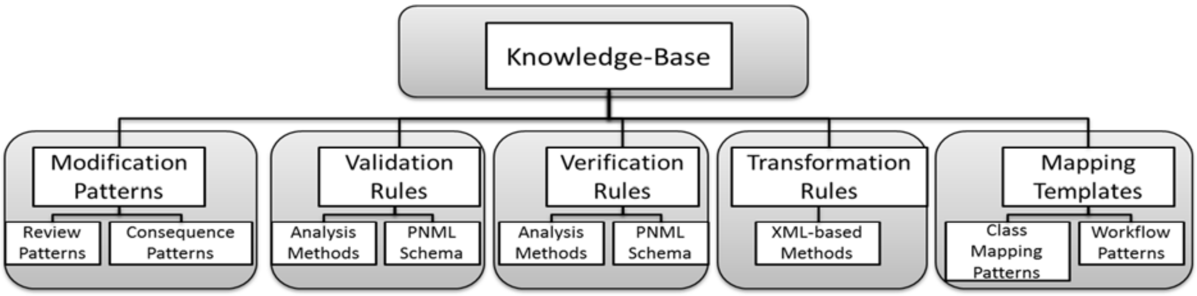

Figure 2. Knowledge based Reengineering Lifecycle of Configured Process Models

4. Approach

Knowledge base consists of three main levels, which are knowledge level, information level and case level. Mapping templates, transformation rules, verification rules, validation rules and modification patterns constitute level of information. Class mapping patterns (Katranuschkov, 2000) and workflow patterns (var der Aalst, 1997) are adapted into the mapping templates (Scherer & Kog, 2010). The suggested approach for PN based Verification of BPMN represented CCP model, which is derived from the PN based model verification for BPMs (Kog, Scherer & Dikbas, 2012), is given in Figure 1. The main idea is transforming BPMN represented CCP models to the PN Mark-up Language(Jüngel et al., 2000) which are both in eXtensible Stylesheet Language (XML) format (Kog, Scherer & Dikbas, 2012). Therefore, xml based methods are adapted in order to create transformation rules.

A prototype tool is implemented in Java to realize the transformation, verification and validation purposes. It is the improved version of tool Process Vericator (Kog & Gok, 2013) and called Knowledge-based Process Evaluation and Modification Tool (KPEM). The XSLT templates are created for the different transformation procedures between CCP and PN models. In addition XSLT templates are carried out for main business process pattern examples, which are derived from workflow patterns (van der Aalst, 2003). The interface eases the transformation for the users. After the transformation has carried out, several analysis methods or tools can be executed. For the PN verification the PN workflow analyzer tool WOFLAN, which was developed by van der Aalst (1999), is integrated in the program. The proposed methodology for the PN based verification of construction process models and detailed description of transformation model can be found in (Kog, Scherer & Dikbas, 2012).

New analysis methods are developed and existing methods are adapted in order to improve verification rules. Process patterns, which provide common or general solutions for the complexity, are adapted for the integration and simplification of the knowledge base as modification patterns. Modification patterns are defined in two main types, which are review and consequence patterns. Review patterns consist of diagnose patterns, error handling patterns and restructuring patterns and consequence patterns consist of decision patterns. In case of an ill-behaved model, the designer can diagnose the problem, handle error and restructure the model according to his experiences or provided through a knowledge base. Conceptual knowledge-based verification (Kog & Gok) and validation rules of CCP models is given Fig. 3., which is derived from the approach given in Fig 2. Verification rules consist of three main rules, which are analysis rules, review rules and consequence rules. Analysis rules are organizes the analysis methods in order to verify model syntax and semantics. In review rules comprises knowledge expertise to recompose ill-behaved models. As a result if there will be no possible condition to resolve the problem, consequence rules are defined to formulate report for model developers.

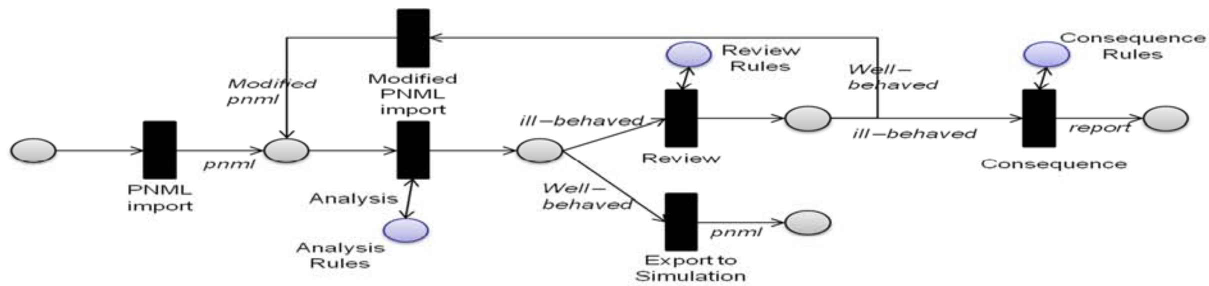

Figure 3. PN represented CCP Model Evaluation

In this study, new analysis methods according to the verification and validation rules are implemented to the KPEM. Soundness analyzer (for the verification) and resource controller (for the validation) are selected methods for instances. Soundness analyzer is working with the same algorithm with tool WOFLAN to examine soundness analysis (Oanea, 2007) of models. Resource controller is implemented to avoid mistaken resource allocation and deadlocks.

5. Case Study

The first case example (Fig. 4) is about the logic of construction work inside a single work section, which is derived from the sample project "Mefisto Hochhaus" (Ismail & Benevolenskiy, 2011) in Mefisto Project (Scherer et al., 2010). This reference process model has been used as a part of the input data for the simulation model using the construction simulation toolkit (Ismail, 2012). The example model was represented in BPMN and exported as a BPMN 2.0 xml file.

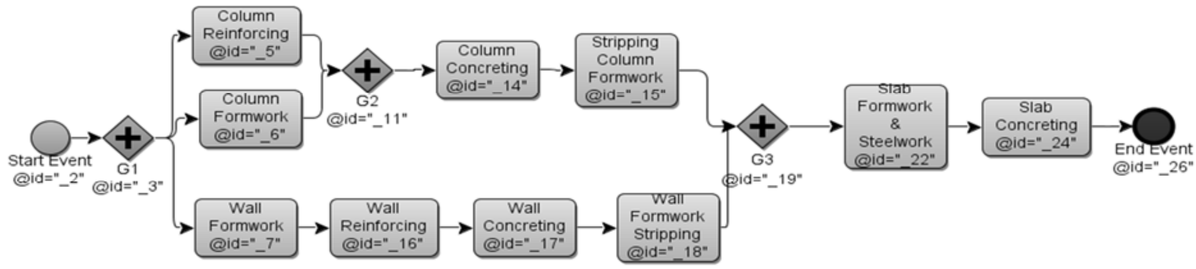

Figure 4. Instance BPMN represented CCP model of simple construction work.

This process model is transformed into the PN model with transformation part of the KPEM tool. The suitable XSLT template is chosen as a transformation method for BPMN source. At the time being this selection was made manual. The automatic selection of the mapping template with the recognition of source file is under development progress. The transformation procedure is completed with the execution of the transform command. The output file, which is a proper PNML file, is saved automatically to the user's folder. After that the PNML file is directly used in the verification part of the KPEM. In this part soundness analysis method is chosen to verify the process model. Soundness test result shows that the model is ensured three conditions of soundness property, which are Workflow net property (van der Aalst, 1997), Boundness and Liveness (Murata, 1989). Hence the instance wall construction model is sound (Fig.5).

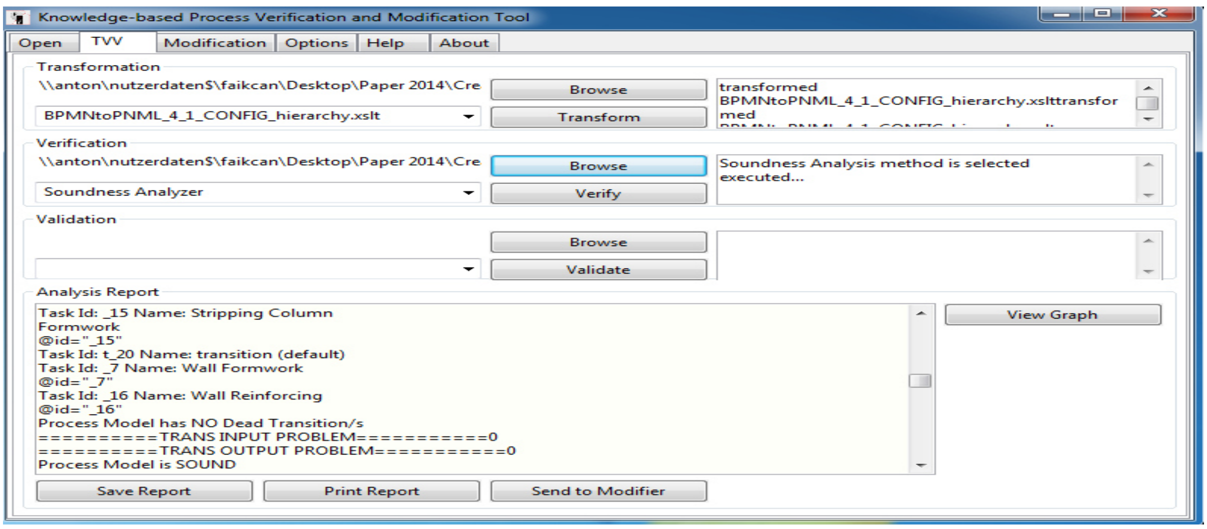

Figure 5.Verification of BPMN represented CCP model of simple construction work.

There are three parallel gateways in the model. Gateway "G3" is modified to exclusive gateway to examine the reliability of KPEM. Analysis results gives automatically that there is an AND-XOR Mismatch between parallel gateways and exclusive gateways (which are shown in GUI of KPEM's graphical view with key id's "_3", "_11" and "_19" and are indicated with bold borders and lines in Figure 6., which damages the soundness of the model. This means, there is a conflict at the end of parallel column and wall works, before starting slab works.

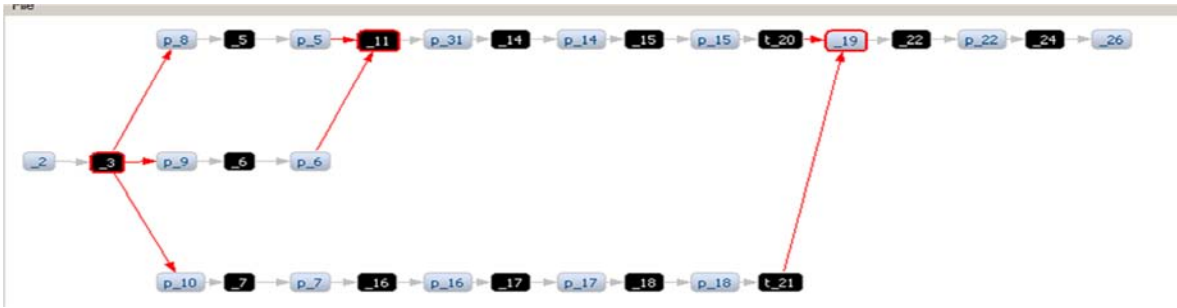

Figure 6.Verification of BPMN represented CCP model of simple construction work (GUI).

The second case example is about the construction of column, which is also derived from the sample project "Mefisto Hochhaus" (Ismail & Benevolenskiy, 2011) in Mefisto Project (Scherer et al., 2010). Ontology based process configuration (Benevolenskiy, Ross, Katranuschkov & Scherer., 2012) is used in this instance model. There is a three level hierarchy (with 27 sub-processes) and three types of predefined resources such as IFC product, construction materials and machines in this group production. Resource controller method is used and analysis results show that the can test the validity of model according to the resources (Fig. 7). In addition, verification methods are used to indicate structural correctness of the model.

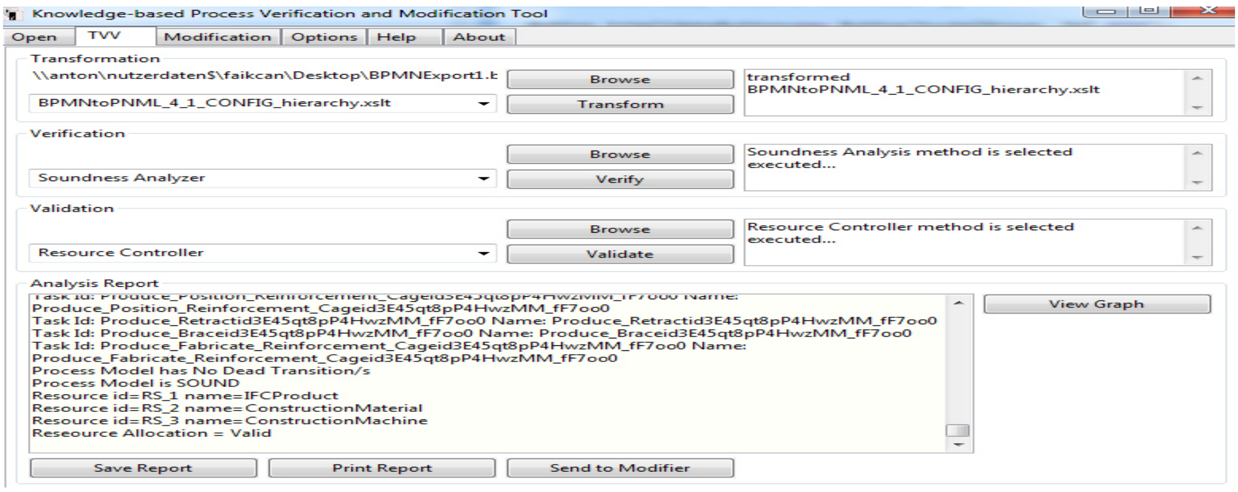

Figure 7.Evaluation of BPMN represented ontology based CCP model of column construction work.

6. Conclusion

In this paper an approach of verification and validation rules is suggested for the evaluation of the CCP with PN. PN was selected, because data losses are usually less compared to other modeling methods. PN gives excellent power to managers to design, control, simulate and analyze process systems. There is a strong mathematical background in PN that is still an attraction for researchers.

A knowledge-based approach is defined conceptually and main rules are given. In further studies, these rules will be defined as patterns for business process reengineering. However this study is aimed to focus on verification and validation purpose. Therefore modification part of the knowledge-based approach (given in Fig. 2) is not defined in the context. Consequently, this work will be enlarged with the aim of validation of other properties in further works. Moreover, besides the existing methods, other methods and PN based analyzing techniques will be developed and implemented in the prototype.

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Using Simulations to better train future and existing Construction Management personnel

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Abstract

In the construction industry, there is a continued need for training current employees as well as future employees. Such training opportunities that exist include safety, technical, and project management. Historically training has included lectures from subject matter experts by those considered to be experts in a particular subject or field. However, this has required removing personnel from projects to allow time for training or by requiring employees to invest time outside the normal working hours for training. With the advent of the internet, on-site lectures have been replaced with webinars and/or telecast to allow personnel to remain in one location and receiving training; however, many educators cite that student engagement is often limited and learning is not as in-depth when compared to in-person training sessions. One new training technology that is developing is the use of virtual simulations that are designed to allow for specialized training while engaging them in the educational process. One such simulation, the COnstruction INdustry Simulation (COINS), has been developed to train students in the management of a construction company managing multiple projects simultaneously. COINS engages students in the decision making of heavy civil construction and commercial building sector. This simulation has been used in the classroom and now is just available to construction firms to use with personnel. This paper describes the development and use of COINS simulation designed and developed to educate future and existing construction management personnel. It is currently used at a number of different universities including the Czech Technical University in Prague.

Keywords: Construction; Education; Simulation; Training

1. Introduction

If one were to survey construction educators and construction trainers, we would fine a small number using large scale complex simulations. Most university faculty opt for traditional lectures using powerpoints and a number use case studies, and a few use management games. The question is why don't we use simulations? The definition of a simulation is the imitation of the operation of a real-world process or system over time. This definition begs the question even move, why don't we use simulations? Fear of technology, availability, overly complexity, etc. One such simulation, the COnstruction INdustry Simulation – COINS (Korman, Johnston, Duckworth), has been developed to train students in the management of a construction company managing multiple projects simultaneously and is slowly moving to advance company trainee. COINS engages students in the decision making of heavy civil construction and commercial building sector. This simulation has been used in the classroom and now is just available to construction firms to use with their personnel.

2. Literature Review

California Polytechnic State University, San Luis Obispo (CPSLO) is one of the three most selective public universities in California and one of the least diverse, yet the faculty still struggle with developing appropriate instructional methods and content to engage students and prepare them in the civil and construction engineering industries. This struggle results from the desire to involve students in authentic activities that teach how to develop constructible designs while retaining the delivery of core engineering fundamentals. Implementing more engaging, authentic learning activities would increase the retention of engineering students who switch majors because instruction does not link theory to practice and would attract and retain a more diverse student population in the engineering majors. Research and the demands of the industry and the current global environment compel diversity (Chang), thus it is imperative that CPSLO increase diversity in its engineering departments while preparing graduates to enter the workforce with the skills necessary to make immediate contributions. Further, industry reports that students' limited preparation often delays their making contributions to integration, collaboration, productivity, and accuracy, all of which are necessary in the engineering and construction industries. Project-based learning, combined with simulations and multidisciplinary learning opportunities, not only significantly enhances the ability of students to successfully enter the modern work environment and to respond effectively to the rapid evolution of knowledge and the ongoing iteration of problems in complex systems36, but such an instructional approach also fosters the learning and participation of non-traditional and minority engineering students (Kramer, Mills). However, based on the experience of the civil and construction engineering (CCE) faculty at CPSLO and feedback from their Industrial Advisory Board (IAB), a knowledge and skills gap exists in the CCE curriculum. This negatively impacts students' preparation as well as the retention and the ability to increase diversity.

While multidisciplinary project-based learning has been advocated in engineering for a number of years, the initiation of the Accreditation Board for Engineering and Technology, Engineering Criteria 2000 (ABET 2000), and its call for a required multidisciplinary experience stimulated increased interest in developing courses in this area. Still more recently, an increased number of papers advocating multidisciplinary project-based curricula have appeared at conferences and in journals. It has become clear that project-based learning is addressing a need in the preparation of engineers that was not previously satisfied by standard curricula (Mergendoller, Strobel).

Dialogue with the construction management Industry Advisory Board (IAB) revealed the following important issues and obstacles our students experience upon entering industry. First, students often have not encountered large-scale team design projects and, therefore, have to learn how to work in such an environment. Thus, on the job, they must gain experience in the process, develop a technical specialization to support their project role, and build their ability to collaborate on and contribute to multidisciplinary projects. Secondly, we discovered that our students were not prepared to apply design and construction engineering fundamentals to real world complex projects, specifically utilizing project controls to monitor and evaluate an active project.

In addition to the educational deficiencies noted in our curriculum, CCE curricula generally do not present an integrated approach to engineering education that includes practical applications of theoretical knowledge incorporating constructability issues. Students often master the course and laboratory work associated with courses in the curriculum, but they do not gain a comprehensive engineering experience that requires them to synthesize what they have learned in their curriculum and extend their knowledge through independent learning that reaches outside their field of study, specifically in the topics of constructability. This is further observed at community colleges where students do not have the opportunity of being immersed in a large-scale engineering academic environment of a four-year institution and frequently lose interest in pursuing further education or an engineering career (Terenzini, Cabrera).

This educational gap is systematic among engineering universities. Design engineers frequently receive limited feedback regarding the constructability of their design once a project has entered the construction phase and how construction engineers receive limited feedback regarding the progress of their project. This stems from the educational gap that exists between design and construction engineering curricula, which fail to address constructability issues and lack educational tools and methods for students to test and validate project control theory (Kilgore, Atman, Yasuhara, Barker, Morozov).

Traditionally, students have not acquired these skills at CPSLO. In fact, our experience and research indicates that while many universities and community colleges offer lower division courses that teach students about project control theory, they are not able to provide an educational experience where students can practice these skills. Therefore, in an effort to produce a project-based learning experience, the CPSLO faculty have been developing COINS–COnstruction INdustry Simulation–to reinforce several key learning objectives and to provide a valuable experience for students to work on projects that require the application and synthesis of project controls and monitoring knowledge. Through the use of COINS, students will be placed in a virtual environment to replicate, as nearly as possible, the working environment they will encounter after graduation. Students will be exposed to exercises that are significantly different from typical homework assignments in conventional courses. COINS requires students to work collaboratively and use effective communication skills. Based on our review of the literature, we expect that COINS will engage students unlike any other teaching intervention as there are currently no PBL solutions using simulations to enable students to conceptualize the demands of scheduling multiple projects with multiple resources. Other engineering simulations, such as Messner's Virtual Construction Simulator, simulate building a specific project, focusing on very specific job areas (Nikolic). COINS, on the other hand, is conceptual in nature, actively involving students in the scheduling of multiple projects and allocating multiple resources concurrently while enabling them to see the relevance in the real world of what they are learning. Finally, we anticipate that COINS will become a model for other civil and construction engineering programs who wish to enhance their compliance with the ABET 2000 requirements and foster the success of a greater number of students Vogel, Bowers, Bradshaw).

3. COnstruction INdustry Simulation (COINS)

Construction Industry Simulation (COINS) is a computer simulation built to simulate the business environment for a construction company. The players, participants, play the role of contractors, competing in a market with variable demand for construction work. The simulation immerses trainees into the day-to-day operations of a construction company, requiring them to management specific aspects of the company with the goal of procuring and managing construction work in terms of its planning, scheduling, and resource allocation. Student trainees have a choice between commercial construction company, a heavy construction company, or a company that does both. Players are required to set up a complete business strategy including the following tasks:

- examine available information
- determine the best portfolio of jobs to bid on
- create strategies to improve bonding limits
- set strategies to create negotiated work
- develop bid prices for desired jobs
- monitor their financial position as work progresses
- monitor and create strategies to improve company's appraisal metrics
- choose and modify their construction methods to meet due dates and reduce costs
- interpret their competitors' strategies
- respond to changing conditions and situations proposed to the company and driven by the decisions and actions of the company

3.1. Projects and Activities

Each period the simulation generates a list of projects available for the teams to estimate, schedule and propose on. The types of projects include the following: highways, bridges, site development, mass excavation, and underground utilities on the heavy civil side, and multi-family housing, educational facilities, hospitals and medical office buildings, commercial office buildings, and industrial manufacturing facilities on the commercial side.

All projects have nine (9) activities that the teams need to schedule, generate and cost estimate. The activities that must be scheduled and estimated include the following: clear and grub, rough grading, excavation, underground piping, concrete forming and placing, backfill and compaction, placement of aggregate base, asphalt-concrete paving, and finish grading. On the commercial side, the activities include the following: excavation, foundation, basement, framing, closure, roofing, siding, finishing, mechanical, electrical, and plumbing.

In addition the simulation creates an Estimated Time and Cost Report for each job. Using the this information, each company must decide which jobs to bid on, the bid price, and which of the five methods to use for each of the activities.

Every activity has five (5) different construction methods that vary in time and cost. The Estimated Time and Cost Report gives labor and material costs and the amount of time required for every activity using each of the five methods. Heavy construction bids are generally unit price bids while commercial bids are lump sum.

3.2. Use of the COINS Simulations

COINS has been used in several courses including: Professional Practice, Construction Estimating, Construction Accounting, Management of the Construction Firm, and Business Practices

During the 2005/2006 academic year, the simulation was used for regional competition between multiple universities in the Associated Schools of Construction Regional 6 and 7 Student Competition.

Most recently, in November 2009, universities from the Czech Technical University (CTU) - Prague, Czech Republic, Auburn University – Alabama, California State University, Fresno - California, Illinois State University - Illinois, Boise State University - Idaho, Western Carolina University - North Carolina, and Washington State University – Washington, participated in an international competition. Competition Results were evaluated in five categories: Highest Retained Earning - received the highest profit, Highest Appraisal

Metrics - the best valuation metrics and third, Most Awarded Projects - the company with the most awarded projects.

4. Game Play Simulation

During the simulation, student trainees experience three distinct phases playing through the simulation. These are:

4.1. Phase I – Project Planning and Design

Students begin the simulation in Phase 1 by being presented with a list of potential projects to review. Considering market conditions, student teams proceed by selecting a project to plan and then designing a project control system for the project. This is accomplished by selecting methods for each project activity and balancing the schedule and cost considerations. In Phase 1, students compete against their peers as well as the simulation's virtual companies for award of the project. Award of projects is based on the team's accuracy and proximity to the simulation's internal estimate. Teams that are not initially awarded a project for their efforts must continue with the simulation, refining their plans, until their plans are awarded a project. Thus, the COINS simulation enables student trainees to learn from their mistakes.

4.2. Phase 2 – Construction Engineering

When a student team is awarded a project, they enter Phase 2. In Phase 2 student teams must manage their project by monitoring and controlling the project activities, analyzing the schedule and costs in reference to the methods to the activities they selected for each activity. Throughout the duration of their project, students are presented with real-life scenarios which they must respond to, thus measuring, testing, and validating the design of the project control system. Therefore, students are able to utilize their knowledge and hone their skills at controlling the process through modifying their project control system. The simulation provides feedback to the students which they then can use to continuously improve their model throughout the duration of the simulation.

4.3. Phase 3 – Project Closeout

Phase 3 begins after students have completed each activity for their virtual project. They have the opportunity to evaluate their performance using several predefined metrics, including Schedule Variance, Cost Variance, Cost Performance Index, and Schedule Performance Index.

5. Student Trainee Learning Process

As mention above, one of the first activities for the student trainees is to determine what positions will make up their main office overhead. This is reevaluated each period, and hire/fire activity is performed by the team. A report is given to the company telling them how they are handling their personnel and it's requirements. Work scheduling is very important in the selection of the methods so projects can be completed by the contractual deadlines, and the costs reduced as much as possible. Each bid price submitted should cover all the firm's direct and indirect job expenses, its main office overhead costs, and the desired profit. At the end of each period the simulation will determine which company is awarded each available project. The lowest bid will not necessarily win since the computer takes into account several other factors:

- Is the firm's cash-on-hand adequate to provide enough liquidity with regard to the bid price?
- Is the bid price below a minimum amount, computed by the program? If so, then the bid will be disregarded as irresponsible and be rejected.
- Is the bid price higher than the unknown contractors, the presence of this simulated company assures a competitive, uncertain environment with realistic bid prices.
- Is the firm within it bond limits?

At the end of each period, teams receive a progress report for the previous two month period, giving a statement of the firm's work progress on each of its jobs during that time. It shows the amount of work completed as well as the expenses incurred for each activity in every one of the company's projects. The amount of work completed during a period depends not only on the methods selected for the various activities, but also on uncertainty factors during that time such as the weather conditions, labor availability, and the fluctuating cost of materials.

An end-of-period financial report is also provided to the participants showing the expenses incurred during that period. It lists amounts spent on direct construction services, bidding costs, delay fines, taxes incurred, and interest on borrowed money. It also shows payments to the contractor by the owner according to the payment requests and gives total cash-on-hand at the end of the period. Each firm may at any time apply for a loan to improve its financial situation. Loans granted are amortized over a one year time period. Changes in company ratios are also logged along with changes to the company's appraisal metrics:

- Is the firm within it bond limits?
- Financial Liquidity
- Financial Success
- Responsibility
- Pace
- Ethics
- Name Recognition

At the end of a period, the firms can examine their Progress Reports and decide on the effectiveness of the methods chosen for the various work activities. If they wish, they may change them and specify different methods for the following periods. The choice of methods allows companies to utilize slower but cheaper methods if they fear budget overruns, or faster but more expensive methods if meeting contractual deadlines is the main concern. In addition, overtime may be used to speed up certain activities, greatly increasing the labor costs. Firm must be concerned with the amount of liquidated damages on each project as they vary from project to project.

At the conclusion of the simulation, the program provides each participating company with a final report, forecasting the expected results of any on-going projects or their position at that point in time. It also shows the final total worth of the firm. Teams should consider maximization of profit as one of their main objective, and one of the primary criteria used to evaluate each firm's performance. As the simulation progresses, evaluations of company ratio, and appraisal metrics can be used to determine successful completion of the simulation.

6. Learning Objectives

The phases described in the previous sections were designed with specific learning objectives to ensure that identified curriculum deficiencies were addressed, integrating knowledge from project planning, project procurement, schedule control, and cost control bodies of knowledge. Tables 1, 2, and 3 provide a list of the learning objectives and mechanism COINS uses to assess student learning.

Table 1. Project Planning and Design Learning Objectives.

Learning Objective	Assessment
Use labor-equipment crew rates and productivity information to select methods for construction activities.	Students submit their reasoning and logic for selecting methods for each activity. COINS provides feedback on cost and schedule completion dates.
Develop a project schedule considering interdependent activity relationships and contract requirements.	Students submit their project schedule. COINS provides feedback on predecessor and successor activities.
Quantify planning, contingency, and bonding expenses and apply to project cost.	Students submit their project cost estimate, including planning, contingency, and bonding expenses. COINS provides feedback on percentages per project.
Calculate and apply percentages of main office overhead cost to multiple projects.	Students calculate the overhead cost and submit with project cost estimate. COINS provides feedback on project resources allotted for the project.
Use information regarding bonding capacity, labor availability, materials availability, liquidated damages, and apply modification	Students submit their rational for selecting resources based on bonding capacity, labor availability, material

factors to develop a construction cost estimate.	availability, liquidated damages. COINS provides feedback modification factors.
Apply value engineering fundamentals to decrease schedule requirements and reduce project cost during design	Students submit value engineering consideration to reduce cost and schedule. COINS provides feedback on applicability and feasibility of proposed options.

Table 2. Construction Engineering Learning Objectives.

Learning Objective	Assessment
Update schedule for in-progress projects.	Students submit their reasoning and logic for selecting methods for each activity. COINS provides feedback on cost and schedule completion dates.
Calculate final project cost, considering scenarios involving labor cost increases, material price increases, and overtime compensation.	Students submit their project schedule. COINS provides feedback on predecessor and successor activities.
Apply project acceleration techniques (changing methods, utilization of overtime, etc.) to decrease project schedule on projects that are behind schedule	Students are required to reduce project schedules for in-progress projects in response to market considerations by reducing their total number of work days.
Quantify cost associated with applying project schedule acceleration techniques.	Students submit their project cost estimate, including planning, contingency, and bonding expenses. COINS provides feedback on percentages per project.
Develop progress payment reports based on work completed to date.	Students calculate the overhead cost and submit with project cost estimate. COINS provides feedback on project resources allotted for the project.
Apply value engineering fundamentals to decrease schedule requirements and reduce project cost for project in-progress.	Students submit their rational for selecting resources based on bonding capacity, labor availability, material availability, liquidated damages. COINS provides feedback modification factors.

Table 3. Project Closeout Learning Objectives.

Learning Objective	Assessment
Calculate and use Cost Variance to determine cost differentials for project cost.	Students calculate cost variances (CV) at project completion. COINS performs an independent CV calculation and provides feedback.
Calculate and use Schedule Variance to determine differentials for project schedules.	Students calculate schedule variances (SV) based at project completion. COINS performs an independent SV calculation and provides feedback
Calculate and use Cost Performance Index to analyze project performance.	Students calculate cost performance index (CPI). COINS performs an independent CPI calculation and provides feedback.
Calculate and use Schedule Performance Index to analyze project performance.	Students calculate schedule performance index (SPI). COINS performs an independent SPI calculation and provides feedback.

7. Assessment of Student Trainee Learning

The simulation has a built-in grading module that can be used to obtain statistic on the various companies for comparison or to use in the classroom for grading the simulation. Each faculty can have their own method of grading. The following criteria can be used by faculty for assessing participation and student learning:

- Is the firm within it bond limits?
- Number of jobs bid
- Minus the jobs rejected (i.e., not enough bonding capacity, substantially low cost estimate, etc.)
- Number of times the number jobs you are the lowest cost
- Number of times the company retained earnings
- Company's appraisal metrics

8. Discussion and Recommendations for Future Implementations

Many new hires will come from academic areas other than Construction management. A need for these employees to understand an overall picture of the industry is important. Another group of employees are in accounting area and they too can benefit from a "capstone" look at their companies. To assist in the development of COINS, the developers have developed an Industry Advisory Board (IAB) from the construction industry as well as a working group of educators to continue the development and ideas for changes. Because of the idea of module development COINS can turn on and off some of its modules, making it a better fit in different classes. For example, estimating can be turned to an automatic mode which in a construction accounting class helps the student focus on accounting and not on the estimating itself which can be very time consuming and complex. Periods can move much quicker giving the students more accounting to analyze and in a shorter time in which they can see the changes that occur within a company without being bogged down in the estimating/procurement of work. Billing can be turned on to auto mode and additional projects can be added to each team to create additional project or backlog. The game play between commercial and heavy/civil construction is also modulized so a faculty can play only commercial, heavy/civil or both can be played in one game. Future additions are also planned as modules, i.e. personnel additions, case studies, and wide use of equipment management.

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Financial savings of the direct fastening technology

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Abstract

Currently there is a pressure in the Czech civil engineering market to reduce the price for deliveries. Therefore, to get a contract, many companies are forced to work for a price just slightly exceeding the costs. Naturally, they seek ways to reduce their operating costs and thus make a profit. Companies may reduce their number of employees, change the existing suppliers of materials for cheaper ones, but in many cases this need not be enough. Another option is an increase in the work efficiency and the associated reduction in the operating costs. The aim of the article is to describe methods that can increase the efficiency of building constructions. The article describes in detail minor mechanization which can save time and, ultimately, the costs. Specifically, we deal with a direct fastening (shooting) of anchor points into reinforced concrete, plain concrete, steel, and brick masonry. The article summarizes a wide range of applications of the anchoring method and a direct relation between time and cost savings. The costs are always calculated by comparing the traditional fixing method and the method of direct installation. The conclusion summarizes practical experience by which it was found out that the direct fastening yields not only cost savings but, to some extent, also better working comfort, because, unlike in the traditional fixing method, no dusty environment occurs.

Keywords: direct fastening, fixing method, efficiency, cost savings

1. Introduction

Long term development of tendencies in construction contracting supports the hypothesis that any economical crisis has major impact on costruction contracting. This, of course, is true for the Czech Republic as it is for any other country. Question lingers, howintense the crisis and its development will be in the years to follow. Since 2008, the tendencies in Czech construction contracting have been mostly negative, as shown in Figure 1.

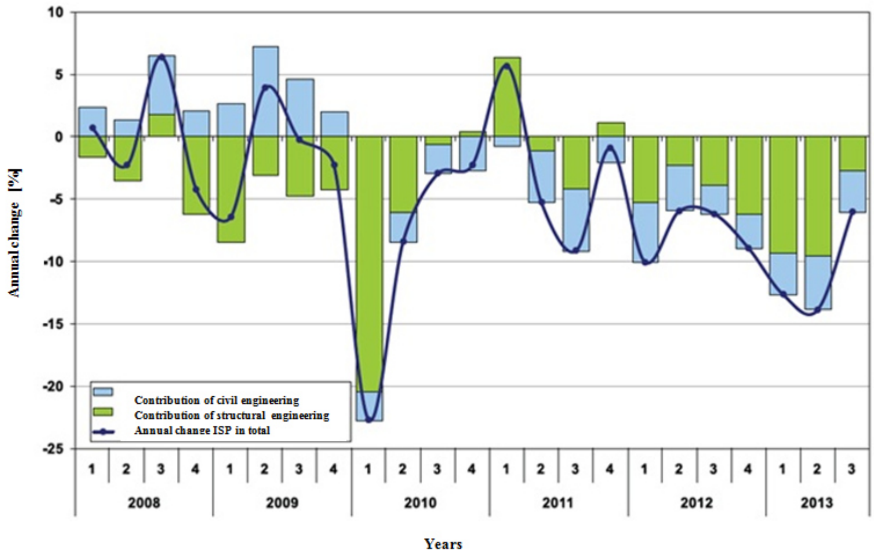

Figure 1. Interannual drop in construction production between 2008 – 2013 in the Czech Republic (Vacek J., 2013)

The low number of contracts increases the competition for every single contract and this situation indirectly creates enormous pressure on contract prices. Public contracts are highly profitable for builders, therefore competition for these contracts is intense. In 2013, contracts were tendered at prices 31% lower than designers estimated for the purposes of tender designs. However, price competition is intensifying further, as prices had been lower by 22% in 2012. Lack of contracts may also be seen through insufficient workload of all currently existing companies. Up to 17% of the companies are out of work. Some of them cannot find calls for bids, or reach the desired price for a contract due to the pressure concerning prices. Companies which cannot face the price pressure, and lower the costs allocated to a contract, will cease to exist (Vacek J., 2013)

There are many possible ways of lowering fixed expenses allocated to a contract, and therefore increase the capacities for competition concerning prices and costs. The most efficient, but least popular, way is reducing the number of essential staff. If the company does not have stable workload for its employees, it is the easiest way of reducing fixed expenses. The intermittent workload may then be outsourced to other companies. Outsourcing in itself is another way of reducing expenses and increasing work efficiency because then the company can focus on the subject of its activities, and not lose time by e.g. counting taxes. Another way of cutting down on expenses is wage reduction for the necessary length of time. Such solution is also much more acceptable for the employees.

Another option towards the increase in competitiveness and efficiency is the use of innovative technologies. These may encompass new construction trends, modernization of company technology, purchase of new machinery, modern construction materials, project visualization, prolonged guarantees, above standard approach, expansion of the services portfolio, reducing the dependency on subcontracts, and last but not least, speeding work and project dates. Nowadays, it is especially the matter of speed, which can help overcome the period of unbearable pressure towards low prices. Speeding the project completion date, or individual project phases, effectively cuts down ultimate costs. Expenses are cut down by the means of paying wages for shorter amount of time, lower total machinery rental costs, or temporary easement costs in cities. Reduction in construction exectution time introduces other ways of cutting down costs such as transport of workers to building site, accommodation for workers if the construction project is executed in a region other than company's usual place of work. All of the aforementioned facts call for new courses of action, or construction technologies, which would bring better results while adhering to project specifications according to project documentation. Such improvement can be reached by small-scale mechanization called direct fastening.

2. Direct fastening

Direct fastening is a quick and efficient method of fastening into plain concrete, reinforced concrete, brickwork and steel, by the means of special nails. Fastening of one nail only takes seconds. Direct fastening is dividet into submethods according to the medium which drives the piston. Powder-actuation is the first of the two. It allows for fastening with the aid of cartridges, the whole system is based on the same principle as a shotgun. However, nails from powder-actuated tool are not capable of flying out far. Gas-actuation is the other method, when the medium which drives the piston is gas compressed in a small container. Small amounts of gas are pumped into a chamber where the gas is ignited which results in a discharge. Both methods allow fastening with the aid of a container of nails. This speeds assembly maximally, and also saves financial means (HiltiCorp., 2007).

2.1. Gas-actuated tool

Gas-actuated tool is named in accord with the medium which drives it – gas compressed in a small container. Gas-actuated tool, gas container and nails are portrayed in Figure 2. Gas-actuated tool is appropriate for the following professions: electricians, plumbers, and plasterboard installers. Plumbers and electricians may use the gas-actuated tool for conductor routing in administrative, industrial, or other large buildings. Plasterboarders can use direct fastening technology especially for fastening of alluminium profiles into floor and ceiling structures. This method replaces traditional ways of fastening conductor routes and plasterboard by drilling holes and fastening materials such as metal or plastic wall plugs (HiltiCorp., 2007).

Figure 2. Gas-actuated tool, gas container, and nails (Hilti Corp., 2013)

2.2. Powder-actuated tool

Powder-actuated tool is named in accord with the medium which drives its piston, i.e. gunpowder in cartridges. As mentioned before, this way of fastening resembles the principle of a shotgun, but it can by no means shoot nails. The tool is safeguarded by a mechanism of double safety-catches which only activate the discharge mechanism after the tool is brought in contact with the underlying material, and when pressure safety-catch is overpowered. There is no need for special education to operate the tool, nor is there need any special safety utilities, as used to be common when the technology was first introduced. The worker will only need the usual safety equipment, such as gloves, and safety glasses. In the beginnings of direct fastening, skill training and safety training were necessary before operating the tools. Safety equipment consisted of a heavy leather jacket and a hard plexiglass headshield. The technology operated in exactly the same way as a ashotgun, and time and again the nail would hit concrete, and bounce backe. Those were the reasons for wearing a leather jacket, and a helmet with a plexiglass shield. However, currently these issues have been eliminated.

Powder-actuated tool is a beneficial tool for electricians and plumbers. It is also suitable for fabric when fastening shuttering spacers, and also for fastening anchors in monolith bonding. It can further be used for thermal insulation anchoring accomplished by the means of special traps (HiltiCorp., 2007).

Figure 3. Powder-actuated tool, nail, and cartridges (Hilti Corp., 2013)

2.3. Examples of direct fastening

As has already been mentioned in subsections 2.1 and 2.2, direct fastening is a method with a wide range of uses in both fabric stage of building, and also in building trades. The major examples of direct fastening, including descriptions, are presented in Figure 4.

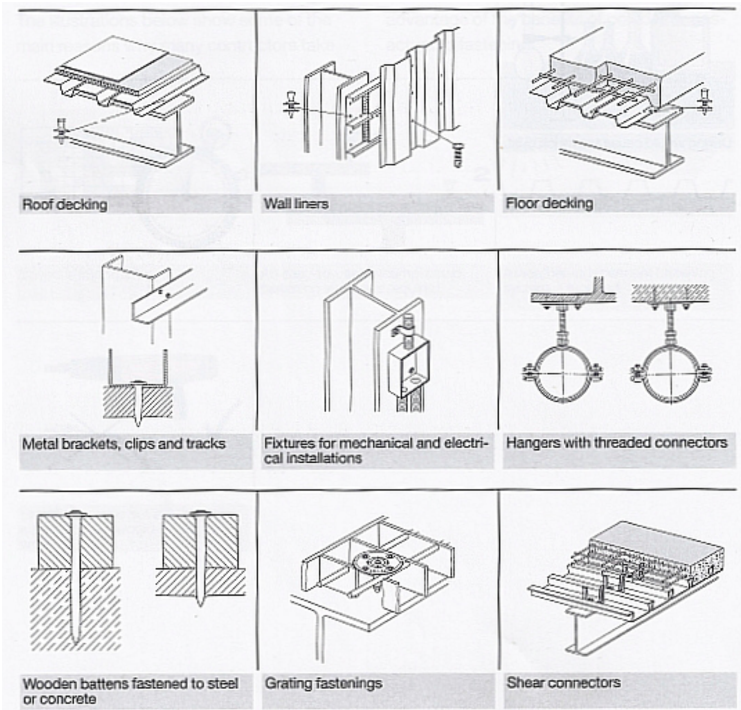

Figure 4. Uses of direct fastening (Hilti Corp., 2007)

3. Economic study of a cable routing project

This chapter presents an economic comparison of a cable routing project executed by the means of the traditional anchoring method, and by the means of direct fastening. Cable routing is realized in total length of 500 m in a two-floor administrative monolith building with ceiling height of 4,8 m. To conduct 500 m of cable routing, there will be need for 1,500 fireproof anchor points.

In both ways of executing the project, anchor material is accounted for, as are the costs of workers, purchase and rental of necessary machinery. With both anchoring methods, decking and scaffolding was rented, and costs of equipment needed for execution of the project were accounted for. Material costs and rental costs follow the usual market prices not including VAT. Productivity of both methods was measured on site of Florentinum in Prague. Each method was timed during an 8-hour shift, and consequently converted to hourly work rates.

The traditional anchoring method with its consequent financial analysis is stated in Table 1. Total costs of the project were 58 025 CZK not including VAT.

Table 1. Economic study of traditional anchoring method

Project specifications	
Number of anchor points [pcs]	1500
Assembly productivity and fastening times	
Assembly productivity [anchor/hr]	20
Total time of project anchoring[hrs]	75
Worker costs for entire project [2 workers]	
Hourly rate of one worker [CZK]	150
Total worker costs per project [CZK]	22500
Material costs	
Fireproof anchor [5,5 CZK/pc]	8250
Fireproof fixing lug [4,5 CZK/pc]	6750
Drill 6/12 - 120 holes/item [90 CZK/pc]	1125

Total material costs [CZK]	*16125*
Machinery purchase and equipment rental costs	
Drifter drill purchase[CZK]	4900
Electric screwdriver purchase [CZK]	4000
Decking rental [1400 CZK/day]	10500
Scaffolding rental [550 CZK/day]	-
Total costs of machinery purchase and equipment rental [CZK]	*19400*
Project costs	
Total costs per anchoring project [CZK]	***58025***

Direct fastening method and its economic analysis is shown in Table 2. Total costs for the project were 43,200 CZK not including VAT. When compared to the traditional fastening method, the costs of the project are 14,825 CZK lower. Should this case study be a project that does not need to take purchase costs of machinery into account, the savings would be higher. Saved time which is due to better work productivity also influences other areas with potential for cutting down costs. Easement time may be shortened, and therefore paid less for, worker accommodation and transport costs may be reduced as well.

Table 2. Economic study of direct fastening method

Project specifications	
Number of anchor points [pcs]	1500
Assembly productivity and fastening times	
Assembly productivity [anchor/hr]	20
Total time of project anchoring[hrs]	30
Worker costs for entire project [1 worker]	
Hourly rate of one worker [CZK]	150
Total worker costs per project [CZK]	*9000*
Material costs	
Fireproof nail including gas [4 CZK/pc]	6000
Fireproof fixing lug [4 CZK/pc]	6000
Total material costs [CZK]	*12000*
Machinery purchase and equipment rental costs	
Gas-actuated tool purchase [CZK]	18000
Decking rental [1400 CZK/day]	4200
Scaffolding rental [550 CZK/day]	-
Total costs of machinery purchase and equipment rental [CZK]	*22200*
Project costs	
Total costs per anchoring project [CZK]	***43200***

Figure 5 graphically displays a comparison of traditional anchoring method and direct fastening in relation to the number of anchor points. It is obvious that the traditional method is cheaper when the number of anchor points is low. Such fact is logical as work productivity does not affect the result much when the total amount of time and anchor points is low. As the chart may seem misleading to investors, let us reinstate that direct fastening becomes financially beneficial from 550 anchor points onwards.

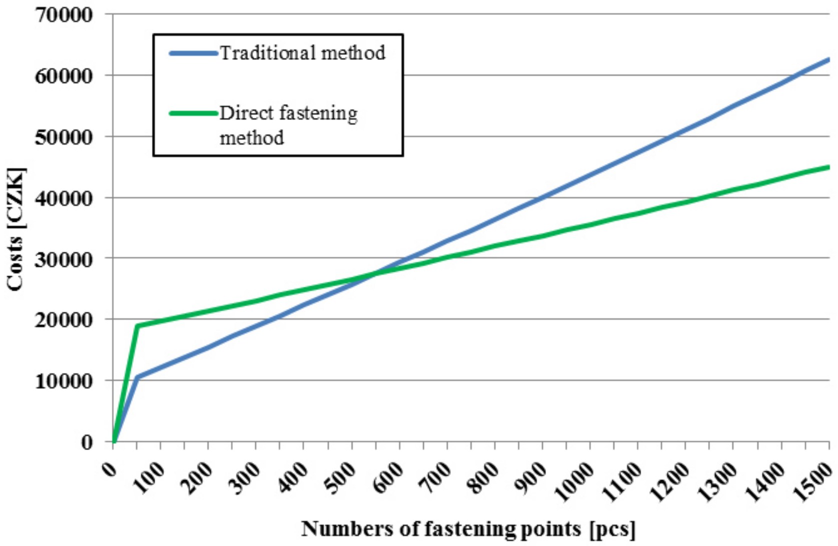

Figure 5. Comparison of realization costs in relation to the number of anchor points (author's data)

4. Conclusion

The presented economic study with a sample subject of cable conducting proves that direct fastening does not bring about a reduction in material costs, yet it improves work productivity and saves both time and workforce. When taken into account, these facts lead to highly interesting total savings in execution costs. Finally, direct fastening also brings the element of work comfork, especially when talking about overhead work. In the traditional method, anchors need pre-drilled holes. That creates large amounts of fine dust, and when drilling overhead, the small debris falls on the workers'heads. With direct fastening, there is no dust created, nor small debris falling. Nowadays, the investors create pressure towards price reductions and speedy project execution. Therefore, direct fastening seems to emerge as a logical standard in advanced and developed countries, in both Czech and foreign markets.

Acknowledgement

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Reducing the costs of high-performance buildings – the integrated design process

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Abstract

Theoretical developments of integrated design process (IDP) suggest that IDP can lower the time and cost of the construction while creating a high-performance building. The purpose of this paper is to introduce a building design approach called integrated design process and to prove that the costs of high-performance buildings can be reduced in a simple way.
In this research the methodology, the effects and costs of the IDP are demonstrated by a successful case study of a new metro station building. At first the inspected building was designed and permitted in a traditional way but this proved to be very costly and slightly energy-efficient. An additional architect office redesigned the building adopting the IDP and optimizing the building from the aspects of indoor comfort, smoke, heat ventilation and structure. It was redesigned with the support of computational fluid dynamics (CFD) simulations, solar radiation analysis and finite element method (FEM) analysis. To this end, an integrated multidisciplinary design charrette consisting of architects, constructors, engineers and environmental specialists improved the project collectively from the beginnings.
Due to the coordinated teamwork of different specialists, the optimal solution of the building skin, steel structure, openings and energy consumption could be achieved. The application of IDP resulted in approximately 47% lower construction costs compared to its highly regulated traditional process.
This case study demonstrates that high-performance buildings do not necessarily imply higher construction costs. The practical significance of the study is to prove that integrating the design process can result better performance and higher cost-effectiveness. Future researches could examine further case studies and provide a methodology for choosing between the IDP and the traditional design.

Keywords: cost-effectiveness; design process; high-performance building; integrated design; sustainable construction

1. Introduction

The conclusions of the European Council of 2007 emphasized the need to increase energy efficiency in the European Union to achieve the objective of saving 20 % of the European Union's primary energy consumption by 2020 compared to projections (EU, 2012). The building sector consumes up to 40% of global energy and with proven and commercially available technologies their energy consumption can be cut by an estimated 30 to 80 percent with potential net profit during the building life-span (UNEP SBCI, 2009). In order to achieve the energy efficiency target, high-performance buildings have to be built but the high first-cost of these buildings causes a significant barrier to their extensive spreading (Vaidya, Greden, Eijadi, McDougall, & Cole, 2009). Further difficulties for implementing high-performance buildings are the higher costs of green construction practices and materials, technical difficulty during the construction processes, risk due to different contract forms of project delivery, lengthy approval process for new green technologies and recycled materials, unfamiliarity with green technologies, greater communication and interest required amongst project team members and more time required to implement green construction practices on site (B.-G. Hwang & Ng, 2013). In this paper it is presented how the high construction costs can be reduced and the mentioned barriers can be overtaken by the application of a new design methodology called integrated design process (IDP).

There are many attempts to describe the IDP and probably the most appropriate definition is the following: "the integrated design process is an approach to building design that seeks to achieve high performance on a wide variety of well-defined environmental and social goals while staying within budgetary and scheduling constraints. It relies upon a multi-disciplinary and collaborative team whose members make decisions together based on a shared vision and a holistic understanding of the project." (Busby et al., 2007). Integrated design

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process is not a new design concept, it could have been applied in many construction projects without naming the process (Larsson, 2009). The first formal implementation of IDP was realized in a Canadian demonstration program for high-performance buildings, the C-2000 program, which was developed and managed by Nils Larsson, Natural Resources Canada. In the C-2000 program the application of IDP resulted that high levels of performance could be reached and that the incremental time and capital costs of the design could be acceptable compared to the subsequent gains (Larsson & Clark, 2000). IDP is similar to other relatively new green construction ideas like Building Information Modeling (BIM) (Forgues & Iordanova, 2010) and Lean Construction, which were developed to deliver high-performance buildings at the same or lower costs compared to conventional facilities. These new ideas are applied in the integrated project delivery (IPD) which is a new delivery system with many attributes that make it highly compatible with green building (Kibert, 2012). The USGBC LEED program also adopted the IDP and awards extra points for its application (USGBC, 2009), there are many attempts to widespread it for other green building rating systems too (Khanna, 2013).

The integrated design process does not concentrate on producing fast design of the lowest first-cost buildings but it aims to implement life-cycle cost-efficient design. IDP represents the major functions and activities necessary for a successful design (Sanvido & Norton, 1994) and it enables the designer to control all of the parameters that must be considered and integrated in the project (Hansen & Knudstrup, 2005). IDP starts with the design process and continues until the end of the project, it must be highlighted that all of the actors need to be actively engaged from its beginnings (Kanters & Horvath, 2012). The design phase is the most important part of the process because if the design phase does not focus on energy efficiency and sustainable principles the project will never be able to reach the appointed high-performance targets. For integrated design it is essential to encourage creative interaction and communication between the disciplines and team members and to think about the project holistically (Lewis, 2004). The IDP is managed by the IDP facilitator who forms the design team (charette) to achieve effective cooperation. In the design charette the clients, managers, specialists, architects, contractors and consultants develop the project together in tight collaboration with other stakeholders (Reed & Gordon, 2000). As cross-disciplinary teamwork is required, the design-build delivery system is the most sufficient delivery system for the IDP, opposite the traditional design-bid-build delivery system (B. G. Hwang & Tan, 2012). In spite of the clear advantages of IDP it also has many barriers to implementation, because of the unfamiliarity with the process, the clients' conventional expectations, perception of risk by the engineers and different fee structures (Vaidya et al., 2009).

There are many theoretical and practical attempts to define the IDP (Busby et al, 2007, Zimmerman, 2006), determine its process (Reed & Gordon, 2000), name its participants (Baiden, Price, & Dainty, 2006) focusing on the construction time reduction (Cheng, Dale, Aspenson, & Salmela, 2011) or energy performance gains (Larsson & Clark, 2000) but there are not many accurate studies about its financial aspects. According to the current studies, the financial aspects of IDP are always highlighted, but the researchers' realizations are different and slightly proven. For example Zimmerman suggests that the overall costs of sustainable building projects are minimal when applying IDP (Zimmerman, 2006), Busby et al. claims that IDP minimizes the incremental costs (Busby et al., 2007), Reed and Gordon assume that IDP increases costs at the beginning of the project but reduces costs during the entire period (Reed & Gordon, 2000) and Vaidya et al. implies other researches does not adequately address the first-cost issue (Vaidya et al., 2009). Quantified researches are even more incomplete, they usually refer to the reduction of time (Cheng et al., 2011) or for example Matthews only mentions that in the construction of the Orlando Utilities Commission North Plant the budget performance was 10% lower compared to the good manufacturing practice (Matthews & Howell, 2005).

2. Methodology

The aim of this study is to prove that IDP can significantly lower construction costs and to provide an example of its process and results. The effects and costs of the IDP are demonstrated by a successful case study of a new metro station building in Hungary. In Budapest the fourth metro line, which went through a long preparatory period and many political skirmishes, is being built now (Schulek, 2008). The subject of this case study is the superstructure of the metro station called Bikás Park which is an irregular glass dome covering the underground station. Its design, redesign and building lasted from 2005 to 2014.

In this paper the financial benefits of integrated design process are compared to its previous traditional design process. At first the metro station was designed by conventional means but its construction proved to be very costly, therefore it was decided that it would be redesigned by IDP. Through the following case study the process of the IDP is demonstrated, the projects contractual relationships are presented, the integrated design team is introduced and it is shown step by step how the actions of the IDP lower the costs of the project compared to its previous traditional design process. The building of the metro 4 in Budapest was a large project with an investment of 1,5 billion EUR (Metro4, 2014), thus it was strictly regulated, it had a complex contractual system and the direct communication between the specialists was not allowed or it was highly limited. The information about the contractual system and communications lines result from our interview with the chief architect and project manager of the project, and the technical data and cost information come from the interview with the manager of the integrated design team.

3. Application of IDP in a construction project

Before applying the IDP, the first architectural and engineering plans of the station were delivered by conventional means according to the strict regulations. The investor made a contract with an architect office whose responsibility was to deliver the building permit drawings. The investor also appointed an independent checking engineer company to control the processes and plans. The conventional plans were realized with a serial scheduling of tasks, none of the planning functions were developed in parallel. The original building form was designed by the architect office, which after an extensive preliminary study advised an arched glass-structured dome as a combination of a spheroid and a sphere form. After the completion of the architectural drawings, the architect office commissioned a structure design office with the structural plans and static calculations of the building. This office developed a conventional structure for the dome with load-bearing beams and arched purlins, where the glass structure consisted of curved glasses. The completed architectural and structural plans were forwarded to the mechanical and electrical engineers to prepare the ventilation, heating, cooling and electrical plans. The engineers had to create a mechanical system which fitted into the accomplished form and structure thus they planned that the emergency ventilation would be used to lead away the heat in the hot summer. After the mechanical and electrical drawings were ready the fire protection engineering followed under similar conditions. The traditional plans were developed according to the Hungarian National Fire Protection Regulation (OTSZ, 28/2011. (IX. 6.) 201. 527. § (2)) and this regulation could have been fulfilled only with around 42 windows. At the end of the design process the final building permit drawings were delivered to the contractor.

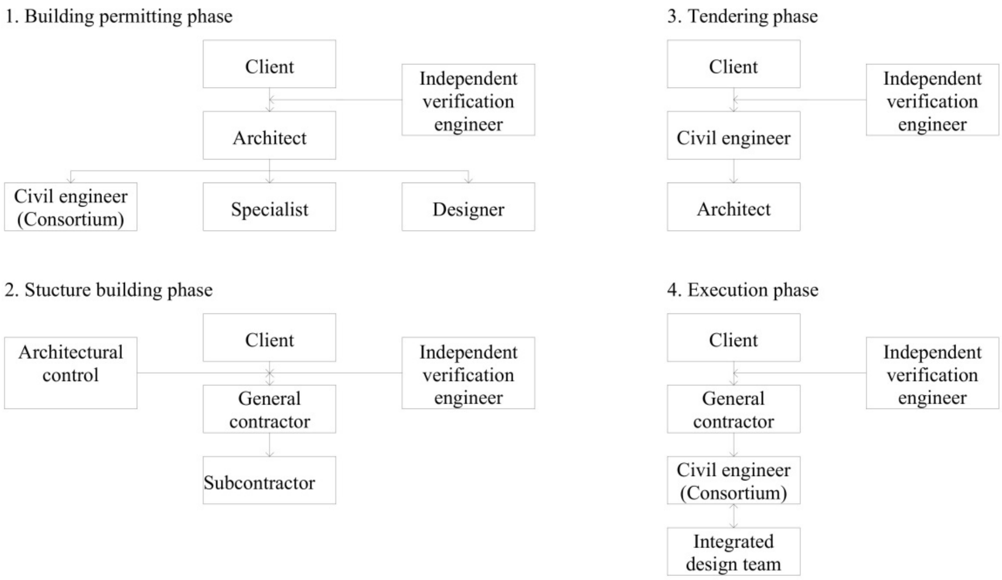

Figure 1. Contractual relationships in different phases of the project

This linear design method could have been adequate for a less complicated common building, where the everyday practices were well-known to all of the specialists. But it seemed to be ineffective and inelastic in this case as the different experts could not communicate to find an optimal solution. Thanks to the inappropriate design the construction costs became extraordinarily high and new changes were required by the contractor. During the design process, all of the contracts were signed in accordance with the FIDIC (International Federation of Consulting Engineers) Yellow Book (Conditions of Contract for Plant and Design-Build), which means that design-build delivery system was used (Figure 1.). Accordingly, the contractor could change the building permit if his decision presented a rationalizing suggestion, which referred to cost reduction or time reduction. The architect office advised to redesign the building with an integrated design team where the team members could optimize the building parameters and lower the costs. The investor was against any changes of the project, because he was afraid that it would increase the costs, so significant management support was needed to convince the investor of the possible successes of the IDP. Finally he agreed and an integrated design team was asked to develop the rationalized plans and the barriers of the regulated communication could be defeated. The redesign was conducted in two phases because of the skepticism of the client. In the first phase the type of the structure and the material consumption of the dome were optimized, while in the second phase the dome was optimized from the aspects of thermal comfort and heat and smoke ventilation. The members of the integrated design team were specialists of architecture, structural engineering, steel, glass, fire protection, underground ventilation, computer simulation and construction, and they were in constant contact with each other and developed the project collectively (Figure 2.).

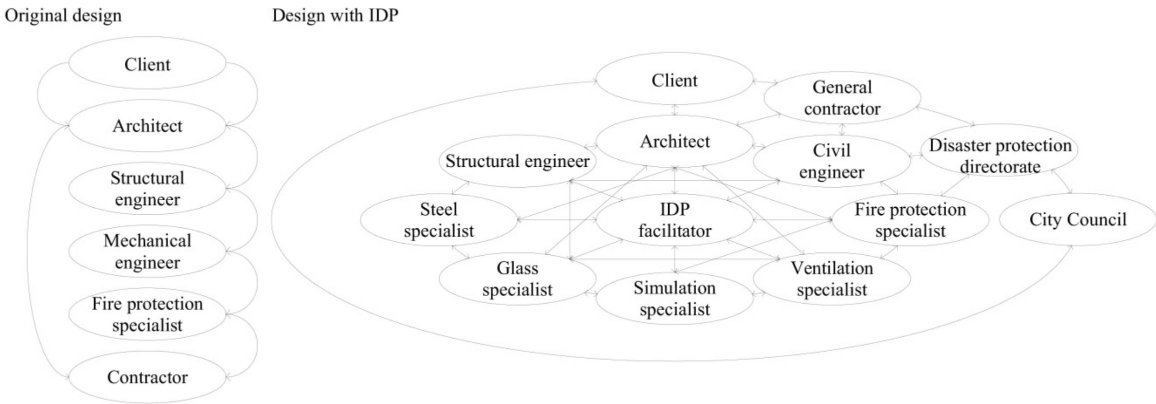

Figure 2. Communication lines before and after applying the IDP

In the first phase of the redesign, effective communication of architects, structural engineers, glass and steel experts was needed, who finally agreed on a steel triangle space frame structure for the dome (Figure 3.). This innovative structure was designed by finite element method (FEM) analysis and could lower the area of the dome and the size of the steel profiles so less material was needed. The square bent glasses could be changed into triangle shaped plate glasses which were simpler and cheaper than curved glasses. Glasses were optimized for the manufacturing size and thickness too. Despite the number of windows was raised to 160 pieces in absence of precise calculations in the first phase. Architecturally the structural changes resulted in a more esthetic and more modern building.

In the second phase of the redesign the cooperation of fire protection specialists, underground ventilation specialists, computer simulation specialists and architects were required to combine the heat and smoke extraction system with the system ensuring the thermal comfort. The mentioned National Fire Protection Regulations include limit values only for the simple quadratic windows so the integrated team calculated with computational fluid dynamics (CFD) simulations the proper values for the triangle windows. The real opening area of the not vertical triangle windows is much smaller than the area of quadratic vertical windows with the same effective orifice area thus the number of opening windows was lowered from 160 pieces to 84 pieces. In order to achieve the convenient thermal comfort the powered windows were planned not only for use in an emergency but could also be opened for everyday ventilation. After profound solar radiation analysis triangle shading was developed and a low-powered ventilator was installed to exhaust the hot air. With these measures the emergency ventilation would not be needed in hot summers as it was originally planned. These modifications took place to create a high-performance building and to lower the construction costs (Table 1.).

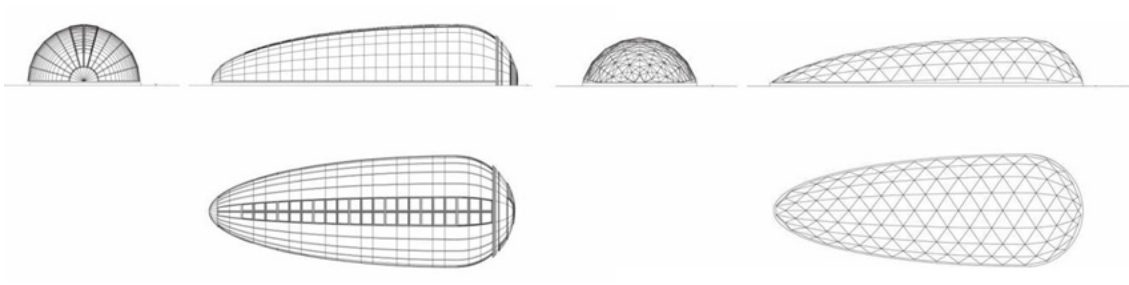

Figure 3. Schematic plans before and after applying the IDP

Table 1. Comparison of technical details before and after applying the IDP

	Original plan	Plan with IDP
Geometry	Cut of an ellipsoid and a sphere	Cut of an ellipsoid and a sphere
Structural system	Beams and arched purlins	Steel triangle space frame
Glass type	Curved glass	Plate glass
Bracing	Separate bracing – unfavorable because of fire-protection	Space frame ensures the bracing
Average height of the construction	3,2 m	< 3.0 m
Ventilation	Through entrance	Through entrance and bottom lane
Cleaning, maintenance	Cleaning construction and cleaning machine	Cleaning construction and alpine technic
Entrance	Arched sliding doors	Arched sliding doors
Material around gate	Metal	Glass
End closure on west side	Metal	Glass
Material of the gate	Metal	Metal

4. Results

Due to the coordinated teamwork of different specialists, the optimal solution of building skin, steel structure, openings and energy consumption was achieved. In the first redesign phase the construction costs were lowered from the 1 111 000 EUR[†] of the dispositional plan to 777 000 EUR of the evaluation construction plan. In this phase the highest cost reduction was due to the lower glass structure costs, which decreased from 654 000 EUR to 218 000 EUR because the plate glass is much cheaper than the curved glass, the area of the dome was lowered and the manufacturing size and thickness of the glasses were optimized. The smaller steel structure profiles of the space frame lowered the steel construction costs from 192 000 EUR to 138 000 EUR. Some additional costs occurred because the original gates and windows were kept with the new structure. In the second phase, when the heat and smoke extraction was combined with the ventilation system ensuring the thermal comfort, the costs were reduced from 777 000 EUR of the evaluation plan to 574 000 EUR of the final construction plan. In this phase the number and thus the costs of the windows were lowered because of successful computational fluid dynamics (CFD) simulations. The new gate was fitted to the new structure and some other smaller modifications were performed which lowered the costs too. Finally the application of IDP resulted in 537 000 EUR (48,33%) lower construction costs compared to the traditional process (Figure 4.).

[†] the average exchange rate of the year 2010, when the costs were summarized, was 275,41 HUF = 1 EUR (Hungarian National Bank, MNB)

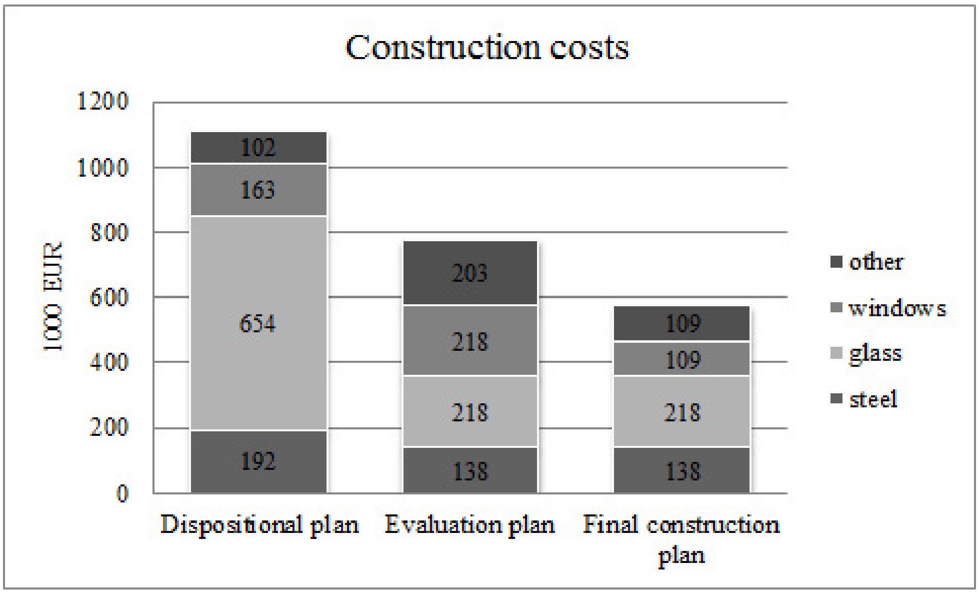

Figure 4. Construction costs before and after applying the IDP

The IDP could significantly cut the construction costs but it also had to increase the design costs. The additional design fee of the integrated design process cost 18 000 EUR which is only 3,38% of the construction cost savings. Including the design costs the final project cost saving was 519 000 EUR (46,71%) and a high-performance building with modern structure, with more pleasant thermal comfort and lower energy consumption for ventilation was created.

5. Conclusion

The redesign and construction of the Bikás Park metro station was a successful example of the application of the integrated design process which resulted in a 46,71% cost reduction of costs compared to its previous highly regulated conventional means. By the means of the integrated design team effective communication of all participants could take place, the different design aspects could be combined, optimal solutions could be used according to every specialization and a high-performance cost conscious building could be delivered. This case study is the proof that IDP is a real alternative to traditional methods with delivering a high-performance building and if this project does not want to be one of the rare successful examples further researches, development and dissemination in practice will be necessary. This was a small building and a relatively complex project, these excellent results cannot be expected from every application. A clearly defined methodology and a measurable indicator system are advised to be developed to determine whether IDP can be adopted in a certain project.

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Defining of decision-making criteria for optimum construction procurement system selection for public works

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Abstract

Public works represent a prominent part of today's civil engineering and therefore considerably affect the construction market. On the Czech construction market alternative construction procurement systems have currently received a lot of attention. An owner, the public work owner especially, choses his contractor according to the price of the project within which the demanded criteria are still fulfilled. The whole process of the selection of the contractor is affected by the needs of the owner and the abilities of the potential contractor. In this traditionally used model, the owner is deprived of the possibility to elect the optimal alternative construction procurement system losing its potential advantages and possibly accepting more risks than necessary. Consequently, the poor variability of the individual system use may result not only in the loss of their potential advantages but also in growing costs and time of the realization.
In this work an owner´s strategy for optimum construction procurement system selection for public works is developed. The strategy is based on the theoretical findings on contract standards according to the public work law. The main concept of the strategy has its origin in each characteristics and its suitability for different types of project. Finally, risk management is applied to the established scheme.
The presented strategy should enable the owner an easier preparation and realisation of the construction project. The work should hopefully help the owner with the decision-making process and save costs and time of the realization in public projects.

Keywords: construction project; construction procurement systems; owner´s strategy; public work; risk management

1. Introduction

Projects in civil engineering are very specific because there is a wide range of participants, whether it is the owner and designer who prepare and finance the project the general contractor and subcontractors who realize it or the final users of the construction project who shall use the project after it is finished. All the relationships and agreements between all the parties of the construction project are properly defined in each type of construction procurement systems. In the construction procurement system one or more agreements are made and these contracts define the way, the construction project will be realized. The agreements determine both the rights and the duties of the parties and they lay down risk the project entails for the participants.

2. Research methodology

This work chose to apply qualitative research that is used when the research requires a deeper understanding of the topic. This type of research can deal with the description of processes, relations, situations, assumption verification, theories or generalization.

There are possible two research methods for this work, positivist and phenomenological, but the phenomenological research method seems more suitable for this work.

A deductive type of research and a case study are used. The deductive approach is about understanding the public procurement in the Czech Republic and the United Kingdom. The research aim of this work is to demonstrate the differences in the particular approaches. It starts with an overall analysis of construction procurement systems, public works and construction procurement system selection and all the differences related to it. The law used for public procurement in the UK and Czech Republic should be nearly identical because it is

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based on the same EU fundamentals. That is why a detailed law analysis is not necessary. Much more attention is on the cases of differences between the procurement systems used for public works.

Multiple case studies are used for this research. A case study is the best way to approach qualitative research. In general the case studies are described as a detailed study of one or a few cases (Yin, 2009). First of all there are two highway projects, one from the Czech Republic and other from the United Kingdom analysed in this work. The optimal approach to the public contracts procurement is described on the comparison of the two different approaches.

3. Construction procurement systems

Nowadays several types of construction procurement systems are used in civil engineering. On one side, there are still traditional construction procurement systems (e.g. Design – bid – build), nevertheless, there are more and more alternative construction procurement systems used such as Design – build, ECI, PPP or PFI projects. Compared to the UK and the US, Czech construction market falls considerably behind with these alternative types of the construction procurement systems. The alternative types of construction procurement systems emerged in the US in the 80s and during 30 years the Design – build system has become more popular than the traditional ones (The American Design/build institution, 2011). The popularity of the alternative Design-build system gradually growths as opposed to the gradual fall of the Design-bid-build. Nowadays, the former is used for more than one half of the US construction projects (Hale, Shrestha, Gibson, Migliaccio, 2009).

3.1. Design – bid – build

This "traditional" system has been used for a very long time. A characteristic feature of this construction procurement system is the involvement of three main parties – the client, the designer and the general contractor. The relationships between these three entities are firstly those between the client and the designer and secondly between the client and the general contractor (Prostějovská, Hačkajlová, Tománková, Hromada, Tatýrek, 2008). The traditional DBB procurement system is designed more or less for such types of contracts where the amount of changes is minimal. In case of any changes the system is not efficient and the changes can cause rising of both the price and the time of realization. The system is mostly focused on the lowest price, but it does not pay any attention to potential risks.

3.2. Design – build

The Design – build system started in the US in the 80s as an alternative to the traditional systems. It is still quite new on the Czech construction market, but it has gradually been becoming more popular. Its typical characteristic is that there are just two parties involved – the client and the general contractor. Their relationship and communication are easier which brings time and cost savings. It is used especially for complex and technically difficult projects where claims and changes are expected during the realization (Dorsey, 1997). DB system is longer used on the UK construction market. DB contracts are used for substantial projects beyond the threshold of Highways Agency frameworks, where the ECI approach is not suitable. Typically, these are larger renewal schemes, or schemes where most design decisions are fixed in advance. Suppliers are expected to complete the required level of design, which must include introducing any potential savings in time, cost and/or quality gained through their previous know-how (The Highways Agency, 2012).

3.3. Early contractor involvement contract

This system represents the best way to connect the design and the construction part of a project. When the company responsible for the design part of a project is also the general contractor, all potential mistakes and claims in the design can be eliminated at least to a minimum. The ECI contract enables all involved sides of the construction to participate and cooperate on the designing phase. When the designing phase is a cooperation of all involved sides of the construction including the contracting authority, the potential claims and disputes can avoid (Mosey, 2009). This form of contract allows supplier engagement at an early stage of a project, in order to draw in industry experience at the design and preparation stages. ECI contracts remain an option for major highways schemes where there is significant scope for input from the supply chain. Suppliers' engagement will be on a partnering basis. Their knowledge and abilities to influence project decisions will have maximum impact in terms of project timing, quality and cost (The Highways Agency, 2012).

3.4. Public – private & Private – finance contract

Another significant group of construction procurement systems are systems which connect the public and the private sector. In this cooperation, projects situated in the public sector are financed and realized by a private client. This cooperation is mostly for a long period, not just for the realization, but also for the project operation. It's interesting contract for both, public and private party (Ostřížek, 2007). Private - finance contract forms are considered for high value, strategic projects, in accordance with government policy. For roads under Design Build Finance and Operate contract forms, the deliverables are centred on the provision of an operating service rather than an asset. Over an extended contract, the private sector assumes responsibility for the operation and maintenance of a length of existing or new road, and can include building specified improvement schemes. Suppliers are expected to partner the Highways Agency in design, construction and operation and form a strategic part of delivering the Highways Agency's aims to their customers (The Highways Agency, 2012).

4. Public works and construction procurement system selection

In the Czech Republic the legislation used for public contracts is Act No. 137/2006 Coll. It presents the different procurement procedures. According to this law, the sealed envelope method for submission of tenders is used on the Czech market. Public tender evaluation is carried out by a commission appointed by the contracting authority, the most important evaluation criterion mainly being the total price. The procedure of evaluation and opening the envelopes is a public act and all involved companies' representatives may attend. The commission has to assess the completeness of each quotation verifying that all the documents mentioned in the tender documentation are attached. The next step is a detailed examination of each attached document. In the case of a failure to comply with the required procedure, the company will be eliminated from the tender. If the quotation contains formal mistakes or if there is some missing information, the company will be asked to complete the quotation. Should the company fail to complete the documents, the contracting authority has the right to exclude the quotation. The contracting authority may evaluate the quotations exclusively by the lowest price or according to the economic advantages and other pre-determined evaluation criteria. The result can therefore be based not just on the lowest price. In the case of the alternative evaluation, the procedure must be determined by several criteria which represent the relationship between utility value and final price. The lowest price is not necessarily the only criterion which can decide the winner of the tender. After evaluating all quotations, the contracting authority announces the winning supplier using the contract which was included in the tender documentation (Prostějovská, Hromada, 2008).

To compare, public work system selection in the United Kingdom is based on national legislation and follows European directives. These two directives are divided in these areas (Ashurst, 2012).

- The Public Contracts Regulations 2006 (as amended by the Public Contracts and Utilities Contracts Regulations 2007 and the Public Procurement Regulations 2011) implement the EU rules relating to services, supplies or works procurements entered into by public bodies other than utilities (the Public Contracts Regulations); and

- The Utilities Contracts Regulations 2006 (as amended by the Public Contracts and Utilities Contracts Regulations 2007 and the Public Procurement Regulations 2011) implement the EU rules relating to services, supplies or works procurements entered into by utilities (the Utilities Contracts Regulations), (together, the Regulations).

The procedure of public procurement in the UK is similar to the one in the Czech Republic. The element which is missing in Czech public procurement law is the importance of the social impact of public contracts. The United Kingdom legislation involves other aspects of public procurement, namely the employment of unemployed people and the environmental impact. This helps improve the public procurement and especially results in the public contracts having many more benefits than just the structure itself. There are a lot of efforts to improve the public procurement contracts and especially efforts to find the ideal procurement system for public procurement systems. The United Kingdom government's advisory unit on infrastructure published the infrastructure cost review which identifies the potential savings. The percentage is very significant because the review says that the potential is up to 15% (HM Treasury, 2013).

The tendering process is similar to the Czech Republic. The main difference is in the evaluation which is based not only on the lowest price but on the above mentioned "Value for Money", a combination of several criteria which can achieve better results as more aspects are included (HM Treasury, 2013).

A clear example of the differences between the two systems may be demonstrated on the comparison of transport projects in the Czech Republic and the UK. Current strategy of the "Road and Motorway Directorate of the Czech Republic" is to prepare all the projects very carefully with special attention to the absolutely accurate project documentation in order to avoid all possible additional works and claims. Traditional DBB construction procurement system is mostly used. To compare, "The Highway Agency" as the contracting authority in the UK is allowed to evaluate every applicant and its capabilities against several criteria before allowing the applicant to participate in the tender. The applicant can also be assessed to be a holder of necessary certificates or accreditations for a specific type of projects. The different kinds of contracts are also used in practice. When "The Highway Agency" strategy is compared to the efforts of the "Road and Motorway Directorate of the Czech Republic" it is obvious that in the Czech Republic this effort still appears to be insufficient.

5. Case studies

Two projects, one from the Czech Republic construction market and one from the UK, were chosen for case studies. These projects are quiet similar for easier and clear general view to this topic. It is not just a comparison of two projects, but in general, it's a comparison of two approaches in different countries for construction procurement system selection for public projects.

5.1. Prague – Dresden D8 highway project

The first thought about a highway from Prague to Dresden emerged in 1938, but the new D8 project began in 1984 with the construction of the first part of the intended highway and it continued in the 1990s. The project not only connects the central part of the Czech Republic with the northern industrial zone, but its impact is also important on the international scale as it brings a highway connection between Prague and Berlin. The first 48 km of the highway were built in years 1990 and the last, 23 km long stretch was opened in 2006. However, the two separate sections of the D8 highway are still waiting to be connected by a third, middle stretch (Road and Motorway Directorate of the Czech Rep., 2013).

The road projects in the Czech Republic are usually realised in the traditional Design - bid - build system which was also used for this missing part of the D8 highway.

Project impacts

Because of the fact that one part of the highway is still missing, the social impact of the project has currently been perceived as negative. Heavy traffic on the bypass route, through the cities around the unfinished part of the highway, caused a number of fatalities and serious injuries.

The unfinished part of the project goes through a national park called Czech Central Mountains which has a volcanic origin and it is a very unique nature reserve even in the international context. Even though the design of the highway was carefully chosen with special attention paid to all geological and environmental aspects, there are still a number of non-profit organizations protesting against the structure.

Project benefits

The public benefits from the project are significant since it is a part of the European highway network connecting a Swedish city Helsingborg and a Greek city Kalamata with the total length of 3305 km. This is the reason why the D8 highway is very important for haulage and passenger transport through Europe from the north to the south.

The project will bring faster transport between the Czech Republic and Germany and its important effect is also the cancellation of the bypass road using communications which were not designed for such heavy traffic.

There are two main problems with the D8 highway project. The first problem is the chosen strategy of the whole D8 project called "salami method". It means that the planning and building permissions were divided into smaller parts and while the non-problematic parts of the project were already built, the rest is still waiting to be finished. The biggest problem of the missing parts of the project is the environmental impact, despite the fact that the design was perfectly prepared with special attention to all possible damages caused by the structure. Even though all environmental studies say that this part of the project is in compliance with all laws and regulations, a number of legal actions are still coming from the environmental activists and associations. This can cause yet another delay of the project.

The second problem is in each part of the highway following the optimum construction procurement system. The Design - bid - build system provides years of experience on both sides of the contract but the truth is that this system is not so ideal for structures as complex as highways, since projects of such complexity are almost impossible to finish without changes.

5.2. Pepperhill to Cobham A2 Highway Widening project

Being a linking project between London, Dover and continental Europe, the A2 highway is extremely important and that is the reason why it's widening had a big priority and interest. The area in question is in an archaeologically extraordinary region and the adjacent areas Shorne and Ashenbank Woods are scientifically interesting for being a home of protected species such as badgers and great crested newts. The reconstructed section of the road is 7 km long and carries over 100 000 vehicles per day. During peak hours the old highway was congested and suffered by a number of accidents. Moreover, the old stretch of the highway was close to a town Gravesend. The prediction of congestion has an upward trend because of the Kent Thameside project progresses. The existing part of the A2 highway around Gravesend was relocated to the south. The whole new route was relocated nearby the Channel Tunnel Rail Link and the original stretch of the A2 highway near Gravesend was adapted to a green corridor (Skanska, 2008).

The procurement system used for this project was Highways Agency ECI initiative. The contractor was involved in the phase of planning, designing and management of the project.

Project impacts

The project has very important strategic and economic impact on regional infrastructure. It is a part of the Government plan of the local infrastructure development. During the construction a special emphasis was placed on reducing the impact of the structure on everyday life of people around the building site and to the users of the infrastructure. The project was planned and designed to prevent or at least to minimize the public discomfort. These requirements were met by using three-lane traffic flow in both ways during peak hours due to the importance of the A2 highway with over 80 million vehicle movements through the building site.

The project also employed up to 250 workers from the Kent area. 34 % of the materials for the project were used from a distance up to 30 km from the building site. The remaining 64 % were brought from a distance not exceeding 80 km.

Project benefits

The importance of the renovation of the highway may be seen in the reduction of congestion and possible traffic accidents and also the time of journey on this highway section. The computer modelling estimates that compared to the old highway, the new design will bring fewer accidents in the next 30 years. According to the computer modelling, the new highway can cause five fatalities, 28 serious injuries and 489 slight injuries in the next 30 years. In comparison to the previous conditions with 285 personal injuries and one fatal accident during the period of July 1998 – June 2003, the new estimate is a great success of road safety.

Another regional benefit provided by this road project is the accessibility of the Ebbsfleet International Railway Station and Thames Gateway which is the largest regeneration project in Europe.

Furthermore, a local benefit is also a slight decrease of air and noise pollution caused by the new highway structure. The A2 highway is located 200 m from the city of Gravesend and the low noise surface and earth embankment reduced the noise disturbance.

The general contractor organized several public meetings with people and developed the design with attention to the needs and wishes of the local authorities. The highway was opened to the public throughout the whole construction process and special attention was paid to the public opinions and comments. Newsletters were distributed among surrounding cities and the media informed the public about potential disruptive road works. In addition, the Highway Agency was also involved in informing about lane closures and other traffic disruptions on their website or even emailed updates to the drivers. The project team was working in an open and transparent manner to provide the best communication to all. Such approach results in all involved people having a feeling of value and fair treatment.

6. Conclusion

The research was designed to show, hopefully in an unbiased way, different construction procurement systems used especially for public projects. The construction procurement system for each project must be chosen very carefully as construction projects are very specific and they require an individual approach.

The traditional Design Bid Build system provides years of experience but it is not ideal for structures as complex like as highways. The DBB system is designed for the type of contract where the amount of changes is minimal and in case of any changes the system is not efficient. In order to avoid these problems a different system should be used for highways projects. An alternative system will involve the initiative of the general contractor in the design phase and it will bring better results to the project. The importance of the influence by the general contractor in the design phase lies in the prevention of changes and delays during the construction. This approach is completely different from the traditional DBB and the whole tender evaluation must be design for this approach from the very beginning.

The Pepperhill to Cobham A2 Highway project is a very good example of the ideal approach to public procurement. Early Contractor Involvement system provides the best combination of planning such a complex structure as highway projects are. The idea is based on the premise that the contractor is a participant on the design phase of the project. This can provide the best solution how to avoid any subsequent mistakes in the project design. The participation on the early phase of the project brought the contractor the best possible opportunity to avoid potential mistakes in the design. The practical experience of the contractor is brought to the design and construction stage of the project. The Early Contractor Involvement system is an ideal way to build complex and complicated projects such as highways, bridges as well as other projects.

In the Czech Republic, the construction procurement system selection, especially for public projects, is based mostly on the lowest price in combination with the time of realization. However appropriate this approach would appear to be, it is not ideal for complex and complicated projects. The future of the selection process of construction procurement system for public projects is in a new approach. The truth is that it requires the project to be prepared more precisely with all its aspects being thoroughly considered. Nevertheless, that is the future of successful projects and it is based on better project preparation and client – designer – contractor cooperation.

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Model for “Bath Tub” effect in construction

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Abstract

In this paper learning curve models with fatigue are investigated. Mathematical learning curve models can be used in construction to predict the time or cost required to perform a repetitive activity. The objective of this paper is to give a model for “bath tub” profile in construction which occurs at the end of repetitive works.
Our evaluation was based on a survey conducted in the spring of 2009 in Budapest and data obtained from literature. Several mathematical models and data presentation method, unit, cumulative average, moving average and exponential average were identified, and each was used for estimation of data.

Keywords: learning curve, construction time estimation, exponential average, bath tub effect

1. Introduction

In construction project management scheduling of the project is an essential problem. Estimation of activities time is a crucial part of the schedule. Learning curves impact job time and in recently used management softwares, which can handle resources, this effect would be handled easily (Hajdu [1], [2]). The objective of this paper is to give a learning curve model for “bath tub” profile in construction which occurs at the end of repetitive works. Learning curves imply that when numerous similar or nearly identical tasks are performed, the effort is reduced with each successive task (Oglesby et al. [3], Drewin [4], Teplitz [5], Everett and Farghal [6,7], Lutz et al. [8], Lam et al. [9], Couto and Teixeira [10]). Learning curve theory can be applied to predicting the cost and time, generally in units of time, to complete repetitive activities. The cumulative average time method was used in the original formulation of the learning curve method, referred to as Wright’s model, in Wright’s famous paper on the subject [11]. A number of researchers have suggested that Wright’s model is the best model available for describing the future performance of repetitive work (Everett and Farghal [6], Couto and Teixeira [9]). In (Malyusz and Pém [12]) the exponential average method with α =0.5 yielded the most accurate predictions. There is little information in the literature about uses of learning curves for construction activities, although it seems that the learning curve principle can be applied to repetitive construction operations (Hinze and Olbina [13]). In this study, we evaluated the data for a real reconstruction work of flat roofing insulation and data were obtained from literature, (Hinze and Olbina [13]). In their study learning curves were examined whether it could be used to accurately predict the production efforts of future units by applying the principles to the prefabricated and driving of prestressed concrete piles. Moreover we investigated data presentation models based on (Mályusz and Pém [14])..

from the body of the table, and immediately above and below the table. Tables must be embedded into the text and not supplied separately. Below is an example which the authors may find useful.

2. Theoretical and practical background

2.1. Mathematical models

Learning curve theory is applicable to the prediction of the cost or time of future work, assuming repetitive work cycles with the same or similar working conditions in terms of technology, weather, and workers, without delay between two consecutive activities. The direct labor required to produce the $(x + 1)^{st}$ unit is assumed to always be less than the direct labor required for the x^{th} unit. The reduction in time is a monotonically decreasing function, an exponential curve, as described in Wright’s [11] paper.

In this study, we calculate the labor hours/square meter for each repeated activity.

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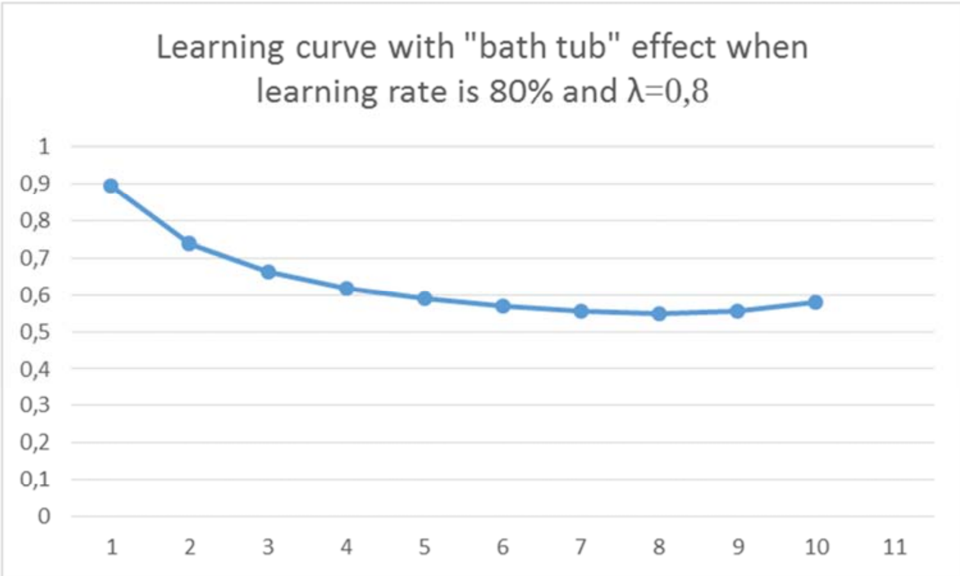
Wright's linear log x, log y model is as follows:

$$\ln y = \ln a + b \ln x; \; y = ax^b = ax^{\log_2 r} \tag{1}$$

where $\boldsymbol{x}$ is the cycle number, $\boldsymbol{y}$ is the time required to complete cycle x in labor hours/square meter, **a** is the time required to complete the first cycle, $\boldsymbol{b}$ is a learning coefficient, and r is the rate of learning. For example if r=0.9 (90%), then b=-0.151. Wright discovered that when the labor cost decreases at a constant rate, that is, the learning rate, the production/cycles doubles. So learning rate is the constant rate with which labor time/cost decreases when the production/cycles doubles in a linear log x, log y model. This feature of the learning rate comes from the logarithms nature and true only in linear log x, log y model. We do not define the rate of learning in the other models. In this paper "bath tub" effect Wideman [15] model is estimated by the following formulae.

$$y = \lambda a x^b + (1 - \lambda) a (k + 1 - x)^b$$

where k is the number of cycles and λ is a real number between 0 and 1. If λ =1 we give back the original learning curve.



2.2. 2.2. Data presentation methods

The unit is the data item that represents the time required to perform one cycle of the insulation work.

Wright (1936) discovered that the cumulative average **(CA)** time decreased by a fixed percent when the output doubles. CA represents the average time or cost of different quantities (x) of units.

$$CA_t = \frac{(Y_1 + Y_2 + \ldots Y_{t\ 1} + \ldots + Y_t)}{t}. \tag{2}$$

where t is the number of cycles, CA_t is the cumulative average in cycle t, and Y_t is the unit time or cost for cycle t.

The moving average **(MA)** in this paper is the average time of the last 3 cycles. Although the MA is an average like the CA, the MA represents the most recent data. More points will help smooth the curve.

$$MA_t = \frac{(Y_t + Y_{t-1} + Y_{t-2})}{3}. \tag{3}$$

The weighted moving average (**WMA**) is a generalization of MA.

$$WMA_t = \frac{(tY_t + (t-1)Y_{t-1} + (t-2)Y_{t-2} + \ldots + Y_1)}{(t + (t-1) + (t-2) + \ldots + 2 + 1)}$$

A weighted moving average has multiplying factors to give different weights to data at different positions. The exponential average **(EA)** is a weighted average of the most recent data and the previous average.

$$EA_t = \alpha Y_t + (1-\alpha)EA_{t-1} \ .$$

$$EA_{t-1} = \alpha Y_{t-1} + (1-\alpha)EA_{t-2} \ .$$

$$EA_{t-2} = \alpha Y_{t-2} + (1-\alpha)EA_{t-3} \ .$$

That is,

$$EA_t = \alpha Y_t + \alpha(1-\alpha)Y_{t-1} + \alpha(1-\alpha)^2 Y_{t-2} + (1-\alpha)^3 EA_{t-3} \tag{4}$$

where $\mathbf{EA_t}$ is the exponential average time for cycle t, EA_{t-1} is the exponential average time for cycle t-1, $\boldsymbol{Y_t}$ is the unit data (time to perform an activity) in cycle t, and $\boldsymbol{\alpha}$ is a coefficient. If $\boldsymbol{\alpha}$ is greater than 0.5, then the effect of new data is greater than that of older data. In this study, value of $\boldsymbol{\alpha}$, 0.5, was examined, based on Farghal and Everett [7].

Our assumption is that an exponential relationship exists between Y_t and x, i.e., between the time required to complete the activity for a given cycle and the cycle number. In other words, our assumption is that equation (1) holds. The relationship between log y and log x described by equation (1) can be plotted as a straight line on log-log paper, and all the regression formula apply to this equation just as they do to the equation. Mathematically, when x and y are given it is solvable for parameters a and b using the least squares method.

2.3. Description of the project

The data for this study were collected by writers in a real roof insulation work. The surveyed project was a reconstruction of flat roofing. During the reconstruction process, the circumstances and the weather were ideal for roofing (sunny, 26–33°C, no wind). The same workers performed the entire project. The technology was repetitive within one part. The workers knew that they were being monitored, but they were not informed as to what was being measured, and they were not disturbed. In the part of the reconstruction process that was studied, the work under consideration consisted of the following activities: slicing up the old waterproofing, laying down 10-cm-thick heating insulation and attaching it to the roof using screws, spreading one layer of rubber waterproofing, and melting it to the cape of the screws. The joining, the fixing of the edges, and the changing of the roof windows were not surveyed. The timer was stopped whenever the workers took a break or performed any activity that was not being studied. Time to complete one cycle was measured only. The timer was stopped when workers took a break. The roof of the hall building was divided into 7 sections. The areas of the sections were not all the same, so during the evaluation, we calculated the labor hours/square meter.

Data obtained from literature (Hinze and Olbina [13]) were part of a project in which 148 concrete piles were cast at work site and driven by a diesel pile hammer. All piles had the same dimensions of 600 mm by 600 mm by 35 m. All piles were cast and installed on site so as to provide support for a harbor structure. The individual time of casting was recorded for each pile.

3. 3. Learning analysis of Hall building

3.1. . Input data

In Table 1, the input raw data for the hall building are in the "Unit" column. The units of the numbers in the Unit, CA, MA, WMA, and EA(0.5) columns are labor hours/square meter.

Table 1. Raw input data of hall building (in labor hours/square meter)

Cycle	Unit	CA	MA	WMA	EA(0.5)
1	2.132	2.132	2.132	2.132	2.132
2	1.789	1.961	1.961	1.903	1.961
3	1.588	1.836	1.836	1.746	1.775
4	1.54	1.762	1.639	1.663	1.658
5	1.575	1.725	1.568	1.634	1.617
6	1.546	1.608	1.554	1.609	1.582
7	1.541	1.558	1.554	1.592	1.562

In Table 2 the input raw data for piles construction are in the "Unit" column. Data is in labor hours/square meter.

Table 2. Raw input data of concrete piles (in labor hours/piles)

cycles	Unit	CA	MA	WMA	EA(0.5)
1	73.80	73.80	73.80	73.80	73.80
2	55.40	64.60	64.60	68.28	64.60
3	52.00	60.40	60.40	63.40	58.30
4	60.00	60.30	55.80	62.38	59.15
5	55.30	59.30	55.77	60.25	57.23
6	61.10	56.76	58.80	60.51	59.16
7	52.60	56.20	56.33	58.14	55.88
8	64.20	58.64	59.30	59.96	60.04
9	54.80	57.60	57.20	58.41	57.42

3.2. Results

Result for piles and for roof reconstruction work are in next 4 tables. In tables numbers show the accuracies – difference between real data and estimation – for different data presentation method. In Table 4 sum differences of EA (2.45) is less than in Table 3. Sum of the total differences (676.96) in Table 6 is less than in Table 5 (726.9) that is this new model gives more precise data then the original one.

Table 3. Results for hall building (in labor hours/square meter). Original result for hall building (when λ =1)

cycles	**UNIT**	**CA**	**MA**	**WMA**	**EA; 0,5**	Best fit
3	0.09	0.11	0.59	0.05	0.54	WMA
4	0.08	0.07	0.49	0.05	0.48	WMA
5	0.25	0.12	0.58	0.15	0.52	CA
6	0.36	0.18	0.61	0.25	0.55	CA
7	0.43	0.3	0.76	0.39	0.58	CA
Sum	1.19	0.77	3.03	0.9	2.66	8.54

Table 4. Results for hall building (in labor hours/square meter)

cycles	**UNIT**	**CA**	**MA**	**WMA**	**EA; 0,5**	Best fit
3	0.09	0.11	0.59	0.05	0.54	WMA
4	0.26	0.35	0.45	0.29	0.36	WMA
5	0.25	0.15	0.54	0.17	0.48	CA
6	0.35	0.17	0.56	0.26	0.52	CA
7	0.41	0.23	0.7	0.35	0.56	CA
Sum	1.35	0.99	2.84	1.13	2.45	8.76

Table 5. Results for piles (in labor hours/piles). Original result for piles (when λ =1)

cycles	**UNIT**	**CA**	**MA**	**WMA**	**EA; 0,5**	Best fit
3	4.99	1.2	10.12	2.01	2.58	CA
4	21.02	11.86	13.34	14.35	21.04	CA
5	24.08	17.62	17.15	20.49	22.37	MA
6	30.43	25.79	35.83	27.67	29.57	CA
7	31.4	33.81	43.36	33.88	32.43	UNIT
8	43.21	46.52	55.51	45.91	43.37	UNIT
Sum	155.12	136.8	175.32	144.3	151.36	762.9

Table 6. Results for piles (in labor hours/piles) Result for piles when λ =0.8.

cycles	**UNIT**	**CA**	**MA**	**WMA**	**EA; 0,5**	Best fit
3	4.99	1.2	10.12	2.01	2.58	CA
4	22.02	17.53	19.7	16.61	17.38	WMA
5	24.9	19.62	21.85	20.5	18.97	EA
6	30.48	20.29	32.86	23.24	26.03	CA
7	32.51	18.46	34.36	23.68	30.27	CA
8	42.79	25.3	46.38	31.43	38.92	CA
Sum	157.68	102.39	165.27	117.47	134.15	676.96

4. Conclusions

In this paper different data presentation methods of learning curve have been investigated to assess which one is the best – the most accurate - to predict the time required for repetitive works to perform cycles in a roof insulation repetitive work. This study was based on data of an insulation work performed in 2009 in Budapest and data obtained from literature. Results of this study show that in some this new model can give us a more accurate estimation of the real data. In our model the λ =0.8 and for some data presentation method λ =0.95 gives the better estimation than original learning curve. Further investigation is needed to find a principal how to get the best λ.

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Measurement of selected risks in the construction elements manufacturing plant using statistical method

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Abstract

Construction elements manufacturing plants functioning on the global market face different types of risks. It is necessary to consider and manage all of the risk occurrences in order to maintain a leading position in construction market, regardless of its influence on the manufacturing plant. Achieving this is possible, among other things, through the development of appropriate models including operating procedures, which are combined with each other chronologically. For example, the following procedures can be distinguished: defining assumptions of production and prices of products, identification and classification of risk, risk analysis, reduction of risk, as well as measurement and control of risk. This paper presents procedure based on the measurement of selected risk occurrences related to manufacturing plant and within a usage of a statistical method. For this purpose, a specific manufacturing plant was used and survey-based research was carried out. The selected measurement method uses a probabilistic approach, including random variables and probability distributions, by which the risks occurring in the manufacturing plant can be described. The potential costs were assigned to each risk occurrence using the Delphi method and by consulting the experts in the field of prefabricated construction elements. In addition, 2 or 3 scenarios concerning minimum and maximum or minimum, average and maximum values of potential cost associated with each risk occurrence, have been developed. As a result, it was possible to estimate the total value of risk occurrences in the manufacturing plant and present it in the form of a probability density function. For this purpose, the Central Limit Theorem was used. The summary of the paper contains the further information related to determination of correlation coefficient between risk occurrences.

Keywords: management in construction, naufacturing plant, probability theory, risk management, statistical method.

1. Introduction

The risk management procedure, which is presented in this paper, is a part of one module in the risk management model for construction manufacturing plants that consists of six modules. Using statistical method, all the risk occurrences are presented by probability distribution functions and the total cost of risk is calculated analytically. At this stage of calculation, the basic laws of probability theory and mathematical statistics, including Central Limit Theorem, are used. The Central Limit Theorem states that "the arithmetic mean of a sufficiently large number of iterates of independent random variables, each with a well-defined expected value and well-defined variance, will be approximately normally distributed". Therefore, it can be assumed that the sum of subsequent risk occurrences described by different types of probability distributions will be very similar to a normal distribution. In order to assess the results clearly, it is necessary to determine the distribution of the two main parameters, namely:

- The expected value of total risk occurrences described by the probability distribution functions $R_{E;man.plant}$
- The standard deviation of total risk occurrences described by the probability distribution functions $\sigma_{R;man.plant}$

A proper measurement of risk in the construction elements manufacturing plans needs to include an estimation of correlation efficiencies between occurrences.

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2. Procedure for measuring the risk using statistical method

A diagram presented in Figure 1 contains 4 modules that describe the risk measuring procedure in the manufacturing plant for construction elements.

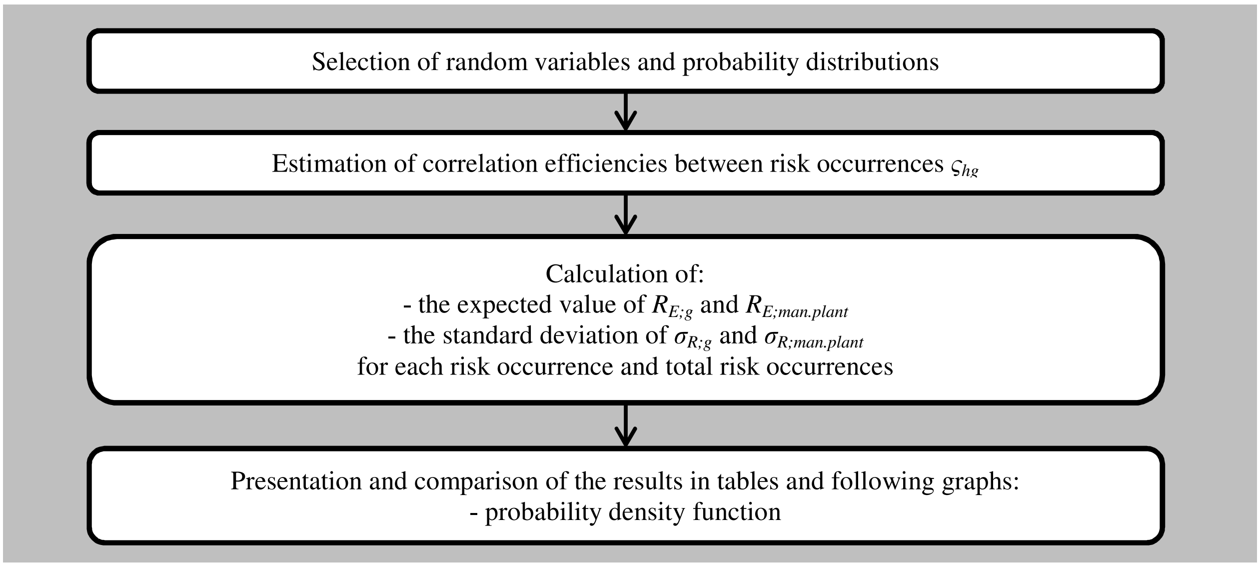

Figure 1. A diagram for risk measurement using statistical method.

The random variables and the probability distribution are selected on the basis of expert knowledge and opinion. Moreover no dependencies were found between risk occurrences, which means that the correlation efficient is equal to 0 and all the risk occurrences are stochastically independent.

2.1. Calculation of the expected value of $R_{E;g}$ and $R_{E;man.plant}$ for risk occurrences in the manufacturing plant

When calculating the cost for a given risk occurrence, the average cost corresponds to the expected value of risk $R_{E;g}$. If the subsequent occurrences are marked as g and their probability as $P_{U1;g}$, the expected value of costs for a given occurrence can be calculated as follows:

$$R_{E;g} = P_{U1;g} \times L_{E;g} \quad (1)$$

where:
$R_{E;g}$ – the expected value of risk occurrence g
$P_{U1;g}$ – probability of risk occurrence g
$L_{E;g}$ – the expected value of cost for a given occurrence g

Depending on the type of random variable, two different formulas for the calculation of the expected value of cost for a given occurence g can be used. For the probability mass function of a discrete random variable the calculation is carried out according to the following formula:

$$L_{E;g} = \sum_{i=1}^{c} (L_{i;g} \times p_{i;g}) \quad (2)$$

where:
c – the total number of different costs
$L_{i;g}$ – discrete random cost variable i for the occurrence g
$p_{i;g}$ – probability of cost i occurence

The calculation of the expected value of cost for a given occurrence g in case of the restricted probability distribution of a continuous variable is as follows:

$$L_{E;\,g} = \int_{L_{\min}}^{L_{\max}} L_g \times p_l(L_g)dL_g \text{ dla } L_{\min} \le L_g \le L_{\max} \tag{3}$$

where:
L_g – continuous random cost variable for the occurrence g
$p_l(L_g)$ – probability density cost function of the occurrence g

After calculating the expected value of risk occurrence g, it is possible to determine the expected value of total risk occurrences in the manufacturing plant using the following formula:

$$R_{E;\,man.plant} = \sum_{g=1}^{n} R_{E;\,g} = \sum_{k=1}^{n} (P_{U1;\,g} \times L_{E;\,g}) \tag{4}$$

where:
n – number of given occurrences
$R_{E;man.plant}$ – the expected value of total risk occurrences

The above formula can be used both under the assumption of stochastic independence and random dependence of risk occurrences.

2.2. Calculation of the standard deviation of $\sigma_{R;g}$ and $\sigma_{R;man.plant}$ for stochastically independent risk occurrences in the manufacturing plant

The calculation of the standard deviation of risk occurrences in the manufacturing plant must be proceeded by the determination of the cost standard deviation $\sigma_{L;g}$ and the risk standard deviation $\sigma_{R;g}$ for each occurrence g. For a discrete random variable $L_{i;g}$, the value of a probability mass function cost variance $\sigma^2_{L;g}$ of the occurrence g is determined by the following formula:

$$\sigma^2_{L;g} = \sum_{i=1}^{c} \left[(L_{i;g} - L_{E;g})^2 \times p_{i;g} \right] \tag{5}$$

where:
$\sigma^2_{L;g}$ – cost variance of the occurrence g

For a continuous random variable with defined limits L_{min} and L_{max}, the cost variance of the occurrence g can be calculated according to the following formula:

$$\sigma^2_{L;g} = \int_{L_{\min}}^{L_{\max}} (L_g - L_{E;g})^2 \times p_l(L_g)dL_g \tag{6}$$

where:
L_{min} – the minimum value of the cost of the occurrence g
L_{max} – the maximum value of the cost of the occurrence g

The cost standard deviation is then determined using the following formula:

$$\sigma_{L;g} = \sqrt{\sigma^2_{L;g}} \tag{7}$$

where:
$\sigma_{L;g}$ – cost standard deviation

Subsequently, using the cost variance of the occurrence g, it is possible to determine the risk standard deviation $\sigma_{R;g}$, according to the following formula:

$$\sigma_{R;g}$$

where:
$\sigma_{R;g}$ – risk standard deviation
$\sigma^2_{R;g}$ – risk variance of the occurrence g

The final step is to calculate the standard deviation of total risk occurrences in the manufacturing plant by the following formula:

$$\sigma_{R;man.plant} = \sqrt{\sigma^2_{R;man.plant}} = \sqrt{\sum_{g=1}^{n} (\sigma^2_{R;g})} \tag{9}$$

where:
$\sigma_{R;man.plant}$ – the standard deviation of total risk occurrences

2.3. Determination of the probability density function of risk occurrences in the manufacturing plant

In order to illustrate the determined parameters of the manufacturing plant on the graph of the probability distribution, it needs to be assumed that the total risk in the manufacturing plant is the sum of subsequent occurrences and is a random variable.

$$p_r(R_{man.plant}) = \sum_{g}^{n} p_r(R_g) \tag{10}$$

where:
$p_r(R_{man.plant})$ – probability density function of total risk occurrences
$p_r(R_g)$ – probability density function of a given risk occurrence

Probability density function of total risk occurrences is expressed by the following formula:

$$p_r(R_{man.plant}) = \frac{1}{\sigma_{R;man.plant}\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{R_{man.plant} - R_{E;man.plant}}{\sigma_{R;man.plant}}\right)^2} \tag{11}$$

where:
$R_{man.plant}$ – random variable of normal distribution of total risk occurrences in the manufacturing plant

3. Measurement of selected risk occurrences in manufacturing plant

The analysis in the manufacturing plant for construction elements includes the following risk occurrences with assigned symbols:
A1 – the risk in the management process that refers to inadequate supervision of employees, improper enforcement of disposals that are issued by the management, unclear division of competences between employees, sluggishness in solving current problems, unclear circulation of documents.
B1 – the risk of employment consisting of different diligence and integrity of a crew working directly on the production line.
C1 - Risks in technological and organizational preparation of production by improper material testing, bad choice of technical means and the incorrect finding recipes.

Table 1 contains the list of the selected risk occurrences with assigned probability distributions, the expected value of cost for a given occurrences and standard deviations.

Table 1. List of selected risk occurrences with assigned cost, probability density function, expected value of cost and standard deviation of cost.

Risk symbol	Occurrence probability	Probability density function type	Minimum cost	Average cost	Maximum cost	Expected value of cost	Standard deviation of cost
A1	45	BetaPERT	49000,00	60333,33	72000,00	60388,89	4346,39
B1	65	BetaPERT	68333,33	81666,67	95000,00	81666,67	5039,53
C1	30	triangular	50000,00	54000,00	58666,67	54222,22	1770,82
		TOTAL:	**167333,33**	**196000,00**	**225666,67**	**196277,78**	**6886,49**

The expeced value and standard deviation of each risk occurrence and total risk occurrences are presented in the Table 2.

Table 2. List of parameters and risk assessment using a statistical method.

Risk symbol	Occurrence probability	Probability density function type	Cost variance	Standard deviation of cost	Expected value of risk occurrence	Risk variance of the occurrence	Risk standard deviation
A1	45	BetaPERT	18891093,40	4346,39	27175,00	911088356,16	30184,24
B1	65	BetaPERT	25396831,71	5039,53	53083,33	1533806613,66	39163,84
C1	30	triangular	3135804,94	1770,82	16266,67	618351137,16	24866,67
		TOTAL:	**47423730,05**	**6886,49**	**96525,00**	**3063246106,98**	**55346,60**

The data in the tables referes to the manufacturing plant of prestressed concrete power poles, employing about 100 people with revenue amounting to about 33 millions PLN. On the basis of the calculations, an example of the probability density function of total risk occurrences is expressed in Figure 2:

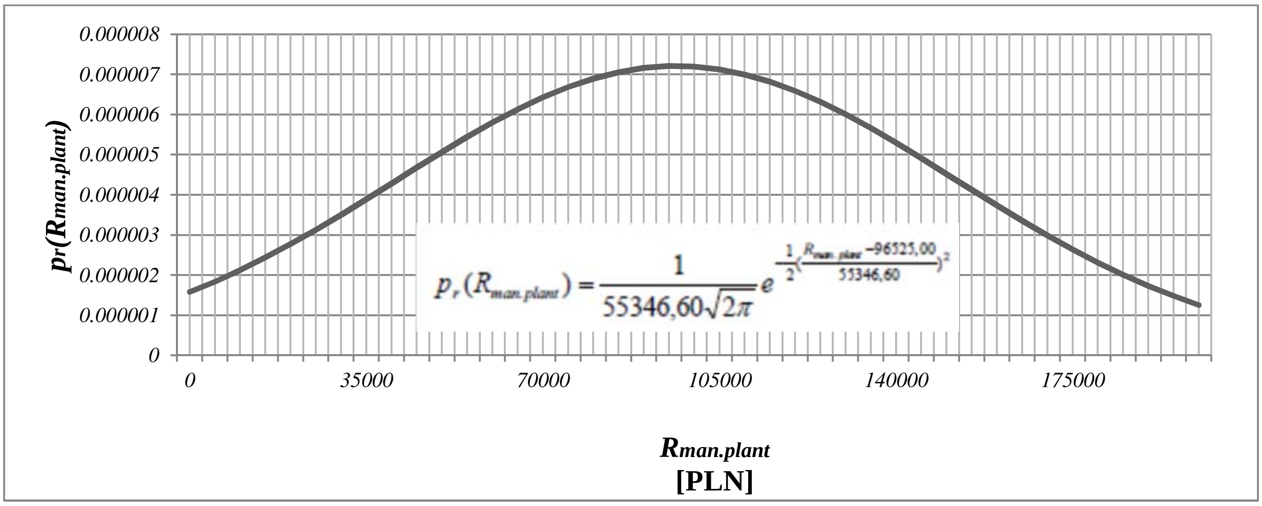

Figure 2. An example of the probability density function of total risk occurrences in the manufacturing plant of prestressed concrete power poles.

It should be emphaized that the above presented probability density function is a result of calculation of some selected risk occurrences in the manufacturing plant of prestressed concrete poles. The expected value of all selected risk occurrences is equal to 96525,00 PLN and the risk standard deviation amounts to 55346,60 PLN. Identification of all risks would include more than 3 risk occurrences for such a manufacturing plant.

4. Summary

The paper presents the measurement of selected risk occurrences in the manufacturing plant for construction elements, using a statistical method. For the purposes of testing, the manufacturing plant of prestressed concrete poles were used. All the necessary formulas related to the determination of the expected value of cost and risk occurrences, as well as the standard deviation of cost and risk occurrences, are described in detail. The results obtained in the calculations are illustrated in the graph of Figure 2 that is approximately normally distributed. Further studies are needed to determine correlation coefficient between risk occurrences. In order to advance this field, more detailed scientific research needs to be undertaken. Progress in this field is possible, but only through a close cooperation with construction industry, especially precast manufacturing plants of different size, production profiles and location.

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Needs, values and post-occupancy evaluation of housing project customers: A pragmatic view

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Abstract

New management concepts focus their efforts on meeting the needs of those involved, especially the customer. Likewise, one of the Lean Construction philosophy objectives bases its management model on the maximization of value for the client. Much research has been conducted on theoretical concepts of needs and value, and the purpose of this paper is to make a pragmatic proposal on how to apply these concepts to housing projects.
This paper presents a compilation of customer needs that housing must meet, taking into consideration that these needs are virtually universal and what changes is the customers' wishes and their level of importance. These needs—obtained through market research conducted on customers themselves—as well as the habitability conditions recommended by housing policies, codes, and regulations, must become the customer quality standards guiding the process. At the end of said process, once the product has been delivered and in the post-occupancy stage, this same document must serve as a tool to assess customer satisfaction and corresponding perceived value.
For the development of this proposal and in order to gather the requirements that every dwelling must meet to satisfy both its residents and society, we have reviewed various rules and regulations of several Latin American countries; we have conducted extensive interviews with customers from different social backgrounds; we have reviewed the literature on this matter; and we have analyzed 10 housing project claims with various construction systems and socioeconomic strata.
Finally, the results of these post-occupancy evaluations will serve as a powerful feedback tool, thus promoting continuous improvement in housing projects.

Keywords: Lean Construction, Value Generation, Customer Value, Post-Occupancy Evaluation, Architecture

1. Introduction

The various theoretical fundamentals of customer-focused management systems are very convincing and completely logical. This key concept is applicable to the provision or delivery of any type of service or product and to any industry or sector. In the construction sector, like in other sectors, theories and concepts also abound, but not as many as their corresponding applications. The reason for this may be that, when we refer to construction, we are also referring to a wide range of services and products. To propose a pragmatic application, this paper refers to the needs, desires, quality requirements, customer satisfaction and perceived value of a specific product: housing.

2. Customer-Focused Approach

Traditionally, success in the construction sector has been measured by cost, time and quality, or cost, time and scope. According to this, many times a project is considered successful if the work is delivered within the deadline, the budget and according to technical specifications. Thus, the work often takes the lead role and the client is a passive recipient of the building at the end of the construction value chain, Kärnä (2009). However, customer-focused management systems are changing this mindset.

In addition to proposing this triple constraint (also called the iron triangle), Atkinson (1999) presents three additional success criteria: the information system, the benefit for the organization and the benefit for the community involved. In this last criterion, customer satisfaction plays a major role.

ISO 9000 reads: "Organizations depend on their customers and therefore should understand current and future customer needs, should meet customer requirements and strive to exceed customer expectations". Figure 1 illustrates the Quality Management System described in the ISO 9000 family of standards. This illustration

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shows that customers play a significant role in providing input to the organization. Once the product has been manufactured, all information on customers' perception of how and to what extent their needs and expectations were met is necessary for monitoring customer satisfaction.

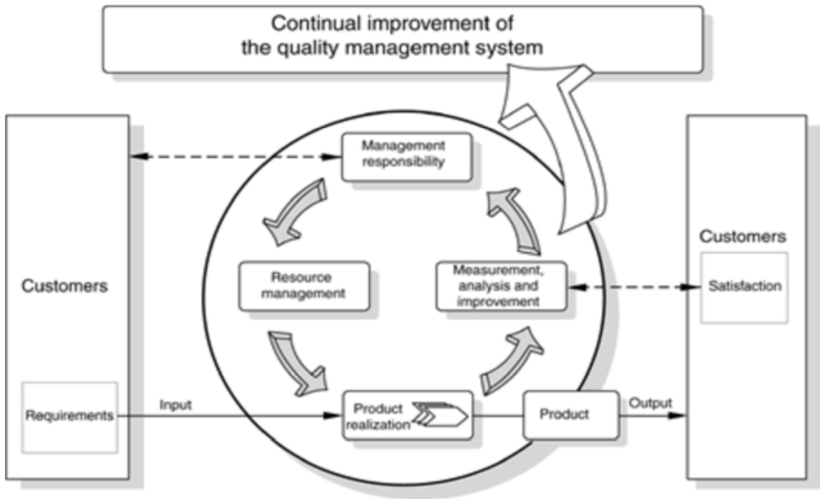

Figure 1. Model of a Quality Management System based on processes (ISO 9000)

The Lean Construction Institute declares loss reduction and value creation for the customer as its main management philosophy. The Institute's various methods, techniques and tools are grouped into the Lean Project Delivery System™, shown schematically in Figure 2. The system proposes a sequence of processes which acknowledges the fact that a construction project should start with the identification of customer needs and values.

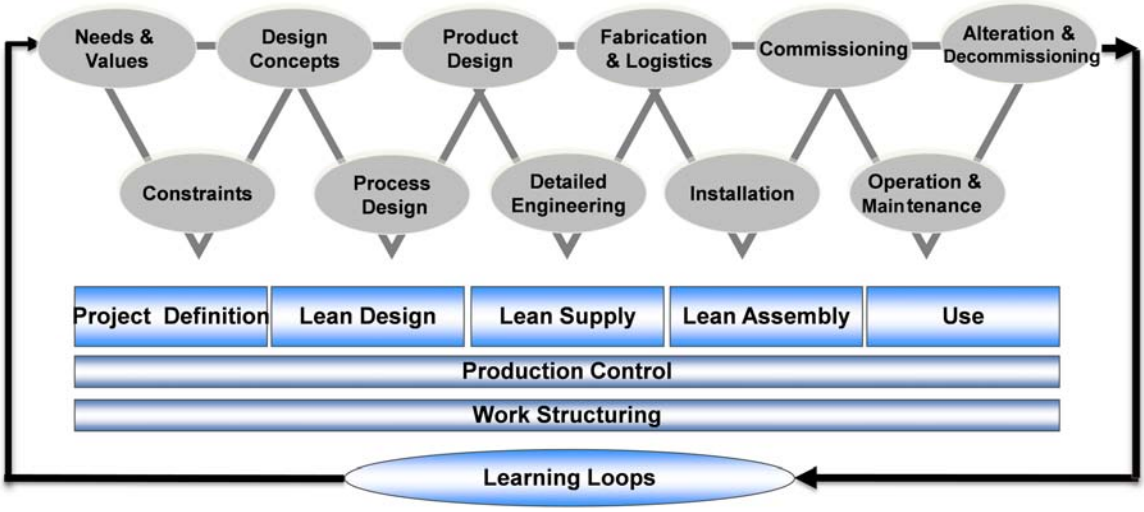

Figure 2. Lean Project Delivery System (Ballard, 2000, 2006 and 2008)

One can also see that the project does not end with delivery and use, but requires a post-occupancy evaluation which—after obtaining information about meeting the needs and desires of the customers and their perception of value—is used as feedback for new projects. Thus, it creates a cycle of continuous improvement aimed at eliminating loss and creating value. Losses and rework are very common because the needs and values of either investors or customers are not completely clear (Orihuela, Orihuela, Ulloa, 2011.)

3. Customer Needs

Kotler, P., Armstrong, G., Saunders, J., and Wong, V. (1996) define Human Needs as a state of deprivation felt by a person. They state that human needs are plentiful and complicated, and are not created by external agents but are an essential part of human nature.

Similarly, human desires are defined as a manifestation of those needs, according to culture and individual personality. As a society evolves, the desires of its members expand, so producers undertake specific actions for the public to feel the desire to acquire their products. They try to establish a connection between what they produce and what people need, and promote their product as a satisfier of one or more needs.

ISO 9000, states "Customers require products with characteristics that satisfy their needs and expectations. These needs and expectations are expressed in product specifications and collectively referred to as customer requirements. Customer requirements may be specified contractually by the customer or may be determined by the organization itself. In either case, the customer ultimately determines the acceptability of the product."

During interviews conducted to understand the customer need for housing, we took into account that there are several types. Kotler (2000) presents the following classification: the needs which are expressed directly by the customer, those which are not specified but are expected, those which are unexpected, and those which are undisclosed.

4. Housing Quality Standards

Many housing rules and regulations specify some quality requirements every home should have. However, not all of these requirements are noticed by customers. On the other hand, there are other customer requirements and expectations that are not specified in these documents.

To select the most important housing quality standards, four sources of information were used: 1.) Collection and review of habitable conditions specified in the housing policies, rules, and regulations of various Latin American countries (Peru, Chile, Brazil, Colombia, Ecuador and Mexico), 2) Research papers published in various journals on attributes that generate satisfaction among residents; 3.) Analysis of 4000 claims generated in 10 housing projects with different construction systems and different socioeconomic levels (Vidal, 2014) and 4.) Residents' interviews on their housing needs, desires and perceptions of value.

Table 1 presents these quality standards grouped into three criteria (Perez and Gonzáles, 2011): 1) Criteria regarding the city, 2) Criteria regarding the neighborhood and 3) Criteria regarding the building itself. Each one is broken down into a second and third level, the latter being questions about the level of compliance with the expected requirements, which the customer and/or organization itself must rate. We have selected a total of 80 questions, 50 to be answered by the customer and 30 to be answered by the organization due to their technical nature. The organization could also rate the customer-directed questions so as to identify and quantify compliance gaps.

5. Post-occupancy customer satisfaction

Kotler (2000) defines Customer Satisfaction as the feeling of pleasure or disappointment resulting from comparing the perceived performance of a product with the customers' expectations. Kano (1984) proposes five types of attributes that a product or service may possess and which generate various feelings of satisfaction or dissatisfaction in customers: 1) Must-be quality element: attributes whose compliance do not generate additional satisfaction but when not provided, generate high levels of dissatisfaction. 2) One-dimensional quality element: attributes whose presence generate satisfaction directly proportional to their implementation. 3) Attractive quality element: attributes which are not expected, but when implemented generate high levels of satisfaction. 4) Indifferent quality element: attributes which if not implemented, will not generate satisfaction or dissatisfaction. 5) Reverse quality element: attributes whose presence are unwanted.

Atkinson (1999) shows us that during the process initiated by the company to meet customer needs, gaps that undermine this objective are generated. Gaps are created in: 1) the real customer needs; 2) the needs described by the customer; 3) the needs as perceived by the project team; 4) the plan developed by the team to meet these needs; 5) the final product delivered to the customer; and 6) customer perception of whether the product meets his/her needs or not.

A multidisciplinary group of professionals with different systems, methodologies, techniques, and tools is involved in this chain of processes; however, at the end of such a chain, the customer is the one who rates the product. Dr. Edwards Deming mentioned in one of his lectures: "... the customer is the judge of quality; he is the only judge who should matter when providing a service or product, the customer will decide on quality."

To measure a customer's satisfaction using Table 1, it is necessary to determine the importance placed on quality standards at the second level. This weighted calculation is independent for each of the three sets of criteria and can be done by the method of scoring and using the Likert psychometric scale (1 to 5). For better validation methods, matrix pairs or hierarchical analysis could also be used. Then the 50 questions of the third level must be answered, asking customers to express their perception of satisfaction or dissatisfaction through a rating scale. In practice, we have found that a good alternative is to use the school grading system, as this is very familiar to our customers; therefore, scores will be clearly expressed.

Table 1. Housing quality requirements and perception for customer satisfaction

HOUSING QUALITY REQUIREMENTS		IMPORTANCE (Weigh)	SATISFACTION (Score)			
First level	Second level	Second level	No. Question (Third level) Total	Organization	User	First level
REGARDING THE CITY	Location in relation to workplace		2		2	
	Location in relation to other activities		2		2	
REGARDING THE NEIGHBORHOOD	Security from natural events		3	3		
	Urban conditions		8		8	
REGARDING THE BUILDING ITSELF	Structural safety		6	6		
	Fire safety		7	5	2	
	Salubrity		6	2	4	
	Functionality		10	3	7	
	Aesthetics		3		3	
	Safety in use		5	2	3	
	Property security		2		2	
	Legal security		3	3		
	Thermal, acoustic, luminance and ergonomic comfort		5	1	4	
	Durability		3	1	2	
	Impermeability		3		3	
	Evironmental impact		8	4	4	
	Accompaniment post-sale		4		4	
			80	30	50	
PERCEPTION OF VALUE CONSIDERING THE LEVEL OF SATISFACTION (Score)						
ADDED VALUE? YES.... NO ..... DESCRIPTION:..						

The average of the third level gives the rating of the second level and the weighted average of these gives the rating for each of the three first-level groups. The rating of the first two groups evaluates the attributes of building location and the third group evaluates design and construction.

According to the Guide to Post-Occupancy Evaluation of the HEFCE (2006), these assessments should be made in the post-occupancy stage, which occurs after a period of approximately one year following handover. It is deemed that the customer may not have sufficient experience to make a proper judgment at any time before this.

6. Customer value

The Institute of Value Management defines Value using formula 1 below:

$$\text{Value} = \frac{\text{Function}}{\text{Cost}} \quad (1)$$

This formula shows that value results from comparing the achievement of purposes or delivery of the expected benefits of the product with their cost. When this comparison is purely economic, it is known as Cost-Benefit Analysis, where the numerator and denominator are expressed in monetary units resulting in a tangible indicator and numeric value.

6.1. Customer perceived value

The perceived value involves the customer assessment of the ability of the products to meet his/her needs. He/she therefore considers the value of the product and its price before making the decision to choose the product that represents the maximum value for the money (Kotler, 2000).

When it comes to the customer perception of value, the numerator in formula 1 represents the degree of customer satisfaction which—as stated above—is a subjective rating. The denominator, in addition to the monetary amount paid, also represents other sacrifice factors involved in buying the product or service. This is especially true when it comes to a house, which is usually one of the most important acquisitions of an individual or family. Therefore, when it comes to assessing the value that the customer places on a house, ratio 2 is more appropriate:

$$\text{Customer perceived value} = \frac{\text{Perceived satisfaction}}{\text{Perceived price paid}} \qquad (2)$$

Once the customer has answered the questions in Table 1, the results are presented to the customer, and then he/she is asked to carry out a second rating on the perceived value, considering the price and the sacrifice made to pay for the house.

6.2. Added Value

Lean Six Sigma defines Added Value as: "activities or essential works that ensure a product or service meets customer needs." A more precise definition would be: "An additional attribute that the customer did not expect, and when perceived, it contributes to increased value." This definition is in line with what Kano (1984) classified as an Attractive quality element.

Posing a simple question to the customer, who has received an attribute or benefit that was not expected, and asking him/her to describe and comment on it will provide a good indicator of whether or not added value has been generated for the customer.

7. Conclusions

To generate value for customers, we need to understand and identify their needs and desires. These should be provided in a document that also indicates their level of importance. This document, supplemented with the relevant technical specifications, will help establish quality requirements that guide the customer-focused management. Once the project is finished and the product is delivered, this document will serve to evaluate customer satisfaction during the post-occupancy period. After rating overall satisfaction, customers will be able to form a second opinion on perceived value and added value.

In brief, this paper proposes the model of a document with the above-mentioned characteristics which serves for housing projects, and can be improved and modified insofar as it is used.

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Export financing in international construction: Case study of Siemens power division in Oman

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Abstract

Many construction and technological firms grew beyond borders of their countries since their market size couldn't absorb their growing production capacities. Similarly, orientation to certain market segments forced these firms to go abroad in order to sustain their revenues, further improve their specialization and expand shareholder value. Due to increasing competition in the world market, traditional prerequisites do not necessarily have to lead to success in international bids. In addition to technological excellence, long-lasting experience, quality and cost leadership, securing project financing can play a crucial role in project bids. International Joint Venture (IJV), led by Siemens, gained an order with an international bid for delivery of two power plants with combined cycle to Oman, due to securing project financing for multinational investor. Project financing, arranged by German state-owned KfW IPEX-Bank, proved to be the turning point in this international tender. Siemens and its Korean partner successfully delivered both power plants in full conformance to investor's requirements. This case study demonstrates increasing and necessary role of government export-oriented agencies and banks for reaching exporters' success in international business.

Keywords: Buyer's credit; Competitive advantage; Construction; Export credit agency; Project financing

1. Introduction

Exporting is considered by governments around the world as a central strategy for economic prosperity in the new global landscape. The focus on exporting, as an engine of economic growth, has taken hold in almost in every country, even in nations with large domestic demand. This focus is not surprising since national governments have discovered that outward-bound international activities generate jobs and taxes at home and that export revenues are instrumental to the enhanced welfare of its citizens (Griffith & Czinkota, 2012). Although many studies have sought to discover the main aspects of export performance, export risks and their hedging, far less attention was given to sources of competitive advantage or the way to build up competitive advantage at export markets. Several studies came to conclusion that essential for export success is access to financial resources (Ling-yee & Ogunmokun, 2001; Leonidou, 2004; Kaleka, 2011). Other study argues that the working capital and financial liquidity requirements of export operations mean that access to financial resources is essential (Morgan, Kaleka & Katsikeas, 2004). Recently, there were just few studies focused on gaining access to export financing (Griffith, 2011).

For running business in international context, there must be a large degree of mutual trust and support. Such a trust is giving confidence to exporter, that buyer will pay for the goods and services received. In addition to that, exporters are recently forced to assist buyers in getting access to credit with competitive credit terms. Delivering project construction together with secured project financing proved to be the key success factor in developing markets which enables these firms to succeed in highly competitive international bids (Pícha & Tomek, 2013). Other study investigated how public insurance schemes could be used to serve trade-related or other objectives (Dewit, 2001). The analysis emphasized the role of government export insurance programmes when exporting to less developed and risky markets, while private insurers still limit their activities to relatively safe markets.

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2. Case Study – Construction of Barka III and Sohar II - combined cycle power plants in Oman

2.1. Sultanate of Oman

The Sultanate of Oman (Oman) is one of the most progressive countries in the Middle East. The country has achieved remarkable growth in all sectors of economy during the past years and is well on course for excellent growth. Crude oil remains the single most important source of the state revenues and it's expected to make the growth and development process of Oman more sustainable in the long run. The Sultanate encourages foreign capital that will enhance the overall development of the country. It should supplement local investment in utilizing its untapped resources, facilitate transfer of technology, know-how, managerial skills, and getting benefit from the worldwide connections of multinational corporation in opening new markets for Omani products.

Oman is committed to a policy of open market economy based on free competition in which the private sector is encouraged and facilitated to play the leading role. Developed infrastructure, incentive packages, attractive corporate tax and tax holidays and simplified business procedures made Oman to become an attractive destination for investment. The government is continuously engaged in making the investment climate as conducive and investor-friendly as possible. Oman's foreign capital investment law has been liberalized, permitting 70% foreign participation in companies automatically in most of the sectors and even 100% foreign capital investment is permitted for projects of national importance.

The country's economy has shown ability to counter and confront the consequences of the large decline in oil prices. The country's economy depends on oil market prices, which suffered from high volatility during the last years. Despite the market situation driven by development of the world economy, the country reported solid GDP growth of 5 % in 2012, resp. 5.4 % in 2011. Together with economic growth, even power consumption is dramatically rising. The less efficient power technologies are penalized through very high gas prices. Efficiency is thus the key leading to success in this market in order to meet environmental criteria. In addition to that, limited natural gas resources have to meet increasing power demand in the country. Oman's power consumption is growing at nearly 10 % a year, which is a driving force for building new power sources.

2.2. KfW IPEX-Bank

The KfW is a German government-owned development bank. It was formed in 1948 after World War II as a part of the Marshall Plan. KfW is dedicated to the sustainable improvement of economic, social and ecological living conditions. Its statutory functions are those of a promotional bank for the domestic economy and a development bank for the developing countries (Kraft, 2003). Nowadays, KfW banking group covers over 90 % of its borrowing needs in the capital markets, mainly through bonds that are guaranteed by the federal government. This allows KfW to raise funds at advantageous conditions. Together with its exemption from corporate taxes due to its legal status as a public agency and unremunerated equity provided by its public shareholders, KfW is able to provide loans for purposes prescribed by the KfW law at lower rates than commercial banks.

KfW IPEX-Bank GmbH (KfW IPEX), as a largest subsidiary of KfW is in charge of project finance and corporate finance related to German or European exports. Its prime focus is on medium and long-term lending to boost the export economy, develop economic and social infrastructure and support environmental and climate protection projects. It also promotes foreign investments in Germany. Unlike KfW banking group itself, it is in direct competition with commercial banks. Therefore, and in response to concerns voiced by the European Commission concerning unfair competition, IPEX Bank has become legally and financially independent in 2008. IPEX Bank's main sectors of activity are ports, airports, toll roads, bridges and tunnels, railways, ships, planes, telecommunications, energy and manufacturing. It plays a major role in fulfilling the promotional mission of KfW. It is represented in the key economic and financial centers around the globe. In 2012 the volume of new commitments generated by KfW IPEX-Bank totaled EUR 13.4 billion.

2.3. Euler Hermes – Export Credit Agency (ECA)

Euler Hermes Deutschland AG (Euler Hermes) is the world-leading credit insurer and provider of trade-related credit insurance solutions. It is a subsidiary of Allianz Group and it is the largest credit insurance underwriter in the world with 34% market share. The Federal Government's export credit guarantee, so called Hermes Cover, protects companies from the risk of bad debt loses in connection with export transactions. These export credit guarantees are mainly targeted at exports to developing countries and emerging markets. Budgetary responsibility is borne by German state. The two companies, Euler Hermes and PricewaterhouseCoopers, support the government in implementing and managing this scheme. The Federal Republic of Germany provides guarantees against commercial and political risks in connection with export transactions and against the political risks of foreign direct investments as well as political risk cover for projects which secure the supply of raw materials to Germany. With Hermes Cover government supports the activities of German companies abroad by means of its foreign trade and investment promotion scheme and in doing so maintains their competitiveness, contributes to job security and promotes exports thus acting as an important growth factor. In such circumstances German exporters are able to build or maintain their market position with the assistance of state export credit guarantees. Export credit guarantees support firms in their efforts to open difficult markets and expand in traditional markets in unfavorable times. By taking out Federal guarantees, German exporters and banks protect themselves from the country and buyer risks involved in export transactions. In addition to non-payment risks, which exist also at home such as insolvency or unwillingness to pay, political non-payment risks also loom abroad, which may result in a complete loss of the trade receivables in extreme cases. These risks include for example the confiscation of goods or the unfair calling of contract bonds. Economic or political reasons may even force an early stop during manufacture. In such a case the exporter will normally be left with the production costs incurred so far on his hands.

Hermes Cover includes commercial and political risks:

- Political risks
  - Bad debt losses due to legislative or administrative measures, war, civil commotion or revolution abroad (the general political risk)
  - Losses due to non-conversion and non-transfer of amounts paid by the debtor in local currency due to restrictions in the international payment system (in the past the most frequent cause of loss)
  - Loss of the right to receive payment due to frustration of contract for political reasons
  - The loss of goods before the risk has passed to the foreign buyer due to political circumstances (e.g., the goods were confiscated, destroyed etc. before reaching the buyer).
- Commercial risks
  - Loss of receivables due to non-payment after a certain period (protracted default)
  - Loss of receivables due to the bankruptcy of the buyer, a composition settlement in or out of court, an unsuccessful judgment execution or suspension of payments by the buyer.

2.4. Siemens in Oman

For the German export industry, particularly the construction and energy sector, the Arabia represents a fast growing region important market. German agencies and institutions such as Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Euler Hermes and KfW IPEX monitor the region and maintain contact with governments and economic institutions to identify business opportunities for German exporters. Siemens takes advantage of cooperation with these institutions as a channel for gaining access to the bids. Siemens has played an important part in many of Oman's key infrastructure projects since it entered the market in 1974 and remained further committed to the region's economic progress. In 2011, Siemens set up its branch and Oman became one of its home markets. Due to increasing power consumption in Oman, government was seeking new power sources in order to satisfy growing demand. GDF Suez is the leading power generator in Oman. This multinational company holds the dominant position in the entire Gulf region with overall operational capacity of 25,000 MW. In June 2009, the consortium of investors led by GDF Suez, authorized by the Oman government, opened tender for delivery of Barka III and Sohar II, two gas-fired power plants with combined cycle and total annual capacity of 1,500 MW. For Oman's sustained economic development, it was crucial that new plants are commissioned on time before the hot summer season when electricity demand soars. Siemens already delivered several facilities for GDF Suez in the past and thus had necessary know-how and a number of related reference projects. There are just a few firms able to design and build such complex facilities with high requirements on technological excellence, innovation, quality and reliability. Besides Siemens, companies from United States, France, Saudi Arabia and Japan joined the bid. International tender for delivery of both plants had multi-criteria ranging from project price, technological solution as well as delivery terms. In order to offer a turnkey solution, Siemens as a purely technological firm entered into an IJV with Korean GS Engineering & Construction Corp.. Project financing facility was structured by KfW IPEX jointly by the two national ECAs - German Euler Hermes and Korea Eximbank (KEXIM). Both government agencies arranged syndicated buyer's credit with appropriate credit cover under attractive terms in order to support the IJV of Siemens and its Korean partner. In case of project failure, Oman would be suffering from shortage of power, thus the projects of Barka III and Sohar II reached strategic character and gained political support. Oman Ministry of Oil and Gas committed itself itself in terms of gas supplies for both plants. Similarly, Oman Power and Water Procurement Company (OPWP), single wholesale buyer of electricity in the country, signed purchase agreement with GDF Suez for plants' production capacity for a period of 15 years. For project scheme see Figure 1.

In March 2010, Siemens submitted its advanced technological solution together with the offer for project financing. Due to subsidized loans from the German KfW IPEX, consortium came out with attractive conditions for investors. Proposed technology, delivery terms, finacing offer with interest rates below commercial market level were finally evaluated by investors as excellent. In June 2010, as a result of joint effort, the consortium led by Siemens won this lucrative bid for delivery of the two 744 MW green-field power plants. GS Engineering & Construction Corp. was responsible for civil construction work, supplied the heat recovery steam generators, electrical transformers as well as equipment installation. Siemens supplied the main components comprising two gas turbines, one steam turbine and three generators.

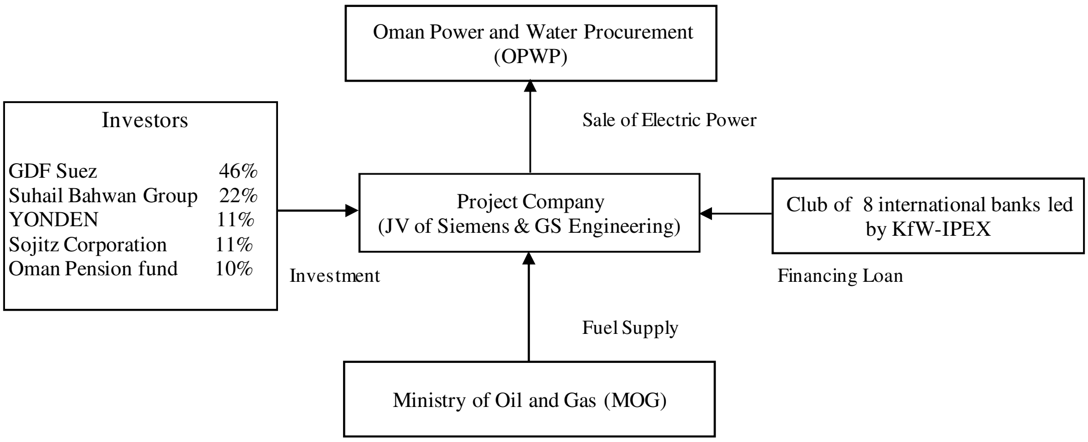

Figure 1. Project scheme

2.5. Financing Structure

The financing facility was structured and negotiated at the bid submission stage of 2009 when financial markets were still recovering from the financial crisis. IJV partners strived to bring competitive financing and attractive financing conditions, which finally led to granting of this power project. The project was financed through a blend of equity, early generation revenues and a senior debt facility involving ECA's Euler-Hermes and Korea Eximbank (KEXIM), and a club of eight international banks: Natixis, KfW-IPEX, Credit Agricole, HSBC, Bayerische Landesbank, Europe Arab Bank, CIC, and Standard Chartered Bank. KfW IPEX contributed around $ 380 million to the total investment volume as well as part of the interest rate hedging. The bank provided fixed-interest loans on CIRR basis (Commercial Interest Reference Rate) over a 17 year period at attractive conditions as part of the promotion of German power plant technology. KfW IPEX was mandated lead arranger and Euler Hermes main coordinator of the financing agreement. In connection with this transaction, credit guarantees against commercial and political risks were issued by Euler Hermes and KEXIM. The share of their involvement was equal to engagement of Siemens and its Korean partner. Insurance covered 95 % of credit volume, uninsured portion was shared by exporters and banks. For export financing model see Figure 2. Due to the volume of financing equaling to $1.3 bn, exceeding limits of KfW IPEX, also other banks were also invited to participate in this transaction. Another motivation was to pool banking know-how, different product specialization and experience with such large transactions. Besides investment credit, wide range of banking products were required such as issuance of performance bonds, warranty bonds, letters of credits, FX transactions, interest rate hedging, FX hedging, etc. All these services were provided by members of the bank syndicate. This transaction marked the first involvement of the German ECA in Oman's power sector projects. Euler Hermes provided comprehensive credit cover of more than USD 600 million for both projects. German KfW IPEX has continued support of the region's power sector spanning almost a decade.

2.6. Project and transaction overview

Project: Combined cycled power plants, Barka III and Sohar II
Production capacity: 2x 744 MW
Territory: Sultanate of Oman
Importer/Investor: Consortium led by GDF Suez S.A. (46 %)
Exporter: IJV - Siemens AG and Korean GS Engineering & Constr. corp.
Role: EPC Contractor
Technical advisor: Mott McDonald
Financing banks: A club of 8 international banks – KfW IPEX (Lead Arranger), Natixis, Credit Agricole, HSBC, Bayerische Landesbank, Europe Arab Bank, CIC, Standard Chartered Bank
Insurers / ECAs: Euler Hermes, KEXIM
Term of delivery: 09/2010 – 04/2013 (full operation as of 06/2013)

<u>Structure of financing:</u>
Contract price: $ 1700 million
Exporting buyer's credit: $ 1300 million (76.5 % of contract volume)
Investor's equity: $ 400 million (23.5 % of contract volume)
Drawing period: 30 months
Tenor: 17 years, 6 months grace period
Technology: Siemens AG (gas-fired combined-cycle turbines)

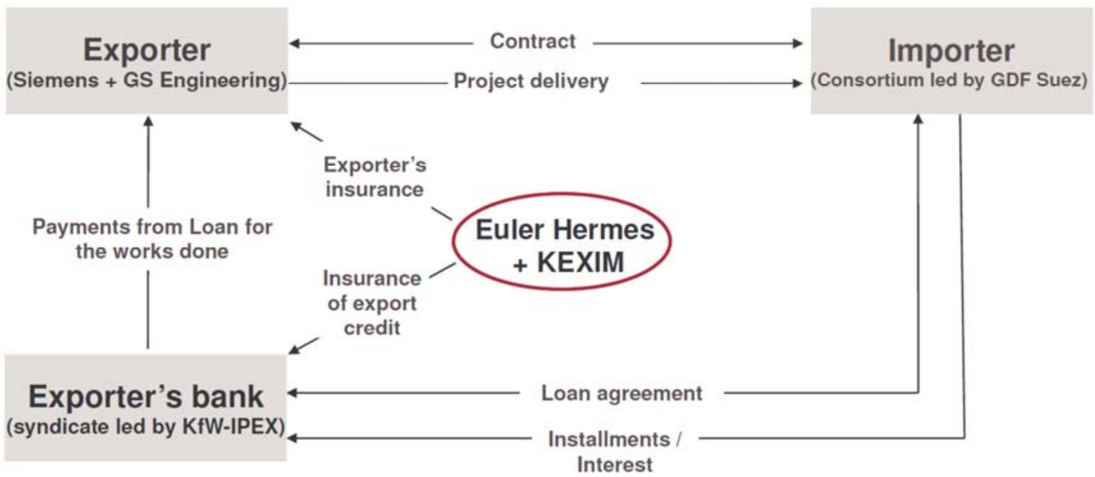

Figure 2. Syndicated Buyer's credit with Hermes and KEXIM insurance

Characteristics of export financing: Syndicated buyer's credit with signs of project financing – the whole project is assessed and evaluated according to the risk related to importer itself, as well as the stand alone project.

Hypothesis:

Based on literature review, current state of knowledge and case study presented, the following hypothesis were formulated:

H1: Strategic character of project and support of foreign country government are essential for successful project execution.

H2: Participation of export credit agencies increases confidence and mutual trust among project stakeholders.

3. Conclusion

The Siemens turnkey combined-cycle power plants Barka III and Sohar II were delivered on time and ahead of peak summer demand in accordance to agreed price and required quality measures. Exporting program of German KfW IPEX enabled advanced Siemens' power technologies to be exported, ensured that vast majority of supplies, services and equipment installed came from German contractors and thus jobs and employment in the home country were secured. This mechanism enables to tap into new markets. Germany further profited through project contribution to country's GDP growth and taxes being paid there. On the other side, with 57.6 %, Siemens executed construction of Oman's most efficient combined-cycle power plants, reflecting the country's focus on advanced technologies with low lifecycle costs. Thanks to advanced German technology, millions of tons of carbon dioxide will be saved. Such projects lead to the firm's further technological improvement and access to other power-engineering bids worldwide and thus drive German export-oriented economy forward. Without state guarantees, neither investor nor financing banks, wouldn't have enough confidence for participation in the project.

Based on above mentioned case study, we identified exporter's key success factors when delivering the project under export financing concept:

- Cooperation with German institutions and agencies monitoring market opportunities in the region
- Close cooperation with national export bank (KfW IPEX) and ECA (Euler Hermes)
- Strategic character of the project – KfW IPEX as a lead arranger supports power sector as well as projects for infrastructure development on the long term basis.
- Guarantees and support of Oman government due to projects' strategic character for the country, leading to increase of confidence of all project stakeholders.
- Possession of advanced and highly efficient technologies
- Wide range of reference projects and international experience
- IJV Partnering with GS Engineering of South Korea
- Cooperation with investor on the long-term basis

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Factors affecting cost overruns in micro-scaled construction companies

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Abstract

The ultimate goal of any construction company is to make profit and thereby earn money at the end of each undertaken project. In order to achieve this goal, construction companies should complete the projects within their anticipated budgets and durations, and expected quality targets. However in most construction projects severe cost overruns occur due to various factors. Experiencing cost overruns is a very important problem for construction companies, but especially for micro-scaled construction companies as they have limited capitals and annual revenues. Severe cost overruns may even cause micro-scaled construction companies' bankruptcies. Therefore, micro-scaled construction companies should thoroughly analyze the factors that prevail in the project in question, which may cause cost overruns, when they prepare their bid prices. The main objective of this study is to investigate the importance levels of factors that may bring about cost overruns in construction projects undertaken by micro-scaled construction companies. For this purpose, an extensive literature review was conducted and 38 factors were identified. These factors were categorized into 7 major groups, which are: 1) Contract-related factors, 2) Time-related factors, 3) Cost-related factors, 4) Quality-related factors, 5) Human resource-related factors, 6) Communications-related factors, and 7) Risk-related factors. A questionnaire, which consists of 10 questions, was designed based on information gathered from the literature review. The questionnaire mainly comprises 3 sections. Six questions in the first section inquire about the background of the respondents. The second section includes 3 questions that aim to investigate the characteristics of the construction companies. The third section has only question, and aims to identify the importance levels of 38 factors that may affect cost overruns. These questionnaires were delivered to 136 micro-scaled construction companies. Out of these 136 companies, 78 returned completed questionnaires. This accounts for a response rate of 57%. Reliability and ranking analyses were carried out on the collected data. The survey results indicated that design problems (i.e., design changes, constructability problems, delays in design approvals) is the most critical factor.

Keywords: Cost overruns, micro-scaled construction companies, questionnaire survey, reliability analysis, ranking analysis.

1. Introduction

The aim of every construction company is to earn money and make profit at the end of each undertaken project. Achievement of this goal mainly depends on completing projects within the anticipated budget, time, and expected quality targets. However, severe cost overruns usually occur in the construction projects due to many factors. Every construction company can be affected by cost overruns if it happens in their projects. However, the most affected construction company type is the micro-scaled construction companies because they have limited capitals and they are more vulnerable to risks. According European Commission Report, small and medium-sized enterprises (SMEs) are divided into 3 groups, namely micro-scaled, small-scaled and medium-scaled companies, depending on the number of the employees and the total annual turnover. In Turkey, although there are a great number of construction companies, most of them can be categorized as micro-scaled companies as they employ less than 10 employees and their annual turnovers are less than € 2 million. Medium and large-scaled construction companies have stronger financial capacities, which may help them in compensating probable cost overruns in their projects. On the other hand, the capitals of the micro-scaled construction companies are very limited. Therefore, severe cost overruns in their projects can lead these companies to bankrupt. The main objective of this study is to find out main factors that may cause cost overruns in construction projects undertaken by micro-scaled construction companies.

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2. Research Methodology

The methodology of this study includes 4 main parts, which are; (1) conducting an extensive literature review on cost overrun reasons in construction projects, (2) designing a questionnaire survey using the information obtained from the literature review, 3) conducting the questionnaire survey on the Turkish micro-scaled construction companies, and (4) carrying out reliability and severity analyses on the collected data.

2.1 Identification of Factors Affecting Cost Overruns in Micro- Scaled Construction Companies

In the light of the literature review on cost overrun reasons in construction projects (e.g., Semple, Hartman, & Jergeas, 1994; Frimpong, Oluwoye, & Crawford, 2003; Koushki, Al-Rashid, & Kartam, 2005; Lo, Fung, & Tung, 2006; Sambasivan & Soon, 2007; Lee, 2008; Kim, Han, & Kim, 2008; Le-Hoai, Lee, & Lee, 2008; Enshassi, Al-Najjar, & Kumaraswamy, 2009; Kaliba, Muya, & Mumba, 2009; Rosenfeld & Iuclea, 2011; Memon, Rahman, Abdullah, & Azis, 2014), it was determined that 38 factors may affect cost overruns in micro-scaled construction companies. These factors were categorized into 7 groups, which are: 1) Contract-related factors, 2) Time-related factors, 3) Cost-related factors, 4) Quality-related factors, 5) Human resource-related factors, 6) Communications-related factors, and 7) Risk-related factors.

Contract-related factors consist of transfer of all risks to the contractor and severe contract conditions. Time-related factors include delays in receiving progress payments, frequent change orders, delays in decision making process, delays in material procurement, late site delivery, inadequate project duration, delays in making payments, inefficient scheduling process, financing problems, and delays in site mobilization. Cost-related factors consist of design problems, mistakes in cost estimates, bribes, extra works not included in the contract, penalties resulting from safety accidents, obstacles from other contractors, unclear project scope, wastage of materials, lack of control over payments on site, theft of materials, laws and regulations prevailing in the region, and penalties resulting from delays. Reasons that prevent the achievement of the desired quality such as reworks, high guarantee period of products, unclear technical specifications, delays in inspection and testing, and penalties resulting from low quality constitute quality-related factors. Human resource-related factors comprise lack of managerial capability of the company, inexperience of the technical staff in the company, and high turnover rate of the staff in the company. Problems arising from the lack of communication such as oral requests from the owner and adverse attitudes of the owner constitute communication-related factors. Risk-related factors include high inflation rate and severe site and weather conditions.

2.2 Questionnaire Design

After identifying and categorizing the factors, a questionnaire survey, which comprises 10 questions, was designed. The questionnaire mainly consisted of 3 sections. Six questions in the first section inquire about the background of the respondents. The second section includes 3 questions that aim to investigate the characteristics of the construction companies. The third section has only question, and it aims to identify the importance levels of 38 factors that may affect cost overruns by using a scale of 1-5, where “1” represents the least importance and “5” represents the highest importance.

2.3 Data Analysis Methods

Reliability of the questionnaire was tested by internal consistency method. The statistical package SPSS® was used for reliability analysis. According to Field (2005), the most common measure of scale reliability is Cronbach's alpha (α). In previous studies, the reliable scale of Cronbach’s alpha was indicated as a value of at least 0.60 (Pallant, 2005). During the calculation of Cronbach’s alpha values, one or more variables can be deleted in order to increase the value (Field, 2005).

Ranking analysis was performed after reliability analysis to obtain the relative importance levels of the factors. Since parametric statistics would not give meaningful results with ordinal data, severity index analysis was conducted. Severity Index (SI), which is used for ranking the factors according to their relative importance levels, can be found by the formula in Equation 1 (Chen, Okudan, & Riley, 2010):

$$SeverityIndex(SI) = \left(\frac{\sum_{i=1}^{5} w_i \times (f_i / n)}{a} \right) \tag{1}$$

where i is the point given to each factor by the respondent, ranging from 1 to 5, w_i is the weight for each point, f_i is the frequency of the point i by all respondents, n is the total number of responses, and a is the highest weight, which is 5 in this study. Then five important levels were converted to SI values, which are: High (H) ($0.8 \leq SI \leq 1$), High-Medium (H-M) ($0.6 \leq SI < 0.8$), Medium (M) ($0.4 \leq SI < 0.6$), Medium-Low (M-L) ($0.2 \leq SI < 0.4$), and Low (L) ($0 \leq SI < 0.2$) (Chen, Okudan, & Riley, 2010).

3. Findings and Discussion

3.1. Sample Characteristics

The questionnaires were sent to the owners, project managers, site supervisors or coordinators of the micro-scaled construction companies by electronic mails or face-to-face interviews. A total of 136 questionnaires were delivered and 78 of them have been completed by respondents. This accounts for a response rate of 57%.

General characteristics of the respondents are given in Table 1.

Table 1. General characteristics of the respondents.

Characteristics of the Respondents	Freq. (%)	Characteristics of the Respondents	Freq. (%)	Characteristics of the Respondents	Freq. (%)
Education Level		***Number of years in the construction industry***		***Number of years in the company***	
Elementary school	4	1-5	19	1-5	55
High school	18	6-10	15	6-10	18
Undergraduate	54	11-15	23	11-15	15
Graduate	24	16-20	13	16-20	8
Age		21-25	12	>21	4
22-30	25	>26	18	***Share of profit***	
31-35	13	***Position in the company***		Yes	15
36-40	18	Owner/partner	49	No	85
41-45	23	Project manager/site manager	46		
>46	21	Other	5		

Three questions were asked about the characteristics of the construction companies. The responses to these questions are given in Table 2.

Table 2. General characteristics of the construction companies.

Characteristics of the Construction Companies	Freq. (%)	Characteristics of the Construction Companies	Freq. (%)
Number of years in the construction industry		***Types of Projects (Cont'd)***	
1-5	10	Institutional and commercial building	81
6-10	32	Specialized industrial construction	51
11-15	25	Infrastructure and heavy construction	45
16-20	19	***Who did supply the material and/or equipment required for the last project?***	
21-25	8	Owner supplied material and equipment	14
>26	6	Owner supplied material	27
Types of Projects		Owner supplied equipment	3
Residential housing	96	We supplied material and equipment	56

3.2. Reliability of the Questionnaire

Cronbach's alpha values were calculated via statistical software package SPSS 16.0. Cronbach's alpha values for each factor group are shown in Table 3.

Table 3. Cronbach's alpha values.

Factor groups	Number of questions	Cronbach's alpha values
Contract-related factors	2	0.776
Time-related factors	11*	0.659
Cost-related factors	12	0.643
Quality-related factors	5	0.631
Human resource-related factors	3	0.753
Communications-related factors	3*	0.677
Risk-related factors	2	0.649

* 1 of them was deleted in order to increase Cronbach's alpha values.

As it is presented in Table 3, Cronbach's alpha value is 0.776 for contract-related factors, 0.659 for time-related factors, 0.643 for cost-related factors, 0.631 for quality-related factors, 0.753 for human resource-related factors, 0.677 for communications-related factor, and 0.649 for risk-related factors. Reliable scale of Cronbach's alpha was indicated as a value of at least 0.60 in previous studies, thus in this study the internal consistencies of the factors are acceptable.

3.3. Ranking Analysis

Severity Index (SI) values of the factors were calculated using the formula presented in the Equation 1. The rankings of the each factor category were calculated by using both the magnitude of the severity indices and average ratings of the factors, the ranking results are shown in a descending order in Table 4.

Table 4. Rank of factors affecting cost overruns in micro-scaled construction companies.

Factors affecting Cost Overruns in Micro-Scaled Construction Companies	Ave. rat.†	SI‡	Rank. by categ.	Overall rank.	Imp. level
Contract-related factors					
Transfer of all risks to the contractor	2.69	0.54	1	8	M
Severe contract conditions	2.53	0.51	2	11	M
Time-related factors					
Delays in receiving progress payments	3.76	0.75	1	2	H-M
Frequent change orders	3.28	0.66	2	5	H-M
Delays in decision making process	2.61	0.52	3	10	M
Delays in material procurement	2.59	0.52	3	10	M
Late site delivery	2.52	0.50	4	12	M
Inadequate project duration	2.31	0.46	5	14	M
Delays in making payments	2.14	0.42	6	16	M
Inefficient scheduling process	2.01	0.40	7	18	M
Financing problems	1.89	0.38	8	19	M-L
Delays in site mobilization	1.75	0.35	9	22	M-L
Delays in works carried out by subcontractors (deleted)					
Cost-related factors					
Design problems	4.19	0.84	1	1	H
Mistakes in cost estimates	3.36	0.67	2	4	H-M
Bribes	3.36	0.67	2	4	H-M
Extra works not included in the contract	3.32	0.66	3	5	H-M
Penalties resulting from safety accidents	3.23	0.65	4	6	H-M
Obstacles from other contractors	3.21	0.64	5	7	H-M
Unclear project scope	2.42	0.48	6	13	M
Wastage of materials	2.29	0.46	7	14	M
Lack of control over payments on site	2.11	0.42	8	16	M
Theft of materials	1.86	0.37	9	20	M-L
Laws and regulations prevailing in the region	1.46	0.29	10	23	M-L
Penalties resulting from delays	1.42	0.28	11	24	M-L
Quality -related factors					
Reworks	3.21	0.64	1	7	H-M
High guarantee period of products	2.63	0.53	2	9	M

† Average Rating on a Scale of 1-5: 1=Very Low. 2=Low. 3=Medium. 4=High. 5=Very High

‡ Severity Index: High (H) (0.8≤SI≤1). High-Medium (H-M) (0.6≤SI<0.8). Medium (M) (0.4≤SI<0.6). Medium-Low (M-L) (0.2≤SI<0.4). and Low (L) (0≤SI<0.2)

Unclear technical specifications	2.25	0.45	3	15	M
Delays in inspection and testing	2.04	0.41	4	17	M
Penalties resulting from low quality	1.75	0.35	5	22	M-L
Human resource-related factors					
Lack of managerial capability of the company	2.08	0.41	1	17	M
Inexperience of the technical staff in the company	2.04	0.41	1	17	M
High turnover rate of the staff in the company	1.99	0.40	2	18	M
Communication-related factors					
Oral requests from the owner	3.73	0.75	1	2	H-M
Adverse attitudes of the owner	1.82	0.36	2	21	M-L
Vague technical specifications (deleted)					
Risk-related factors					
High inflation rate	3.49	0.70	1	3	H-M
Severe site and weather conditions	3.19	0.64	2	7	H-M

According to the ranking results, only 1 factor, namely “Design Problems”, has “High” importance level for cost overruns in micro-scaled construction companies. This factor is located under the category of cost-related factors. As cost overruns are directly related to cost related factors, this result is very reasonable. Design problems can be caused by several different reasons, such as customer demands, lack of control on drawings, etc. Design problems may cause increases in project cost as well as duration.

Based on the survey results presented in Table 4, a total of 11 factors, which consist of 2 time-related factors (i.e., delays in receiving progress payments, frequent change orders), 5 cost-related factors (i.e., mistakes in cost estimates, bribes, extra works not included in the contract, penalties resulting from safety accidents, obstacles from other contractors), 1 quality-related factors (reworks), 1 communication-related factors (oral requests from the owner), and 2 risk-related factors (i.e., high inflation rate, severe site and weather conditions), were recorded to have “High-Medium” importance levels.

17 out of the remaining 24 factors, which comprise 2 contract-related factors (i.e., transfer of all risks to the contractor, severe contract conditions), 6 time-related factors (i.e., delays in decision making process, delays in material procurement, late site delivery, inadequate project duration, delays in making payments, inefficient scheduling process), 3 cost-related factors (i.e., unclear project scope, wastage of materials, lack of control over payments on site), 3 quality-related factors (high guarantee period of products, unclear technical specifications, delays in inspection and testing), and 3 human resource-related factors (i.e., lack of managerial capability of the company, inexperience of the technical staff in the company, high turnover rate of the staff in the company), had “Medium” importance levels. Remaining 7 factors were recorded to have “Medium-Low” importance levels and none of these 36 factors (2 of them had been deleted in order to increase the reliability) has “Low” importance level, which indicates that all these factors, to some extent, may cause cost overruns.

4. Conclusion

This study aims to investigate the importance levels of factors that may cause cost overruns in construction projects undertaken by micro-scaled construction companies. For this purpose, a questionnaire survey was conducted among 78 Turkish micro-scaled construction companies. Reliability and ranking analyses were carried out on the collected data in order to test the reliability of the questionnaire and find the relative importance levels of these factors, respectively. The ranking results revealed that 1 out of 36 factors has “High”, 11 have “High-Medium”, 17 have “Medium”, and 7 have “Medium-Low” importance levels. None of these 36 factors has “Low” importance level. Most of the factors, which have “High” or “High-Medium” importance levels, are “cost-related factors”, “time-related factors”, and “risk-related factors”. Since these factors have direct influence on the project cost, this finding seems very reasonable. The findings of this study can help micro-scaled construction companies to understand and prevent the root causes of cost overruns in their future projects.

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Subcontracting Practices in International Construction Projects: Evidence from Turkish Contractors

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Abstract

It is commonly acknowledged that main contractors mostly subcontract the large portions of the tasks on construction projects. While subcontractors carry out the great amounts of the actual production work, main contractors act as construction management agents, are more involved in site organization and management tasks, and only control whether the work is performed according to the conditions specified in the main contract documents and related specifications. Subcontracting is also a very common practice in international construction projects. Main contractors, which operate in the international construction industry, tend to assign the large portions of the tasks to subcontractors. This study aims to explore the subcontracting practices of the Turkish contractors, which predominantly undertake international construction projects. For this purpose, a questionnaire survey was conducted among thirteen Turkish contracting companies to investigate the extent and involvement of these companies in subcontracting, reasons for subcontracting, problems experienced with subcontractors, and the criteria considered when selecting subcontractors. A direction for future studies that will focus on subcontracting in international construction projects was developed based on the findings of this preliminary study.

Keywords: International construction projects, questionnaire survey, subcontracting practices, Turkish contractors.

1. Introduction

A company that performs particular tasks on a construction project can be defined as a subcontractor. A subcontractor which has a contractual relationship with a main contractor can supply laborers, materials, equipment, tools, and designs (Arditi and Chotibhongs, 2005; Eom et al., 2008). Different types of services and/or resources can be provided to main contractors by subcontractors in the construction industry. The classification of subcontractors is based on the supplied services and/or resources. For example, Mbachu (2008) defines three different categorizations for subcontractors. The first category indicates trade subcontractors. They are specialized on specific trades such as paintwork, brickwork, etc. The second category includes specialist subcontractors, which provide specialist services such as electrical, plumbing, insulation etc. The third category is called labor-only-subcontractors that perform labor-only services (i.e., skilled craftsmen).

Main contractors only control the actual production work. They have to be sure that subcontractors perform their obligations in accordance with the conditions specified in the main contract document and related specifications (Ulubeyli et al., 2010). Nowadays, subcontracting has become a very common practice on many construction projects. However, main contractors should be aware of the risks of subcontracting. For example, the main contractor may have problems in coordinating the subcontractors when the majority of the work is carried out by a group of unknown subcontractors. Having problems in coordinating the subcontractors would also negatively affect the control of the quality and progress of the subcontractors' works (Cooke and Williams, 1998; Okoroh and Torrance, 1999; Kumaraswamy and Matthews, 2000; Cox et al., 2006; Karim et al., 2006; Ng et al., 2009). In the event of failure to complete the project, the main contractor is solely responsible to the owner even if this is because of the performance of the subcontractors. Therefore, the selection of the subcontractors is crucial for completing the project successfully in terms of time, cost, and quality (Shash, 1998; Arslan et al., 2008; Mbachu, 2008; Hartmann et al., 2009). However, many main contractors don't attach enough importance to the selection of the right subcontractor for the right job. They tend to select their subcontractors solely based on the lowest bid price. The risk of working with unqualified, incompetent, inexperienced, and insufficiently financed subcontractors should not be underestimated by the main contractors (Tserng and Lin, 2002; Luu and Sher, 2006; Arslan et al., 2008; Mbachu, 2008; Hartmann et al., 2009). A main contractor may fail to complete a construction project because of incapable subcontractors that bring about additional costs such as reworks due to

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poor quality of work, claims, disputes, etc. Main contractors should be more careful in selection of subcontractors in international construction projects, because an international construction project is subject to its own uncertainties without the risks of subcontracting (e.g., Polat and Arslan, 2010; Polat and Duzcan, 2011).

The globalization of construction markets has forced Turkish contractors to undertake international projects. Exploring the subcontracting practices in international construction projects might be helpful for main contractors in shielding themselves from the negative outcomes of possible failures in subcontracting. For this purpose, a questionnaire survey was conducted among thirteen Turkish contracting companies to investigate the extent and involvement of these companies in subcontracting, reasons for subcontracting, problems experienced with subcontractors, and the criteria considered when selecting subcontractors. Turkish contractors were selected as a sample, because they have attained an important position in the international construction market. The findings of this preliminary study can be used in developing a direction for future studies that will focus on subcontracting in international construction projects.

2. Research Methodology

This research was conducted as a pilot study. This study aims to investigate the subcontractor selection practices of Turkish contractors, who predominantly undertake projects in international construction markets. For this purpose, a questionnaire that consists of twelve questions was designed by using the information obtained from the literature review on subcontracting practices in the construction industry. The questionnaires were delivered to 102 large-scaled Turkish contractors, who are the members of Turkish Contractors Association (TCA) and mostly do business in international construction markets. Out of these 102 contractors, 12 returned duly completed questionnaires. It corresponds to a response rate of 12%. The contact people were top managers or project managers, who are in charge of subcontractor selection process.

3. Discussion of findings

Table 1 summarizes the general characteristics of the respondent construction companies. The respondent companies were asked how many technical and administrative employees work in their company. The survey results revealed that the responses were mainly drawn from medium-scaled and large-scaled construction companies employing over 50 technical and administrative personnel. 82% of the respondents are construction companies with annual turnover exceeding $50,000,000 in international markets. Overall, 22% of the respondents were involved in both building and residential work, while the remaining 30% and 26% were involved in heavy construction and industrial work, respectively.

The respondent construction companies answered the question concerning the maximum number of workers assigned to a project. As shown in Table 1, 82% of the respondent construction companies had employed more than 1001 workers and 18% of the respondent construction companies had employed workers in a range of 501-1000. Geographical dispersion and the number of projects, which were undertaken by the respondent companies in the international markets, are presented in Table 1. 36% of the respondent companies had undertaken more than 50 projects as a main contractor. The rest of the respondents (64%) had undertaken less than 20 projects as a main contractor. The respondent companies have many years of experience in undertaking construction projects in the international market. Table 1 shows that among respondent companies, 45% have experience less than 20 years, while 55% have more than 25 years of experience in undertaking projects in the international markets.

Table 1. General characteristics of respondent construction companies

Characteristics	Percentage of Respondents
Number of technical and administrative personnel	
1-9	-
10-49	9%
50-249	27%
>250	64%
Average of annual turnover in international markets ($ Millions)	
<50	18%
50-100	18%
>100	64%
Type of work	
Residential	22%
Building	22%
Heavy Construction	30%
Industrial	26%
The maximum number of workers assigned to a project	
<100	-
100-500	-
501-1000	18%
1001-5000	45%
>5000	37%
Geographical regions that the company undertakes projects	
West/Middle Europe	7%
East Europe	21%
Middle East	21%
Far East	7%
Africa	21%
Former Soviet Countries	17%
Other	7%
Number of projects undertaken in the international markets	
1-9	27%
10-19	27%
20-29	9%
30-39	1%
40-49	-
>50	36%
Number of projects undertaken as a main contractor	
1-9	28%
10-19	36%
20-29	-
30-39	-
40-49	-
>50	36%
Number of years of experience in undertaking projects in the international markets	
1-5	-
6-10	9%
11-15	18%
16-20	18%
21-25	-
>25	55%

Table 2. Reasons for subcontracting

Reasons	Level of importance*
Reduce costs	4.45
Lack of specialized skills	4.00
Lack of specialized machinery and equipment	3.82
Save time	3.09
Reduce risk	3.00
Improvement in quality	2.91
Complexity of the project	2.73
Legal obligations	2.55
Traditional	1.91
Absorb fluctuation in prices	1.82
Maintain relation	1.36
Tax advantage	1.18

*5.00 = Very Important, 4.00 = Important, 3.00 = Moderately Important, 2.00 = Slightly Important, 1.00 = Low Importance, 0.00 = Not Important

Question 9 was asked to identify the reasons for subcontracting. Table 2 shows the importance that respondent companies attach to each potential reason for subcontracting in a descending order. The survey results indicate that out of 12 potential reasons “reduce costs” and “lack of specialized skills” score 4.45 and 4.00 respectively, which are higher than “important”. “Lack of specialized machinery and equipment”, “save time”, and “reduce risk” have scores that correspond to between “moderately important” and “important”. “Improvement in quality”, “complexity of the project”, and “legal obligation” score 2.91, 2.73 and 2.55 respectively, which are between “moderately important” and “slightly important”. “Traditional”, “absorb fluctuation in prices”, “maintain relation” and “tax advantage” score between 1 and 2, which is lower than “slightly important” (Table 2).

Question 10 was meant to find out the importance levels of the factors affecting the subcontractor selection process of construction companies that undertake projects in the international markets. The importance that respondent companies attach to each factor is presented in Table 3 in a descending order. Out of 37 potential factors “attendance at site meetings in previous projects” and “relationship with the main contractor” score 2.91 and 2.82 respectively, which are slightly lower than “moderately important”. 11 factors score between 3 and 4, which are between “moderately important” and “important”. 24 factors affecting the selection of a subcontractor score higher than “important”. The first 3 of them, namely “budget performance in previous projects”, “track record on-time completions” and “experience in similar projects” score slightly lower than “very important”.

Table 3. Factors affecting the selection of a subcontractor

Factors affecting the selection of a subcontractor	Level of importance**
Budget performance in previous projects	4.91
Track record on-time completions	4.82
Experience in similar projects	4.82
Reliability	4.73
Experience in previous projects	4.64
Quality performance in previous projects	4.55
Strength of workforce	4.55
Possession of necessary equipment	4.55
Efficient programming of subcontract work and proper fit with main contractor’s master program	4.45
Evidence of adequate resources/capacity	4.45
Leadership qualities and ability to manage own workforce	4.36
Reference from previous employers and financiers	4.36
Technical competence and experience in the job at the hand	4.36
Knowledge of the project environment	4.27
Health and safety records	4.27
Readiness to mobilize on site	4.27
Competitiveness of the tender price	4.09
Experience in the construction industry	4.09
Possession of skilled workforce	4.09
Ability to prepare method statements	4.09

Financial capacity	4.00
Current workload and commitment	4.00
Owner's acceptance of the subcontractor	4.00
Regular payments for employee benefits	4.00
Efficient resource management and waste minimization	3.91
Accessibility	3.91
Ability to work efficiently with other subcontractors	3.82
Payment of wages on time	3.82
Surety bonds covering tender	3.64
Ability to submit tender price on time	3.64
Existence of ISO9001:2008 QMS certificate	3.55
Reputation and attitude	3.45
Existence of ISO14001:2001 EMS certificate	3.36
Contractual risk of subcontracting	3.27
Existence of OHSAS:18001 certificate	3.27
Attendance at site meetings in previous projects	2.91
Relationship with the main contractor	2.82

**5.00 = Very Important, 4.00 = Important, 3.00 = Moderately Important, 2.00 = Slightly Important, 1.00 = Low Importance, 0.00 = Not Important

Question 11 was asked in order to explore the importance levels of the factors that are considered in the assessment of subcontractor's performance. The survey results indicate that out of 11 factors only "good communication network" scores 2.91, which is slightly lower than "moderately important". "Good working relations with other subcontractors", "ability to manage changes without unnecessary claims", and "fair and minimal claims" score 3.91, 3.82 and 3.36 respectively, which are higher than "moderately important" and close to "important", whereas the remainders score higher than "important". The first three factors that have the highest score are "on-time completion", "completion without a budget overrun", and "quality of work consistent with the quality level" (Table 4).

Table 4. Assessment of the subcontractor's performance

Factors affecting assessment of the subcontractor's performance	Level of importance***
On-time completion	4.82
Completion without a budget overrun	4.82
Quality of work consistent with the quality level required of the main job	4.73
Good working relations with main contractor's team	4.55
Compliance with contract terms and conditions	4.55
Onsite health and safety practice	4.45
Ability to manage the financial and contractual risks inherent in the subcontracts	4.09
Good working relations with other subcontractors	3.91
Ability to manage changes without unnecessary claims	3.82
Fair and minimal claims	3.36
Good communication network	2.91

***5.00 = Very Important, 4.00 = Important, 3.00 = Moderately Important, 2.00 = Slightly Important, 1.00 = Low Importance, 0.00 = Not Important

The respondent companies were asked about the main problem areas of subcontracting (Question 12). Respondent companies reported that "work progress", "quality", "cost overrun", and "lack of cooperation between personnel of main contractor and subcontractor" are the major problem areas of subcontracting. "Difficult to coordinate activities" and "coordination between subcontractors" score 3.73 and 3.64 respectively, which are higher that "moderately important" (Table 5).

Table 5. Main problem areas of subcontracting

Problem areas	Level of importance****
Work progress	4.91
Quality	4.82
Cost overrun	4.45
Lack of cooperation between personnel of main contractor and subcontractor	4.18
Difficult to coordinate activities	3.73
Coordination between subcontractors	3.64

****5.00 = Very Important, 4.00 = Important, 3.00 = Moderately Important, 2.00 = Slightly Important, 1.00 = Low Importance, 0.00 = Not Important

4. Conclusion

This study revealed that Turkish contractors prefer to work with subcontractors in international construction projects, for a very important reason, i.e., reducing cost. Turkish contractors achieve cost savings by subletting the large portions of tasks to subcontractors as they are able to carry out the tasks more quickly at a lower cost with higher quality than the main contractor because of their specialized skills, and machinery and equipment. The survey results indicated that Turkish contractors pay attention to the performances of the subcontractor candidates in previous projects during the subcontractor selection process. Moreover, Turkish contractors consider “on-time completion”, “completion without a budget overrun”, and “quality of work consistent with the quality level” as three most important factors when they assess the performances of the subcontractors they worked with. This study also revealed that Turkish contractors experience severe problems in “work progress”, “quality” and “cost overrun” when they work with subcontractors. In construction projects where most of the works is subcontracted out, the success of the overall project mainly depends on the performances of the subcontractors. Therefore, main contractors should be very careful when they select the subcontractors, especially in international projects.

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Enhanced use of ICT by SMEs in construction: a scenario thinking approach

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Abstract

Information and Communication Technology (ICT) plays a number of significant strategic and operational roles in the construction sector. However, a number of studies have highlighted a series of challenges within this sector, from value-proposition aversion (regarding ICT expenditure), through to lack of awareness (capability), and inability to 'measure' tangible outcomes (benefits) associated with ICT deployment. Given these issues, and also acknowledging the levels of nested fragmentation that exists in sectoral disciplines – especially within small to medium enterprises (SMEs); this paper presents a chronology of interrelated factors peculiar to the sector which has directly/indirectly influenced this slow (low) technology adopter positioning of these organisations. This paper argues that there is a need to break the status quo use of ICT by SMEs, and a need to realise the benefits garnered in other sectors as a means of not only enhancing the existing business, but also creating new innovation opportunities (especially in the early adopter S curve). Using a scenario thinking approach, this research presents a framework which highlights the causal "deficits" associated with low ICT penetration in the sector. This framework also identifies the key forces that influence and impact upon ICT usage in the construction sector, especially the interplay of key pivotal forces (through the competing push-pull continuum). A series of different scenarios for ICT uptake, adoption and diffusion are envisioned. These were developed with the help of industry experts in order to embed relevance and establish priorities against tangible indicators. This framework presents a future state ICT vision for SME's, one which places direct emphasis on SMEs' perspectives (operational and strategic) and future business aspirations.

Keywords**:** Construction, Deficits, ICT Adoption, Investment decisions, SME, Technology adoption

1. Small and Medium Enterprises in Construction

SME's play an important role in the construction sector globally. SMEs are defined as non-subsidiary, independent firms which employ less than 250 employees; where small firms are generally those with fewer than 50 employees, and micro-enterprises have at most 10 employees. However, SMEs account for over 95% of firms, corresponding to 60%-70% of employment in many sectors including construction where they work as consultants, constructors, or suppliers on a variety of construction projects (OECD 2000). Given this, technology and globalisation has been seen to reduce the importance of economies of scale and many of the traditional shortcomings associated with SMEs e.g. lack of financing, difficulties in exploiting technology, constrained managerial capabilities, low productivity, risk-aversion (OECD 2000). It is in this backdrop that a new roadmap is needed for the use of ICT by SMEs in the built environment sector (Love, Irani, and Edwards 2004).

2. Case for ICT in the Construction Sector

Operations in the sector are generally realised through the term "projects" (with well-defined starting and finishing lines and pre-defined outcomes). These projects are often conducted by firms collectively, more often in association with other specialised services providers, each of whom can be conceptualised as a "firm". Together with other stakeholders they make up the "industry". Researchers have argued for the relevance of new production philosophies unfolding in manufacturing that require production activities to be analysed as processes as against functions, controlled for such concepts as minimal variability and cycle-time (Miozzo et al. 1998), with continuous attention to reduce waste (processes, material etc). This process-based view of construction is seen as the basis for a new ICT agenda for the sector. However, construction firms are slow to exploit ICT (Acar

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et al. 2005) and the industry invests little in ICT, with only few contractors being able to fully integrate ICT into their business processes and service delivery.

3. Literature Review

There is a paucity of literature on how stakeholders can purposefully address the problems of the sector with the aid of ICT. Acknowledging this, it is recognised that the ICT landscape cuts across boundaries of organizations, functions, and stakeholders; the products and services of which create a larger picture for the potential ICT use in the sector (Sawhney and Mukherjee 2013). However, coverage is scarce from a project-firm-industry standpoint, taking into account the specific requirements of the SME sector – some of the challenges of which can be seen in Table 2.

Table 2. Summary of Research Literature Reviewed

Publication	Main Findings
Integration Of ICTs With Business Processes: Insights from SMEs (Shiels, Mcivor, and Reilly 1998)	This paper avers that organizations can derive economic benefits as also managerial knowledge, skills and experience to make a significant difference in exploiting new opportunities; and proposes Technical Integration, Operational Integration, Inter-Organizational Integration and Strategic Integration.
A Business Process View of the Impact of ICT in Real Estate (Mazumder and Chatterjee 2007)	The paper highlights the need for control over project resources – materials, manpower, money and time schedules in an overall effort to ensure stakeholder satisfaction (meeting customer satisfaction without compromising on profitability).
3G/WiMAX rollout to propel demand for IP-based networks(Prakash 2010)	This article shows how networks are moving completely to all IP-based networks thus freeing up applications and services from specific requirements of the network. Additionally, it also throws light on how everything could move over the same network- voice, video, text and image. This has far-reaching implications that will potentially impact business models of core ICT operators in the days to come. Major drivers of these networks include (a) price on legacy services; (b) higher and varying bandwidth requirements on mobile networks owing to proliferation of advanced edge clients like iPhones and high-end smart phones; and (c) newer Web-based data applications and increased video content on the network because of the increased use of various networking applications through fixed and mobile networks.

4. Demand-Pull Requirements

Anecdotally the construction sector has been referred to as a sector that has missed the ICT revolution. This may be an overstatement or media-hype; but the sector has not fully embraced ICT compared to other sectors. This may be due to a myriad of issues, including the peculiarities of the sector, operational boundaries, fragmentation etc– see Supply-Side Drivers

On the supply side, developments in ICT including the ubiquity of networks; prevalence of web-based services over multiple devices; convergence of voice, text and video services over IP-based networks; miniaturisation of ICT devices; technological advances and robust all-weather devices; increasing bandwidth availability; low-cost alternatives; proliferation and possibilities over open source integration; cloud-based infrastructure and services; all have an impact on ICT adoption. Table 3 describes this in more detail.

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Table 3: Demand Side Requirements for ICT as a Solution in the Construction Sector

Specificity	ICT adoption as a Solution
Unwieldy paper documents	Transmitting heavy and precious documents over ICT networks reduces waste
Geographically separate locations	Multi-member teams are spread out to distant locations and ICT-enabled communications are the only alternative
Lack of information for project management	Lack of consolidated project information at one place delays decision making and impairs project control and monitoring. ICT represents the only way to bridge this gap
Many-to-many relationship and temporary combination of parties	At any point in time team members are potentially members of different projects performing same, similar or completely different roles. A standardized process view as against a function-view enabled subsequently through ICT is the only logical way to reduce confusion and maximize efficiency
Association with big players	Big players often require that smaller players be ICT-enabled sufficiently as a qualification to partner with them
End-user convenience	End user convenience often mean that service providers have to be ICT-enabled (particularly SMEs competing for foothold)
Increasing relevance of Cost, Quality and adherence to	Deviations of time, cost, scope and quality from planned/promised performance and timely decision making for responding to problems and disputes are among common problems faced in the sector today.

Specificity	ICT adoption as a Solution
delivery schedules	Customer expectation will likely rise in the future on these aspects. ICTs represent an indispensable tool to address these issues
Rising Volume of Work and the resultant deluge of data	As the global economy recovers the volume of work will increase manifold with time, implying more information handling by the industry to arrive at the most optimum solution under the emerging constraints. Planners, too, will be deluged with data even as it becomes more imperative for them to take the right decisions at the right time with the right set of information

5. Supply-Side Drivers

On the supply side, developments in ICT including the ubiquity of networks; prevalence of web-based services over multiple devices; convergence of voice, text and video services over IP-based networks; miniaturisation of ICT devices; technological advances and robust all-weather devices; increasing bandwidth availability; low-cost alternatives; proliferation and possibilities over open source integration; cloud-based infrastructure and services; all have an impact on ICT adoption. Table 3 describes this in more detail.

Table 4 Supply-Side Drivers for ICT as a Solution in the Construction Sector

Specificity	ICT adoption as a Solution
Ubiquity of Internet	As penetration rates go up for both PCs and Internet and countries across the world roll out their broadband strategies and plans ubiquity of the Internet over fixed or wireless networks will definitely follow
Prevalence of web-based services over multiple devices	Web-based applications and services are currently the norm and, as a direct fall-out, there is a need to deploy a variety of channels for service delivery for users to consume services anytime (24X7), anywhere (through ubiquity of the Internet) and anyhow (through multiple channels). Besides making available services hitherto inaccessible new channels give users have a free choice to access a service; users would choose the one that realizes the highest relative value for them.
Convergence of voice, text and video services over IP-based networks	All-IP based networks are gradually becoming a preferred technology, as voice, video, and data converge onto a single system, reducing the capital expenditure for service providers. Organizations are migrating from multi-platform based network infrastructure to a single-IP based network with the latter acting as a catalyst for an organization's network convergence between voice, data and video infrastructure. The availability of 3G/4G will further enhance quality and speed, allowing networks to manifest the full extent of their capabilities.
Increasing bandwidth availability and affordability	The Internet revolution is being influenced by telecom players' strategies to reduce cost of access (Smartphone costs are falling rapidly as players achieve scale economies even as the expansion of 3G/4G services is likely to reduce connectivity costs). With time, therefore, bandwidth hungry applications and services would become more common.
Low-cost alternatives	Massive economies of scale will likely drive down prices for lower-end PCs, tablets and smartphones such that large numbers of less affluent families in emerging markets could afford them. This will further increase scale and enable even less expensive devices, such as the $100 smartphone. This "virtuous circle" will also make possible the perennially improving smartphone, as well as the $100 tablet (Deloitte 2014).
Proliferation and possibilities over open source	Open Source promises better quality, higher reliability, more flexibility, lower cost, and an end to predatory vendor lock-in. Since OSS does not limit or restrict who can use the software, the type of user, or the areas of business in which the software can be used, this makes for opportunities for customization and community innovation within agencies as well as with other stakeholders, citizens and SMEs (Waring and Maddocks 2005).
Cloud-based infrastructure and services	Advances in cloud computing make it possible for agencies to share the same ICT infrastructure to access software, services, and data storage through remote infrastructure, making it possible for ICT to become a new "utility" model. For an organization, therefore, for a set or variable, usage-based fee (and sometimes, free) it could contract with a provider to deliver applications, computing power, and storage via the web. Computing therefore becomes location- and device-independent, and computing tasks and information are available anytime, anywhere from any device—so long as there is access to the Internet (AGIMO 2011).

6. The Case for ICT for SMEs

In today's global economy it is important for SMEs to maintain their competitive edge. ICT is a tool for SMEs to improve innovative power and competitiveness, especially to develop a global network of product exchange. Indeed, ICT has become a utility item, just like electricity (Wen, King, and Jaska 2008). For example, increasing wireless penetration by 10 percentage can lead to an increase in gross domestic product of about 0.5% (Foster 2007). Essentially there are three ways in which ICT can bring competitive advantage (Wen et al. 2008):

- by changing the industry structure and altering rules of competition;
- by creating competitive advantage through new ways to outperform rivals; and
- by spawning whole new businesses

For example, an investigation of factors affecting ICT acceptance was undertaken in the UK with 188 SMEs. This concluded that small businesses that readily adopted new ideas and were willing to exploit new knowledge would have a competitive edge over their competition (Selamat, Jaffar, and Kadir 2011). The main incentives behind the adoption of ICTs by SMEs relate ostensibly to 'gain' e.g. reduced transaction costs, lower risk, information gathering/dissemination, increased inventory control and quality control, improved relationships with customers and suppliers and the increased control over distribution and marketing of products.

7. ICT for SMEs in Construction

Love and Irani (2004) noted ICT adoption issues should take into account relevance (a) for SMEs in the sector; (b) for ICT adoption by SMEs in general; and (c) for ICT adoption in construction sector (Figure 2). Figure 2 shows the complexities caused due to the intersection of demand-side factors, supply-side factors, and specificities of the construction sector. These complexities have been encapsulated as "deficit" areas for the sector; which has resulted in low adoption of ICT by the construction sector in general and SMEs in the construction sector in particular (Vitkauskaite and Gatautis 2008). Through a detailed literature review and expert interviews the following deficit areas relevant to the issue of adoption of ICT by SMEs in the construction sector were identified (Sawhney and Mukherjee 2013): Collaboration Deficit; Standardization Deficit; Service Delivery Deficit; Efficiency Deficit; Decision Support Deficit; Transparency Deficit; and Democratization Deficit, with ICT infrastructure/applications at affordable rates.

From Figure 1, this paper builds on previous work in the following areas:

- It takes into account more holistically the information requirements of all stakeholders including the end-users, regulators and the industry associations;
- It presents three views as illustrated above to provide information and services- the project view, the firm view and the industry view;
- It has a predominant thematic focus on the SME segment of the industry in an overall effort to bring about equitable development of the sector; and
- It also talks about institutional arrangements to operationalise the solutions.

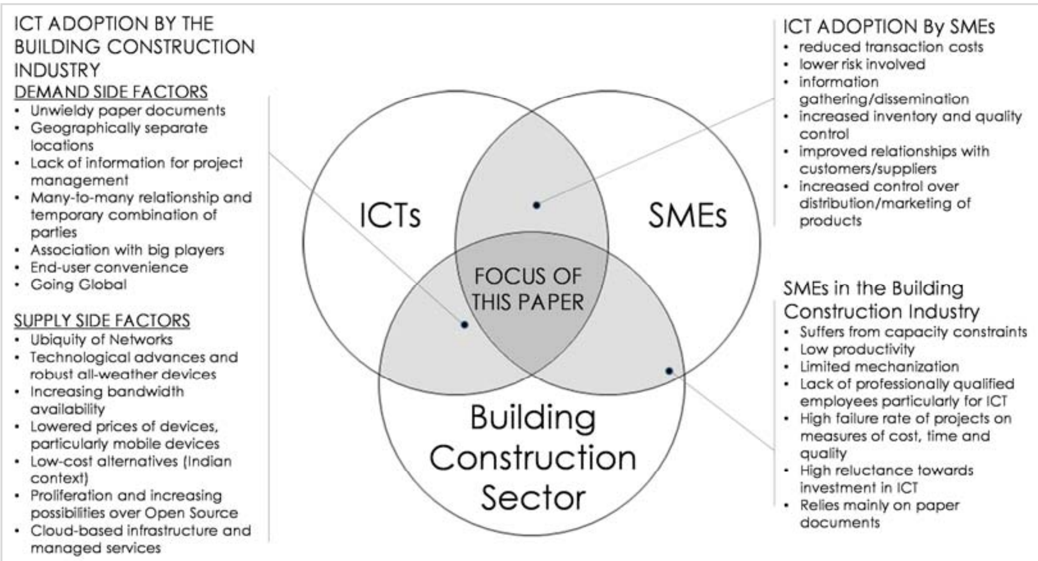

Figure 1: Commonality of Issues to be addressed for ICT adoption for SMEs in the Indian Construction Industry

8. Research Methodology

Scenario thinking or planning concerns planning based on the systematic examination of the future by picturing plausible and consistent images of the future (Chermack 2005). Delphi, in turn, attempts to develop systematically expert opinion consensus concerning future developments and events. Numerous researchers have stressed that both approaches are best suited to be combined. Due to their process similarity, the two methodologies can be easily combined. Generally speaking, the output of the different phases of the Delphi method can be used as input for the scenario method and vice versa. In this case, the methodology adopted was the "Prospective Process Approach Using Scenario Planning Techniques" in conjunction with Delphi with industry experts across the board. A scenario is the set formed by the description of a future situation and the course of events that enables one to progress from the original situation to the future situation (Godet 2000). Scenario Planning (SP) is a disciplined method for imagining possible futures that organizations/industries have applied to a great range of issues (Schoemaker 1995). Also called scenario thinking or scenario analysis, it is a strategic planning tool/method that enables the development of flexible long-term plans (Erdogan et al. 2009). Ranking the issues and trends according to (a) Level of impact upon the strategic question; and (b) degree of uncertainty (likelihood) of occurrence, four different scenarios as illustrated was constructed (Figure 2). The most favoured "Globally Competitive" was then developed further for elaboration.

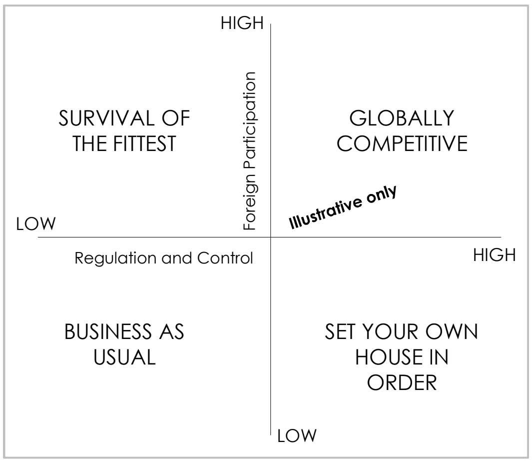

Figure 2. Illustrative Four Scenarios

9. Conceptualising the Landscape

There a direct requirement for ICT systems to transform the SME-centric sector; similarly, it is important to acknowledge the need for: appropriate economies of scale, adopting common standards, protocols and guidelines for solutions that are interoperable to meet the information needs of all stakeholders (Ahuja, Yang, and Shankar 2009; Love et al. 2004). However, different requirements of information and services emerge at each of the levels of project, firm and industry. Cloud-based infrastructures and open source need to be considered for different components of the solution to make these solutions affordable to smaller organisations. It is recognised that a Total Cost of Ownership comparison needs to be made before making a specific choice and a blanket preference is not advisable. Whilst these issues are beyond the scope of this paper, Figure 3 presents the different components of the composite ICT landscape and trends for the building construction industry at each of three levels of project, firm and industry.

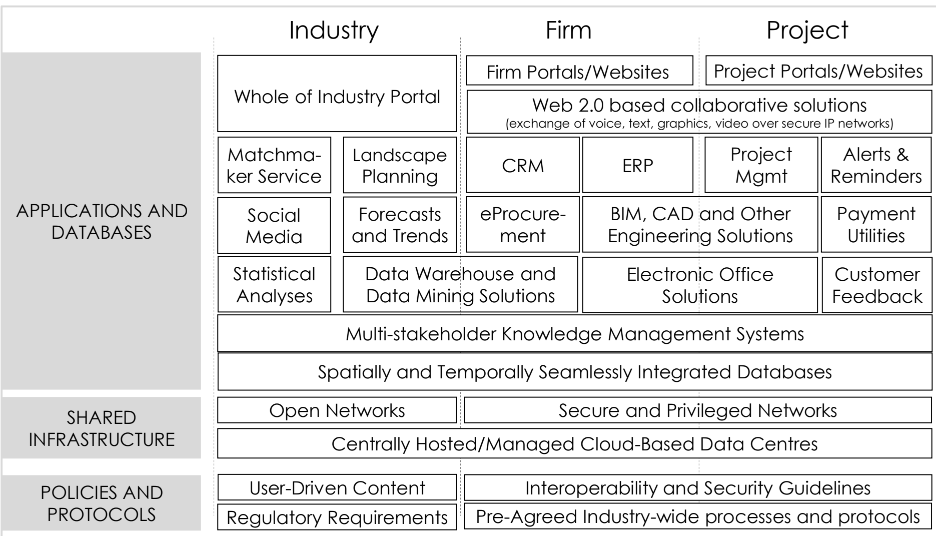

Figure 3. Components of the Composite ICT Landscape for the Building Construction Industry

10. Conclusion

The ICT landscape for the construction sector is still predominantly fragmented. Solutions are therefore needed. For example, the different categories in the solution landscape could be further decomposed and customised into modules through a conceptual "rack" based on pre-agreed industry-wide standards, protocols and guidelines (to create interoperability). Adherence to such globally accepted standards together with the advantages made available by a ubiquitous networks, affordable devices and cloud-served applications and services would ensure that the best platform is presented to SME's. Users would then need to make a choice of modules from the rack depending upon their suitability for their operations at each of the three levels of project, firm and industry. In some respects, this is happening through the use of Building Information Modelling. Solution conceptualisation must however consider that data integration and interoperability can completely transform the industry. This may need further strategic roadmaps and support/promotion by regulators and/or industry associations to manage and drive this transition.

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Life Cycle Cost optimization within decision making on alternative designs

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Abstract

The purpose of this paper is to highlight the role of the life cycle cost criterion in deciding on the proposals of construction projects. Owners commonly use construction cost minimization. In order to achieve the maximum value for money all costs incurred over the whole life span must be evaluated. The optimization of the life-cycle cost of a project, construction, and equipment is essential for a complex decision-making process. Then, the solution with the minimum value of the life-cycle cost can be chosen. Life cycle costing (LCC) is a method of economic analyzing of all costs related to constructing, operating, and maintaining a construction project over a defined period of time. Having the costs and savings we can then directly compared these areas and be fully informed when decisions are made. The greatest benefit of life cycle costing can be obtained in the initiation phase of construction projects. The paper summarizes the issues of life cycle costing (LCC) and analyzing. The paper presents the most frequently used methods of cost calculating. The paper also clarifies the necessary data and a suitable process of life cycle costing is proposed. The paper presents the results of a survey focused on the use of LCC by public owners and developers. Decision-making using the LCC optimization is demonstrated in the case study. This case study is a public building. The client's benefits of integrating LCC into decision-making processes within project preparation are summarized in the conclusion.

Keywords: Building; cost; design; decision; life cycle.

1. Introduction

The lowest investment cost (the lowest price) is often the only priority in the process of preparation of the budget in a construction project. If we consider a building's lifespan as tens of years, assessing project alternatives in terms of only investment costs occurs as shortsighted and insufficient. Running costs (operation costs, maintenance and renovation costs) are an important section of investment during the life cycle. Life cycle costing (LCC) should be an inseparable part of decision making on financially expensive investments, which most construction projects can be classified. Calculation of life cycle costs provides a completely new economic view on building design. This paper covers the implementation and incorporation of the LCC criterion in the decision making cycle for preparation of construction projects.

RICS (Royal Institution of Chartered Surveyors) introduced a method of collecting data about running costs of buildings in 1971 (BMCIS - Building Maintenance Cost Information Service). The British ministry of industry published a document "Life-cycle costing in the management of assets" in 1977. In 1983, a framework for data collection was published applicable to establishing a project LCC (Flanagan et al., 1989). The concept of LCC has been accepted as a British Standard since 1992. The LCC definition was revised in 2000 and incorporated in the ISO 15686 Part 1 - Service Life Planning. Recently, a centre for Whole Life Performance has been established at the Building Research Establishment (BRE) to provide the Secretariat to an industry-led Whole Life Costs Forum (WLCF) (CPN 2000). This Forum is intended to enable members to pool and receive typical WLC information through a members-only database, and produce industry-accepted definitions, tools, and methodologies (Edwards et al, 2000). The TG4 group was established as a part of the work group for sustainable construction in 2001. This was done to prepare a report on calculation of LCC in construction and formulate a recommendation how the LCC should be implemented in the European policy. The output is a report "Task Group 4: Life cycle costs in construction". The latest initiative is the project titled "A common European methodology for Life Cycle Costing" (Davis Langdon, 2007). Life cycle costing is a technique to estimate the total cost of ownership (OGC, 2003). The technique can assist decision-making for building investment projects (Flanagan et al., 1989). LCC is particularly useful for estimating the total cost in the early stage of a project (Bogenstatter, 2000). A LCC process usually includes the following steps: planning of the LCC analysis (e.g.

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definition of objectives), selection and development of the LCC model (e.g. cost breakdown structure, identifying data sources and contengencies), application of LCC model, and documentation and review of LCC results (NSW Treasury, 2004). There have been extensive research and reports on LCC (Davis Langdon, 2007). Nevertheless, LCC is not commonly applied in Europe or USA.

According to ISO/DIS 15686-5 (2006), Life Cycle Costing is both a tool and technique, which enables comparative cost assessments to be made over a specified period of time, taking into account all relevant economics factors both in terms of initial capital cost, future operational costs and asset replacement costs, through to end of its life. Also LCC will take into account any other non-construction costs and income. Life Cycle Cost (LCC) represents the overall costs spent in course of the building's whole life cycle. Their structure is presented in Fig. 1, as a part of Whole Life Cost (WLC).

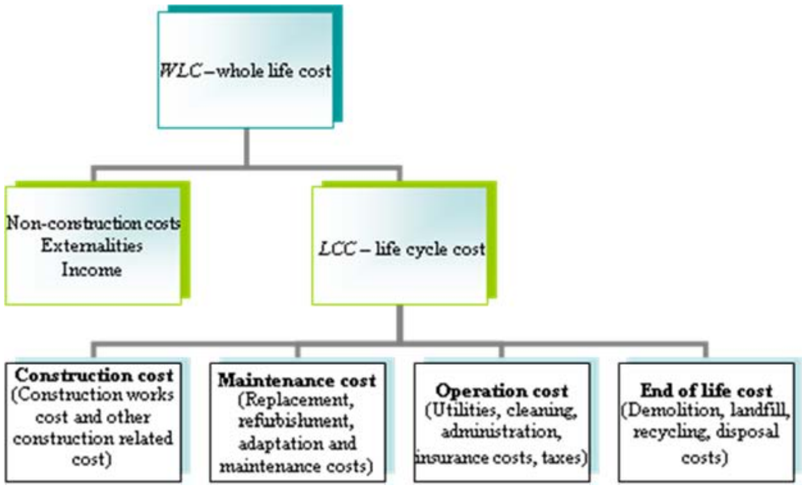

Figure 1. The structure of Life Cycle Cost (Developed in terms of ISO 15686-5)

2. Application of LCC in the contexts of a building's life cycle

Each building passes through several phases during its life cycle. Four basic phases of a life cycle may be defined:

- Pre-investment phase (preconstruction),
- Investment phase (construction),
- Operation phase,
- End-of-life phase (liquidation, conversion, modernization, etc.).

Opportunity studies, Pre-feasibility studies, Feasibility studies, and Urbanistic/Architectural studies are developed in the course of the *pre-investment phase.* Market analyses and cost-benefit analyses are completed. It is recommended to include preliminary calculations and LCC analyses as well as Life Cycle Analysis (LCA) and Risk Analysis during this phase.

The *investment phase* consists of preparation and execution of the investment plan (construction). This phase includes the design phase (planning and design) and the construction phase (preliminaries, construction and commissioning). It is advisable to include the calculation and analysis of the life cycle costs in this phase based on the planning documentation, and updates as more detail documents are developed. Included in update are documents for building permission, and also Life Cycle Analysis (LCA) and Risk Analysis. Project documents should be developed specifically based on owner's requirements up to the LCC level, i.e. not only construction costs should be reviewed, but all those costs generated in course of the operation of buildings. Operation costs (costs of heating and cooling, lighting, cold and hot water supply, sanitation, etc. in buildings), maintenance and renovation costs will establish information for the facility operator. The LCC analysis can be applied when selecting design alternatives, selecting alternative structures (e.g. building envelope, roofing, windows) and selecting services and technologies (e.g. heat sources and heating systems, air-conditioning, security systems, and similar). Contractors have nowadays been motivated to provide the lowest prices possible irrespective of future costs of use. The long-term economic effectiveness should be more emphasized in order to reduce future maintenance and other costs. Those structures, whose failure results in abnormal recovery costs, must be subjected to a detail analysis. Possible design variations must be assessed in terms of their effect on the future LCC. Any such variation of material, different structural design or different technical equipment must be subjected to LCC calculation. If a design variation should worsen building parameters in this respect it should not be permitted.

Maintenance management plays an important role in the *operation phase* in terms of overall LCC. The criterion for replacement of a structure or equipment is the comparison of increasing operation costs and replacement costs versas related lower operating costs. In this phase it is appropriate to update the calculation of LCC and compare the actual values (i.e. spent costs of power, water, services, cleaning, and similar) with those planned costs. Possible differences may be used for the facility management, but they may also be used as a feedback for similar construction projects.

3. Life Cycle Costing

As discussed, LCC are overall costs spent during the whole life cycle. These are the costs spent during all four life cycle phases. The greatest benefits from LCC are obtained when they are analysed in the pre-investment phase. The potential for affecting the overall LCC is at its peakduring the pre-investment stage.

Table 1. The Structure of Life Cycle Cost in Czech Republic

Life Cycle Cost of Building (LCC)	
Investment (acquisition) costs	**Operation Costs**
• Design and other fees	• Power supply costs
• Construction costs	• Water and wastewater costs
• Cost of operation units	• Waste disposal costs
• Land	• Service fees, insurance
• Secondary costs related to locating the building	• Security costs
• Other costs	• Cleaning and maintenance costs, costs of maintenance of green
• Costs related to machines, equipment, inventory	• Administrative fees
• Other investment costs	**End of Life Cost**
• Running costs for preliminaries and construction	• Liquidation costs
Maintenance costs	• Cost of recovery of rubble
Renovation costs	• Landscaping costs

In most buildings, operation costs take up the greatest share of LCC. This is because these costs relate to the longest phase of the life cycle – use period. Aside from operation costs, a great part of LCC is maintenance and renovation costs. They make up the costs that must be spent to maintain a building in operable condition and prevent and/or remove defects and equipment malfunctions occurring during the life cycle. Each structural element and piece of equipment has a certain expected life span. After that life span has expirated, these elements loose their technical capacity, reliability and quality due to natural ageing and use. It also takes money to maintain and renovate them continuously. Depending on the type of a structural element and piece of equipment, costs may have to be spent just once or in cycles. Regular maintenance of a building is very important and should not be neglected. Costs that have to be spent on eliminating various emergencies caused by neglected maintenance are usually much higher than costs of regular maintenance.

Life Cycle Costing Methods uses costs spent at present and those to be spent in the future. To secure these values as comparable, the time value of money must be considered in calculations. Calculation of LCC works with prognoses of life cycles lengths, future costs, and the discount and inflation rates. When there are not available good data, "treating" this information and data is the key factor for successful implementation of life cycle costing. The most suitable and most commonly used approach to assessing LCC of buildings is (TG4, 2003) the Net Present Value (NVP) and the Equivalent Annual Cost (EAC). The latter approach is beneficial in the case of alternatives with variable life spans. The stochastic LCC calculations must be complemented by a sensibility analysis. Sensitivity of the NPV or EAC of the alternative's life cycle throughout the analysed time, discount rate, and similar is researched. The goal is finding a break-even point defined as the entry parameter value causing the cheapest alternative's LCC to become equal to the second cheapest one (Kishk, Al-Hajj, Pollock, Aouad, Bakis, Sun, 2003).

Data necessary for calculation and analysis of LCC may be classified in three groups:

- data for conversion of costs spent in course of the life cycle to the present value, the so-called discount rate, inflation rate, length of the analysed period,
- data on costs, i.e. costs within the defined structure, life cycle phases,
- other data, i.e. the quality of the building and structures, intensity and method of use, and technical parameters.

In the case of a LCC analysis, the life span of the building and/or its structures and equipment is distinguished from the length of the analysed period. Buildings are specific because of their long technical life exceeding the economic life. Most sources agree that for analysing LCC for buildings, considering a long period is not appropriate. Sources (Flanagan, Kendell, Norman, Robinson, 1987, Ashworth, 1996) agree on the length of the analysed time as a maximum 25 – 30 years.

4. Implementation of LCC in decision making

The LCC calculation should be use as a tool for effective selection from project alternatives in every phase of the project's life cycle. The potential of its effective use is in the design phase. The possibility to affect the LCC decreases with the project development from 100 per cent to approximately 20 per cent in the construction phase. Only a very small chance to affect operation costs exists at the moment construction commences. Literature refers that 80 to 90 per cent of operation, maintenance and renovation costs are determined just by the design. Implementing the LCC criterion in the decision making during the design will allow a more effective selection among competitive alternatives (design, detail, structure, equipment).

The value of the LCC criterion is set up based on LCC calculation. Depending on where in the construction phase, LCC may be a preliminary calculation or a detail calculation of LCC in the later investment phase (design phase). The detail LCC calculation is based on more specific project documents and data. Parallel with the detail LCC calculation of the building as a whole are conducted detail calculations regarding structures, equipment, materials, and other crucial items in terms of costs. For the decision-making process – see also Table 2.

Table 2. Decision-making process based on LCC criterion

1	Defining the purpose and scope of decision making
2	Defining of the range and key parameters for LCC calculation
3	Summarizing data to the evaluated alternatives
4	Economic evaluation of alternatives
5	Selection of the optimum alternative based on the LCC criterion

Total LCC are calculated in the frame of the economic evaluation. For example either as the Net Present Value or the Equivalent Annual Cost. Also LCC may be calculated using the internal yield rate or recovery rate. The obtained costs may be presented as: LCC (at present prices of NPV), LCC per 1m^2 usable floor area, per 1 functional unit (m^2 of offices, 1 student), Building's annual equivalent LCC or LCC for key structures and equipment, i.e. EUR/year, LCC per 1m^2 of usable floor area per year (EUR/m^2.year), Cost per a functional element, component, or system.

5. Case study

The example project is the design of the Central Depository of the Museum of Decorative Arts in Prague (MDA). This is a building with two underground and three aboveground stories, compact in shape, with a circular footprint of a regular equilateral polygon with 120 sides. The loadbearing structure is a reinforced concrete cast in-situ frame combined with reinforced concrete walls. The built-up volume is 60,000 m^3; the built-up area is 2,800 m^2. It is a project with public funding. The Table below shows the decision making process based on the LCC criterion.

Table 3. Decision making process - the Museum of Decorative Arts in Prague

Step		Contents
1	Determining the decision making goal	Support/refusal to build the Central Depository of the UPM according to the low-energy standard (Alternative 2), comparison with the current condition (Alternative 1)
2	Defining the range and key parameters of the LCC parameters	Project phase: before starting designing the documentation for building permission, i.e. preliminary calculation of LCC
		Relevant costs: Construction costs – buildings, project and engineering support services, surveys, land Operating costs – power, water and sewerage fees, cleaning, facility management and administration, insurance
		Discount rate: 3% (alt. 0% and 6%)
		Analysed period: 30 years (alt. 50)
		Low-energy standard: walls = 0.13 W/m^2K, roof = 0.11 W/m^2K, floor and outer basement wall = 0.2 W/m^2K Cooling of the Central Depository with (de)humidifation to year-round 50 % ± 5 %
3	Summarizing the data referring to the evaluated alternatives	Alternative 1 (current): in-house data, accounting (operator) Alternative 2: expert estimates (designer, technical institution)
4	Economic evaluation of alternatives	Calculation of LCC (NPV) Risk assessment, precariousnesses, Sensitivity analysis (effect of a change of a discount rate, length of time)
5	Selection of the optimum alternative based on the LCC criterion	Comparison of LCC for Alternative 1 and 2 Comparison of running costs for Alternative 1 and 2 Recommendation to build a low-energy building

Table 4 presents the review of LCC calculation for the design of the Central Depository of the UPM (Schneiderova Heralova, 2013).

Table 4. LCC of Alternative 2 (new build for the Museum of Decorative Arts in Prague)

Project Title: Central Depository of UPM **Perios of Analysis:** 30 years		**Discount rate:** 3% **Basis of Cost:** 2012		
Cost Category	**Total (EUR)**	**Unit cost (EUR/m^2)**	**Net present value (NPV)**	
			Total (EUR)	**Unit cost (EUR/m^2)**
Building	13 461 538	1 303	13 461 538	1 303
Design and other fees	523 077	51	523 077	51
Land	1 153 846	112	1 153 846	112
Construction costs and land - total	15 138 462	1 465	15 138 462	1 465
Maintenance costs	6 014 865	582	3 906 140	378
Operation costs	4 913 538	476	3 210 251	311
Disposal costs (excluded)	0	0	0	0
Total Life Cycle Cost	**26 066 865**	**2 523**	**22 254 852**	**2 154**

Construction and operating costs are estimated based on the developed documents used for planning permission. Land related cost is the purchase price; the price of the project documents and engineering support services are the result of a public request for proposal; the price of surveys is taken over from the books. Buildpass (Macek, 2010) software was used to estimate the costs of renovation (set up using the ratio model for a comparable public amenity). Aside from the total LCC for a building the cost per 1 square meter of usable area is also presented. The liquidation costs are not subject of this analysis. The impact on the LCC of discount rates and period of analysis was tested.

The decision to carry out the investment, the Central Depository of the Museum of Decorative Arts in Prague is supported as correct. Running costs related to 1 m^2 of usable area are substantially lower in the case of the Central Depository compared with the reference alternative; they establish only 25 % of running costs of the Alternative 1 (current state).

6. Summary and Conclusion

Decision making based on the LCC criterion brings benefits to the owner. Making decisions based on the LCC criterion represents a completely new economic view of construction projects in the design phase. Assessing of buildings (investment projects) in terms of life cycle costs is one good possibility to meet criteria 3E, i.e. their economy, effectiveness, and efficiency. This is important for projects financed from public funds that must clearly demonstrate financial effectiveness. The LCC analysis was used for a public building, the Central Depository of the Museum of Decorative Arts in Prague. Based on data obtained from the engineering office and the project documents for planning permission, a preliminary calculation was conducted for the purpose of strategic decision making. This analysis concluded that the decision to build the Central Depository in the proposed low energy standard was the best.

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Study on the cost structure of the highway projects in the Czech Republic

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Abstract

Despite the general price decrease of construction projects the price of highway projects has tended to rise. Research has shown that building highways in the Czech Republic costs about 30% more than comparable projects abroad, for example in Germany and Austria. This paper will identify possible causes within the process of construction of highways. The paper will also identify the possibilities of cost optimisation for the construction process.

The total cost of highways consist of the construction cost (hard cost), the development cost (e.g. design fees, management fees), and the site cost (e.g. purchase of the land). This paper will present an analysis of the total costs of selected sections of the highways recently built in the Czech Republic. The elements that influence the total costs are design parameters of the road (category) and the topography. The output of this analysis is the average cost per one kilometre of a highway divided by the category of the road and the topography characteristics (urban/rural area, flat, hilly or mountainous area). The paper also analyses the additional costs associated with the overall project, especially the cost of the development of the project documents and the purchase of the land. These additional costs can significantly increase the total cost of a traffic project.

The authors summarize the causes of the high costs and at the same time proposes methods to reduce these costs. The public sector may use the results to identify ineffectiveness of construction processes in the area of traffic projects in the Czech Republic. The proposed optimisation procedures should lead to cost reductions.

Keywords: construction costs, cost optimization, cost reduction, motorways, traffic project.

1. Introduction

The issue of cost of highway projects has many studies, especially at the national level (e.g. Berechman, 2011, Link, 2014, Lambropoulos, 2013). There are also several studies in the Czech Republic (e.g. Stepanek, 2012, Nyvlt, 2011, Horak, 2007) that relate specifically with the efficiency of the construction and maintenance of the highway project within the life cycle.

Many departments of transportation have recently started to utilize innovative contracting methods that provide new incentives for improving construction quality. These emerging contracts place an increasing pressure on decision makers in the construction industry to search for an optimal resource utilization plan that minimizes construction cost and time while maximizing its quality (Rayes, Kandil, 2005).

The professional and lay public have been recently ever more often asking questions regarding the quality of construction of the transport infrastructure, its planning, and the total costs related to construction of highway infrastructure in the Czech Republic. Stories are often published in media about building Czech highways is much more expensive than constructing comparable roads abroad. The findings from many conducted studies is that the state administration does not spend taxpayer money economically. These studies have also found that the state projects are uneconomically and ineffectively designed. Thus the end result, the public does not get the added value from the state and must use poor and unsafe transport infrastructure. Lately it has been impossible to find some completed highway section in the Czech Republic where the cost had not been increased in the course of construction. The influence of various lobbying groups can be felt during preparation and realization of highways. Often suspicion of corruption is there. Effective quality and cost control is missing, and public contracts are not sufficiently transparent. Because of these results, the public considers the transport

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infrastructure as a black hole in the state budget. This paper will identify possible causes of inefficiency within the process of construction of highways and identifying the possibilities of cost reduction.

Few highway agencies use performance measures for cost estimating. The study (Harper 2014) synthesizes, categorizes, and validates existing performance measures for cost estimating of highway projects to assist with improving estimating accuracy.

2. Cost structure of highway projects

Highway construction costs include a wide range of items. These costs are project design, engineering support services and surveying, costs of transport infrastructure, secondary costs related to siting of the project, running costs of preliminaries and construction, and similar other costs. The highest share from the total budget of a highway naturally is construction, i.e. the cost of each element of the infrastructure (roads, bridges, flyovers, town bypasses, etc.). Also purchasing of the land is another large portion of the total budget of the transport infrastructure in the Czech Republic.

The primary elements in a highway project is cost estimate can be broken down into the following groups:

- Preliminary engineering (PE).
- Right-of-way and utilities (ROW).
- Construction costs (C).

Preliminary engineering is the development of a project beginning will planning to designing of the complete project. The right of way is defined as the purchase of land from a landowner. This land provides the available space row needed to build and construct a road project. Construction costs are the expenses incurred during the construction process from project bidding to purchasing materials and completing the construction work on the project. These expenses are functions of project and roadway design (width, number of lanes, location).

Analysis of the total costs of selected sections of highways recently built in the Czech Republic has been completed. Seventy-four projects were analysed with total costs of 7.8 billion euro. A more detail analysis was conducted on 29 projects with total costs of 3.0 billion euro. The average total cost of 1 km of a multiple lane highway was EUR 15.1 million; the average total cost of 1 km of a single lane motorway is EUR 13.7 million. The study also analysed additional costs associated with the project, in particular the cost of the development of project documents and the purchase of the land. These additional costs can significantly increase the total cost of a highway project.

The structure of total costs is presented in Fig. 1. The left picture shows the structure of multiple lane highway costs, the right one refers to single lane roads.

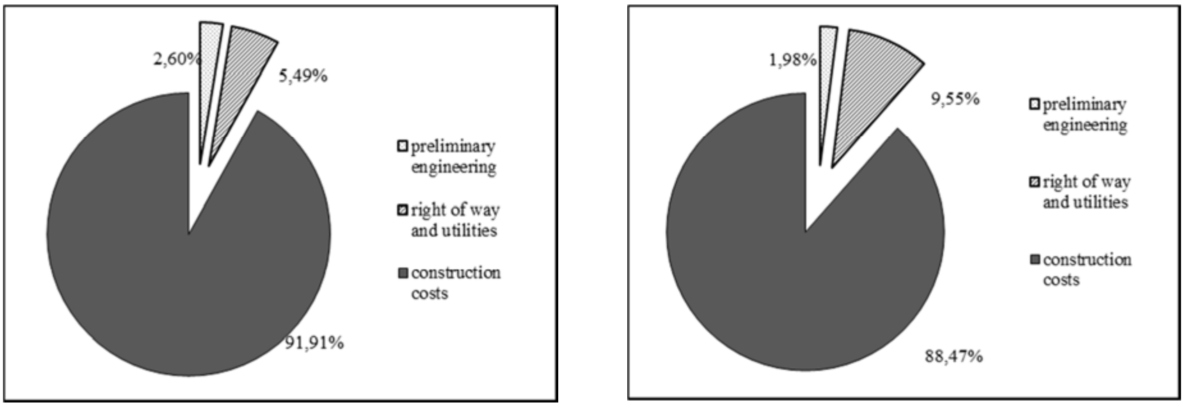

Figure 1. Cost structure of multiple lane highways (D) and single lane roads (R)

Table 1. Cost structure of highways (average).

Highway category	Group of costs (mil. EUR/km)		
	preliminary engineering	right of way and utilities	construction costs
D 26,5 - 27,5 m	0,38	0,80	13,39
R 22,5 - 27,5 m	0,26	1,24	11,52

The element that influences the total costs is the most the design parameters of the road (category), and the topography. The result of the analysis is the average cost per one kilometre of a motorway and expressway divided by the category of the road and the topography characteristics (urban/rural area, flat, hilly or mountainous area).

Table 2. Unit price of construction objects, flat area.

Highway category	Unit price of construction objects - average (mil. EUR)
D 33,5	7,13
D 27,5	5,12
D 26,5	6,33
R 27,5	5,03
R 25,5	3,91
R 24,5	3,90
R 22,5	3,94

The assumed construction costs increased by 68% during the planning decision procedures and by 37% during the building decision procedures. The reason for this increase is the designing of unjustified infrastructure, ineffective technical solutions, and accepting requirements involved in planning and building decision procedures (often unreasonable requirements on environmental protection).

3. Causes of high costs

3.1. Insufficient planning of purchase of land and construction

We have been witnessing the two responsible bodies (first of all the Road and Motorway Directorate of the Czech Republic/RSD and the Ministry of Transport of the Czech Republic) for this work having no long-term concept of planning preliminaries and construction of the highway infrastructure. There does not exist priority road projects which have been authorized for construction as soon as possible. A clear linkage between planning the road infrastructure and real public funds is missing. The present criterion for approving construction of individual traffic projects is the status of the design and possibility of financing from EU funds. This approach cannot lead to reaching a high effectiveness of the construction of traffic projects in the Czech Republic. Integral sections of continuous transport routes cannot be completed using this approach and the number of incomplete sections of roads has been increasing disproportionately.

Planning and constructing of the transport infrastructure in the Czech Republic does not currently build on an approved conceptual and strategic document (master plan) that would contain specific information on proposed dates and costs of each particular project. One document, the General Plan of Development of Transport infrastructure (GEPARDI) does contained this necessary strategic information. This strategic document does show a change in attitude of the public sector in the field of preliminaries and construction of the transport infrastructure. It was hoped that this document will help and effectively cover and manage the development of transport infrastructure in the Czech Republic.

The GEPARDI document defined specific priorities of traffic projects with their assumed date of completion 2020. Unfortunately, the Czech government did not approve this strategic development document in the end. The consequence of this decision has created this current poor state of the transport infrastructure. When the Road and Motorway Directorate of the Czech Republic/RSD and the Ministry of Transport of the Czech Republic have available work with only general strategic documents focusing on the basic targets and the visions, they are destined to produce unexpected result. When there are described problems preventing effective and economic planning and construction of the transport infrastructure, poor results will happen.

The path forward for effective and professional management of public funds in the field of transport infrastructure is defined by creating and using a medium- and long-term strategic plan. This plan should contain specific information on the planned priority transport infrastructure projects, and the sequence of priority projects in terms of the importance of their completion. Also each project needs to describe its importance on a national, regional and international level. It will specify the maintenance and renovation plan for the existing transport infrastructure in terms both financing and organisation. The plan should define clear rules for allocation of funds flowing into the transport sector and it should specify real and stable sources for financing for transport infrastructure. It could compare various alternatives of technical and economical solution of individual traffic projects including their assessment in terms of environmental impacts and other issues. In general, transparent and stable criteria for decision making and assessing should be established. The state administration should use this plan as a mandatory base for its day to day and future work.

3.2. Methods of financing

Larger highway projects are financed through the State Fund of Transport Infrastructure in the Czech Republic. This is a legal entity subordinate to the Ministry of Transport of the Czech Republic that uses the income for the benefit of construction, modernisation and maintenance of larger transport projects (roads, motorways, railways, and inland waterways). The Fund was established in 2000 in order to stabilize sources of financing to be spent on the transport infrastructure. Financial resources spent on the transport infrastructure must annually begin often maintain a stable level because preparation for traffic projects before construction take several years. The period beginning with developing a concept for a traffic project untill its commissioning usually takes 12 years in the Czech Republic. Unfortunately, due to the personal and organizational turbulences we have recently been witnessing within the relevant state administration bodies, we may expect further extending of this unacceptable long time. The structure of the income of the State Fund of Transport Infrastructure is shown on following Table 3.

Table 3.Income of the State Fund of Transport Infrastructure (SFDI) (in CZK Mio).

Income type	2014	Budget outlook 2015	Budget outlook 2016
Road Tax yields	5 200	5 300	5 300
Consumer Tax yields	7 500	7 200	7 200
Highway and motorway road fees	3 900	3 900	3 900
Toll yields	8 000	8 300	8 300
State Subsidies	18 400	12 300	12 300
SFDI Total Income	**43 000**	**37 000**	**37 000**

Source of data: The budget of the State Fund of Transport Infrastructure for 2014.

4. Methods of optimisation

4.1. Use of CBA at planning of preliminaries and construction

One of the tools that may effectively help the public sector at assessing traffic projects in terms of their meaningfulness, effectiveness, and selection of the most appropriate alternative of both technical and economical solution is the Cost-Benefit Analysis (CBA) (see Figure 1). This method allows us to answer the basic managerial question: “What, who, where will the gains and losses be on a built investment project?” The method allows the user to transfer the benefits and effects of an investment to specific cash flows (income and spending) based on the effectiveness of the investment. The effectiveness of the investment may be calculated by means of financial and decision making indexes (Net Present Value - NPV, Economic Rate of Return - ERR, Internal Rate of Return - IRR, Payback Period - PP, and similar indexes.). By evaluating the planned investment by the CBA method or using another managerial decision making tool, it may be shown that a traffic project that has approval may have a rate of return for three or more generations. Also these tools can project running future costs may be required for future frequent renovation and maintenance of structural elements. Not having this knowledge early can create burden to public budgets that will restrict the further local development of the transport infrastructure (Godinho, Dias, 2012).

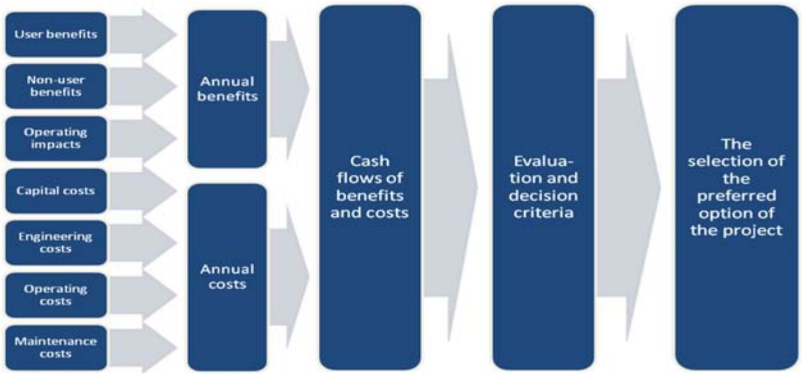

Figure 2. Cost-Benefit Analysis Framework

Source of data: Elaborated based on http://www.sehsr.org/reports/feasibility/chapter13.html, 2014.

The CBA method helps the owner decide whether an investment is acceptable and effective. If the financial and decision-making indicators for some traffic project come out positive, the basic condition for the CBA method is met. There is an assumption that the planned investment is more beneficial than detrimental to the owner. The owner must nevertheless also review whether the owner can finance the project and maintain it fully financially sustainable in a long-term perspective. Results of the CBA method are not sufficiently informative value. For instance, a project may be built that is highly valuable for the public but may generate substantial negative cash flows. To assess whether the planned financial burden is still acceptable for the owner further economic and managerial studies have to be performed. These studies are case studies, a feasibility studies, and a business plans. These studies provide further important data on the planned project helping to make the decision whether the project should be built or not.

Recommendations:

- Provision must be made for priority projects of the international, national and supra-regional significance when planning the traffic infrastructure development strategy. This strategy can be defined on the basis of the results of elaborated managerial-decision making studies (CBA, Feasibility study and similar). Change in the future demand of users which can be affected by fuel and toll prices must be also taken into consideration.
- Provisions must also be made for balancing the financial allocation to individual transport sectors (road transport, railway transport, water and air transport) and mutual connection of projects from different transport sectors.
- The need of investment in new traffic projects must be assessed in terms of the system as a whole with considerations for maintenance and renovation of the existing transport infrastructure that may need funding.
- All prepared investment projects must be mutually compared in order to determine the exact sequence of traffic projects in terms of their effectiveness, desirability and impact on the state budget and the environment. Alternative technical and economic solutions of these traffic projects (road vs. railway transport, various alternatives of directional, altitudinal and lateral design of roads, PPP projects, and others) must also be assessed.
- The public must be involved in each phase of the preparation of any traffic project. The public must have a chance to participate in the development of the concept of any traffic project. This approach will allow developing alternatives and other solutions from which the most appropriate ones can be selected. This approach will create the least negatively rising from the operation of a traffic project. Accepting this form of communication with the public will also allow positive approach for citizens to participate in preparation and construction of any particular traffic project. This allows the public to participate in the decision making processes.
- The process adopted for the development strategy of the transport infrastructure must be binding for all participating state bodies. These bodies must follow this strategy systematically and without an exemption. Only such projects that complying with this strategy should be approved for construction. It is not good policies to allow short-term political criteria to recommendations resulting from managerial-decision making studies.

4.2. Financing of traffic projects

Recommendations:

- Preparation of the budget for the State Fund of Transport Infrastructure for each following year must be open and transparent. The whole process of the state fund's budget preparation and approving should be available to the public on the Internet. This way the public can comment on the preparation of the state fund's budget.
- The development of the budget for the State Fund of Transport Infrastructure must be clearly linked to the approved and binding development strategy of the transport infrastructure in the Czech Republic.
- The State Fund of Transport Infrastructure must subject all planned traffic projects to an external professional due diligence, assessing them in terms of economy, desirability, the structure of financial resources, preparedness for construction, and environmental impact.
- Each prepared project must contain a realistic and detail budget which will include all negative externalities and investments. The project budget must contain all cost items reduced to the minimum.
- Mechanisms must be developed that allow feedback in the field of costs. The planned costs must be continuously compared with the real cost and in the case any deviation occurs, the sources that caused the change should be clearly identified. The mechanism must be capable of continuous updating of the internal construction price database.

5. Conclusion

According to the conceptual plans developed by the Ministry of Transport in the late 1990´s, the highway and motorway network would be completed today. Yet according to the current development it will take at least 32 more years and the money spent to achieve this goal will be over 19 billion EUR. The potential of possible savings in the process of construction of highways and motorways may be estimated in the range of 12 – 20 per cent of the total construction costs of these projects. To verify this estimate we compared the comparable construction costs for construction of one kilometre of a highway in the Czech Republic and Germany. This price was 13.0 Mio in the Czech Republic and 10.4 Mio in Germany; the difference being 25 % lower.

The paper summarizes the causes of the high costs and at the same time proposes methods to reduce the costs. The public sector should use the presented results to identify ineffectiveness of construction processes in the field of traffic projects in the Czech Republic. Implementing the proposed cost reduction procedures will lead to the cost reductions of these types of construction project in the future.

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A systematic approach for evaluating innovation management in construction companies

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Abstract

The increasing competition within the construction industry has created a growing concern for innovation, being appreciated as an important lever for competitive advantage. However, despite its need, there are some critical barriers that make innovation in construction very difficult. In addition, the perceived risk of innovation is almost unacceptable to the sector's culture. These factors limit the innovation efforts being made. Thus, appropriate mechanisms are needed to overcome these limitations and propose actions to promote innovation and innovation management in constructions' firms. The aim of this paper is to describe an approach to innovation management that includes a system for evaluating the status of innovation management in construction companies (SEGi by its acronym in Spanish), i.e., all activities undertaken by a company to integrate innovation opportunities to improve its performance. The system has been structured based on both quantitative and qualitative methods, whose application allows evaluating the state of innovation management and generating proposals for actions to solve the detected limitations.

Keywords: construction companies, evaluation, innovation, management, system.

1. Introduction

A society without innovative organizations limits its development and is condemned to retardation and poverty (Schumpeter, 1978), and its lacking is a characteristic of developing countries (Matos, 2007). The competitiveness of a country depends upon the ability of its industries to innovate and improve (Porter, 1991).

Although there is a consensus in other industries about the importance of innovation, the construction industry is reluctant to incorporate innovation and innovation management. This scenario then shows a shortage in the performance of innovation management as well as the need of counting with an evaluation system for this function in construction companies so that performance gaps and deficiencies can be identified, and companies supported for improvement. This paper proposes a system for the evaluation of innovation management (SEGi by its acronym in Spanish) of construction companies that was tested in three construction companies that were used as case studies. The next sections describe the research general background, methodology and main results.

2. General background

In the literature it is possible to find many definitions of innovation, but according to Seaden and Manseau (2001) in all of them there is certain trend and convergence: it is increasingly seen as a process that improves the competitive position of a company through the implementation of a wide spectrum of new ideas. Regarding innovation management, it is important to consider that the process of innovation cannot be separated of the strategic and competitive context of a company (Afuah, 2003) because it allows aligning the operation approach of the organization.

2.1. Innovation in construction

Within different industries, the construction industry is often considered behind of the others regarding innovation, showing the greatest inherent inability for innovation and a great difficulty in adopting innovations from other areas (Harty, 2008). Since Bowley (1960), the literature refers to two types of innovation in construction: 1) process innovations, and 2) product innovations. However, there is no consensus about the importance of each type for the construction industry, a fact that produces disunion in the innovation's strategy

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and resources (Lim and Ofori, 2007). Lately, the growing competence in the construction sector has promoted concerns about innovation as a lever for success.

In addition, it is known the fact that in the construction industry it is very difficult to innovate and its risk is considered almost not acceptable (Blázquez, 2005) for companies. Some studies show that in the construction industry, there is a lack of trust in front of ideas and proposals of change and innovation (Serpell, 2002). The majority of companies do not consider attractive to invest in research, development and innovation (R+D+i) because they have not understood it as a key factor for competitiveness (Correa et al, 2007). Even more, Ocaranza (2001) concludes that it is necessary to have an efficient and structured system to promote innovation in construction in Chile. One of the inputs for a system like this is the evaluation of the capability of construction organizations with regards to innovation management.

2.2. Maturity models

A maturity model provides a systematic framework to carry out the comparative evaluation and improvement of performance (Demir and Kocabas, 2010). These models lead the organization strategically and link it with continuous improvement alternatives, requiring a deep knowledge of the current position of the organization in a defined domain and the desired future position (Brookes and Clark, 2009).

A search for maturity models was carried out and two were found that resulted appropriated for the application under development. The first was the CMMI (Capability Maturity Model Integration) model largely appreciated due to its extensive adoption by different industries (Chrissis et al, 2009). Its purpose is to help organizations to improve their processes for development and maintenance and allows to approach this improvement using two different representations: continuous and by stage. The second was a maturity model related to risk management that resembles the kind of structure to be used for innovation management (Yeo and Ren, 2009).

3. Research Methodology

The research focused on how to evaluate the innovation management in a construction company and, starting from this evaluation, to propose better practices for improvement. Then the SEGi was the expected result of this research effort. To develop this system, the following activities were carried out:

1. Literature review.
2. Data gathering through questionnaires and focus groups.
3. Results analysis using descriptive statistics and qualitative analysis.
4. Pilot case study and case study of three companies that were used for the application of SEGi, and
5. Validation of results through case studies, statistical tools and intern consistency.

Then, the experimental model in this case corresponds to the development of an evaluation system in which the dependent variable is the innovation management capability and the independent variables are the innovation drivers (iD). A maturity model was then built using the innovation drivers and the maturity models found in the literature.

For the interaction with companies, two approaches were selected as indicated above: questionnaires and focus groups. Characteristics of participant companies are shown in table 1. The internal validation was carried out by showing the results of the questionnaire to a team formed by professionals and managers of each company (different from those that answered the questionnaire). They reviewed the obtained maturity levels for each innovation driver obtained by each company together with the description of each driver, so that they could indicate if the results corresponded to each company's reality in this topic. To analyze the data from questionnaires a regression analysis was carried out and used to study the relationship between the dependent variable (innovation management) and the independent variables (innovation drivers).

Table 1. Characteristics of participants in the research

Company	Size	Trades	Number of participants professionals	Number of focus groups
Company A	Large	Engineering and Construction	16	2
Company B	Medium	Real estate and Construction	14	2
Company C	Medium	Construction only	20	2

4. The innovation management evaluation system (SEGi)

SEGi contains three major components: 1) innovation drivers, 2) an innovation management maturity model, and 3) an application methodology with its instruments.

4.1. Innovation drivers

From a bibliographic review, more than 20 preliminary innovation drivers were identified. Later, with the support of the three construction companies shown in table 1, and through the application of a methodology based on focus groups, these preliminary innovation drivers were analyzed in depth and grouped into six major categories as shown in figure 1. These drivers are described below.

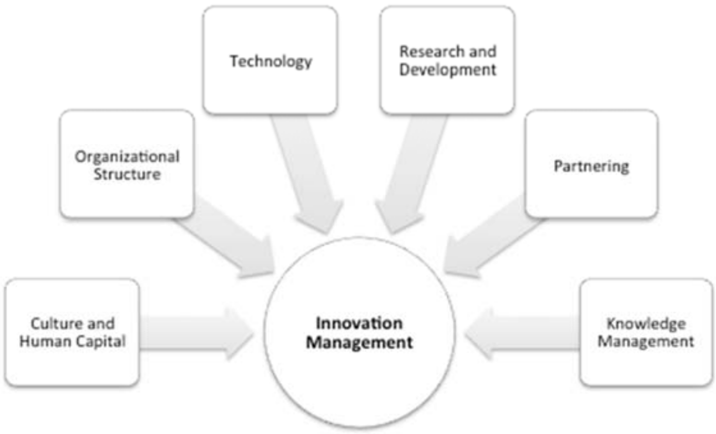

Figure 1. Innovation drivers model

The culture and human capital driver addresses the attitude of professionals and executives of the company in front of change, the workers' perception about the management commitment with innovation, the practice of training of professionals and executives, and the level of support to team work. The organizational structure driver centers on the way in which decisions are made inside the organization and the level of autonomy of decision-making. The technology driver focuses on the application of technology in the construction processes and methods, considering both, the kind of technology used as well as the frequency of application of it. The research and development driver addresses the ways and reason of the company for realizing innovation and development. The partnering driver refers to the alliances or association of a company with external companies, research centers and universities for innovation and development purposes. Finally, the knowledge management driver refers both to internal and external knowledge.

4.2. The innovation management maturity model (MGi)

The MGi considers five maturity levels that measure the condition of each of the six innovation drivers. Its architecture is based on the representation by stages of the CMMI, because it is a systematic and structured way of approaching to improvement. To achieve the description of each driver for each maturity level, a combination of innovation and risk models was used. An example of the maturity levels and their description is shown in table 2.

Table 2. Maturity levels of the MGi

Level	Name	Description
1	Basic	The innovation is ad-hoc, and it depends on individual efforts. There is a lack of knowledge about the need of innovation management and there is no attempt to recognize the benefits of innovation. There is no investment in training.
2	Accepted	Innovation management and its benefits are accepted. The research is carried out by necessity and is planned. Some training intents are realized. There is a recognition of the need of information management processes.
3	Conscious	There is consciousness of innovation at the organizational level and of the own knowledge. There is a definition of formal processes of innovation management and a beginning of its application. A more proactive behavior in front of changes is starting.
4	Systematical	Systematization and diffusion of innovation through the organization as a whole. Repetitive processes with continuity trends, and controlled and evaluated. Establishment of innovation management.
5	Optimized	Innovation management processes are optimized. Continuous learning and synergy in the organization. Innovation management integrated to the culture and way of life of the company.

4.3. The application methodology with its instruments

Two methods of data recollection were designed: 1) the application of a questionnaire (quantitative method) and the realization of a focus group (qualitative method). The questionnaire is used for measuring the maturity level of the innovation management capability. The latter is used for obtaining more depth in the scope of the analysis.

To apply the questionnaire and obtain the maturity level for each innovation driver and for the innovation management capability as a whole, a scale from 1 to 7 was defined. This scale has been divided into five segments, one for each maturity level with the relative weights for combining the assessment values as shown in table 3.

Table 3. Relative weights of the codification scale

Segments:	Level 1	Level 2	Level 3	Level 4	Level 5
Proportion	1	1	1	2/3	1/3
Relative weights	0.25	0.25	0.25	0.167	0.083

These weights were determined after the application of the pilot case in which, all the levels were assumed to have the same relative weight. Then, using the weights shown in table 3 and considering the scale from 1 to 7, in table 4 it is possible to see the segment limits of the codification scale, for each maturity level of the MGi.

Table 4. Relative weights of the codification scale

Segments:	Level 1	Level 2	Level 3	Level 4	Level 5
Lower limit	1	2.5	4	5.5	6.5
Upper limit	2.5	4	5.5	6.5	7

Then, the questionnaire allows the contextualization of the innovation drivers through situational descriptions of these for each maturity level, assuring that this instrument gets the data that is looked for.

To summarize what has been described in the last sections, figure 2 shows the general application process of the SEGi.

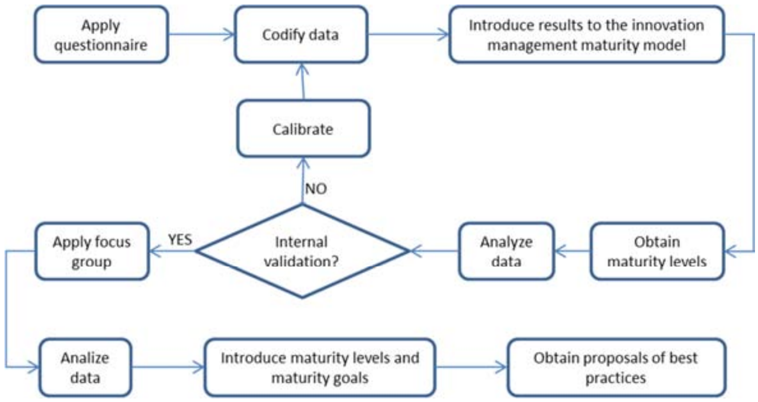

Figure 2. Application procedure for each case study

5. Research results

The SEGi was applied to three construction companies. Besides obtaining the maturity levels of each company, the research team obtained a set of interesting opinions about the system. First, the questionnaire was well accepted by the participants. They highlighted the reduced time required to fill out the instrument. Second, they indicated that when they did not recognize by its name a factor (innovation driver) to be evaluated, the situational description of the factor allowed them to recognize the factor within the company. Third, the description of the factors allowed them to appreciate different situations of a same variable, widening the understanding of each one and differentiating better the situation of the company. In addition to these opinions, they greatly approved the application of the focus group approach since it allowed a better comprehension of the meaning of the maturity level and, in this way, self-evaluate, accept and understand the gaps that existed for each innovation driver.

5.1. Maturity evaluation results

The results obtained by the companies are shown next. The table 5 shows the maturity level of each company for each innovation driver.

Table 5. Maturity level of each company for each innovation driver and for the company as a whole

Innovation drivers	Company A	Company B	Company C
Culture and human capital	3	3	3
Organizational structure	2	2	2
Knowledge management	2	2	2
Research and innovation	2	2	2
Technology	3	2	2
Partnering	2	2	2
Maturity level of the company	**2**	**2**	**2**

It can be seen that the maturity level of the three companies was very low and similar. Professionals and managers that participated in the internal validation of the results considered that the results of the evaluation reflected to a great measure the real situation of the companies regarding innovation management capability. Regarding the focus groups, the results obtained are:

1. The understanding of the shortcomings of the company allowed them to contextualize more clearly the innovations drivers inside the company and to establish cooperation and interdependency relationships between them.
2. They concluded that the major impact of innovation in a construction company is produced when the innovation add value to the final product of the company.
3. They concluded that the strongest barrier in front of innovation is the culture and human capital management practices.

6. Conclusions

A brief description of a systematic approach for evaluating innovation management capabilities in construction companies that has been developed as the result of a research undertaking has been presented in this paper. This methodology has been successfully applied in three construction companies by the way of a system for evaluating innovation management organizational competences.

It can be concluded that the application of SEGi in the cases studied was able to obtain satisfactory results regarding the evaluation of the innovation management capability of each company. Even more, all the R^2 coefficients obtained for each questionnaire are over 0.75, a number that is considered acceptable. If in the future, more cases are studied it will be possible to increase the reliability of the obtained evaluations and to adjust the different elements of the measurement methodology.

The participants of the study expressed their satisfaction with the quality of the results and the value of the tool. With the results obtained in the evaluation and with the added internal knowledge of the organization, a construction company can obtain a good understanding of the factors that affect its innovation management capability, identify the weakest issues, and to better focus the improvement efforts in this area.

The research in this area might consider new areas of study, like a system for monitoring and controlling the application of best practices using a framework like the Balanced Scorecard, an expert system that uses the evaluation system as a learning tool, and to study how to increase the effectiveness of the best practices proposed by the SEGi.

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Managing changing functions by design alliance A case study

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Abstract

Facility user processes are rarely constant. Instead, they change over time – especially in the healthcare sector. Paradoxically, current design management practices are based on the assumption that the functions in the facilities are predominantly fixed. This contradiction generates several risks for managing the building project. The aim of this this paper is to introduce a new model to manage risks related to functional changes from building owner perspective in design phase of a building project. The model integrates users in the building design process through an open building based and user-friendly design approach Design Alliance (DA). The DA is a design briefing, procurement, agreement and open building based design management method. The DA brings designers, owner and users together to collaborate, improve design flow, and find design solutions that fulfil the requirements of the brief. The research method is action research and the case project is a new 40 million euro healthcare centre located in the city of Järvenpää, Finland. The main conclusion of the case study is that building owner can manage the risks related to changing functions by DA approach in the design phase of the building project. In the case project the functional changes were intense during the three-year observation period due the organizational development of the user organization. In fact, the functions and processes changed extensively, which led to a 27% room program update. This study has important practical implications especially for building owners and building developers. The benefits of the DA seem promising as in the case project the functional changes were successfully managed in functional and conceptual design phases. The fundamental functional changes had no negative effect to the project budget, schedule, quality or cooperation between stakeholders. In addition, the users and the building owner stated that the co-working and user orientations in design process exceeded their expectations.

Keywords: alliance; briefing; flexibility; open building; risk management

1. Introduction

Current construction management practices are based on the assumption that functions that functions a user performs in the facilities are fixed (Saari et al. 2007). Traditional construction management process aims to create facilities for specific users, that are well-known in terms of identity and requirements. It is assumed that users are able to define all their requirements during the project briefing stage and approve the design solutions presented to them on print in the design phase.

The aim of this this paper is to introduce a new model to manage risks related to functional changes from building owner perspective. The research method is action research. Based on the literature review findings, the authors develop a new procurement method for design: Design Alliance (DA). Following that, the DA is piloted and further developed in a case project. The case project is a new 40 million euro healthcare centre located in the city of Järvenpää, Finland. Finally, the results of the case project are collected and analysed. This study focuses on the briefing and design phases of the construction project.

The paper structure consists of three sections. Firstly, relevant earlier research is reviewed. Secondly, the research approach is presented and the DA conceptualized. Final section provides results summary, with discussion and conclusion.

2. Aspects of the design management

2.1. Briefing and design management in traditional healthcare projects

In the architecture/Engineering/Construction (AEC) industry briefing is the stage of construction process in which owners define the requirements for their construction project (Ryd 2004) to lead the design process. According to a wide benchmark study by Popov (2010), the briefing process in the healthcare sector has typically four phases: planning and commencement, functional programming, space programming, and approval of the final document.

Clients, designers and academics present critics on current briefing practices and the brief content in the healthcare sector. Strategic thinking and user goals are often lacking from the project briefing. Moreover, the designers complain that the briefing documents are not useful in practice. In effect, the briefs are often too lengthy and containing too detailed specifications, that are not clear, consistent or complete. (Ryd 2004; Bogers et al. 2008; Elf et al. 2012). Clients, on the other hand, sometimes have the impression that the brief is poorly understood by architects, or even ignored (Bogers et al. 2008). In briefs the facilities are usually programmed for specific purposes using a fixed detailed room program. Such practices do not support user changes management in construction process (Saari et al. 2007). □Moreover, it is infrequent that briefs contain measurable targets (Elf & Malmqvist 2009).

After the briefing phase, the design of the building begins. First and foremost, the design phase seeks to find design solution to fulfil the requirements set in the brief. According to Koskela et al. (2002), the main challenges in the design process include poor flow of design process and the lack of interest to generate value for the facility users. Consequently, unnecessary rework is done. The main reason for this is poor ordering of the design tasks.

2.2. Open building

The DA utilizes open building method. The open building approach is based on the philosophies of Habraken (1962). He developed the concept where a building can be divided into a permanent base building (or "support") and modifiable spaces (or "infill"). Kendall (2005) has suggested that in healthcare the infill should be divided into secondary system (e.g. walls) and tertiary system (e.g. furniture) to manage complexity. The open building procedure has bee□ used mai□ly i□ reside□tial housi□g a□d i□ healthcare. (Saari et al. 2007; Pektas & Ö□güç 2011)

In particular, open building differs from the conventional way of construction management in terms of management of user requirements and ordering design tasks. In open building brief, the functional requirements are not described on a single space program that determines every room that should be implemented into the design. A single room program does not satisfy a wide range of needs and preferences as well as the future demands of the users. The open building approach also acknowledges that building design is a collaborative process, which involves many participants with diverse backgrounds. Thus, the management in ordering design tasks is of utmost importance to reduce complexities and to balance divergent interests of the related parties. Involving the users in the decision- maki□g process is a priority i□ ope□ buildi□g. (Tiuri & Hedma□ 1998; Saari et al. 2007; Pektas & Ö□güç 2011)

Saari et al. (2007) have developed a practical process to utilize open building principles in the project briefing stage. In the briefing stage, the buildings should be divided into two parts: a permanent base building and an infill. The requirements for infill contain flexible room program including the information of what types, how much, and what kind of interior environment of spaces the infill must offer to be implemented in the design and use phases. In effect, the main requirements for the base building include information on how the base building will enable the infill requirements.

2.3. Target cost method and collaborative project delivery

Target cost method can be utilized to manage costs in DA process. The main principle of target costing is to make cost and value drive the design process instead of calculating the cost after the design is complete. A target cost for the project is an outcome of the feasibility studies and is the target the design team is going to design to. Systemic application of target costing leads to significant improvement of project performance. The final costs of projects are on average 15% less than market cost (Zimina et al. 2012). Target costing has been utilized in Finland since the 1970's to generate project budget. It is widely in practical use. Kiiras et al. (2005), have successfully implemented target cost method into an open building design management.

Collaborative construction project arrangements are often needed to foster design flow. Recently project partnering, project alliancing and integrated project delivery have been presented to the market. These project delivery arrangements have several similar features such as early involvement of key parties, transparent financials, shared risk and reward, joint decision-making, and a collaborative multi-party agreement. The features incorporate in all the arrangements to a varying degree (Lahdenperä, 2012).

2.4. Findings of the literature review

Based on the literature review results, the authors develop a new procurement method for design: design alliance (DA). The design alliance is a design procurement, agreement and open building based design management method. The method aims to integrate designers, owner and users to collaborate, improve design flow, and to find a design solution, which fulfils the requirements set in the brief.

According to the reviewed studies, the building brief should be based on user's strategic vision and project's measurable goals for base building and infill. The brief should be concise and contain clear, consistent and complete information. In addition to the brief, more emphasis is needed on the ordering and managing design tasks to improve the flow of the design and user orientation. The open building approach, target cost method and collaborative project arrangements are potentially highly beneficial to address these questions.

3. Research design

The research is conducted as an action research. The research process utilizes Lewin's (1947) process of change and consist of unfreezing, change and refreeze phases. In the unfreezing phase, spring of 2013, the authors were recruited as project managers and advisors to a new healthcare centre project located in the city of Järvenpää, Finland. At this point the authors were aware of the issues related to construction design and procurement. This was because the same healthcare centre project had been terminated two years earlier due to problems related to design requirements and procurement. Based on the literature review findings and project planning activities, the authors investigated the DA as a potential solution to tackle the issues. In the change phase, the authors further developed the DA through expert group work and piloting it in the case project. The professional group was constructed from the academic and practical construction and healthcare experts in the areas of construction management, healthcare design, BIM management, and procurement law. In the summer of 2013 the DA was procured to execute the design work. Finally, in the refreezing phase the authors collected and analysed the results of the DA to manage risks related to functional changes in the conceptual design phase.

The research data collection process, description of the data, and utilization of the data is described in the Table 1.

Table 1. The research data

Data collection	Description of the data	Utilization of the data
1. Investment decision (1/2011)	The project brief and procurement materials for design and build competition in 2011 produced by the former project managers (621 pages)	Providing background information for DA brief
2. Investment decision (6/2013)	The results of feasibility studies, the risk analysis of the project, two drafts and final version of the DA brief, two drafts and final version of DA procurement materials, and DA audition materials produced by the project managers (548 pages)	Formulation of the DA
Designers' selection and procurement decision (9/2013)	Two drafts and final version of DA agreement and DA audition materials produced by the project managers and designers (252 pages)	Finalizing the DA
Design milestone 1 analyses (1/2014)	The designs related to functional solution and the analysis of the solution produced by the project managers, designers and users (135 pages)	Observing the effectiveness of the DA
Design milestone 2 analyses (3/2014	The design related to base building and type rooms and the analysis of the solution produced by the project managers, designers and users (155 pages)	Observing the effectiveness of the DA

The case project, a new healthcare centre, will offer the basic health and social services for 35 000 inhabitants of the city of Järvenpää, Finland.

This healthcare project offers an interesting case study platform to develop, test and evaluate how DA is able to manage the functional change. In effect, the functional change of the user i.e. the social and healthcare services of the city has been intense for years. To illustrate this change the room programs for the new healthcare centre were compared from January 2011 and from January 2014. The room programs were programmed to determine the rooms that the facility must have to support the functions that time.

Project's architects generated the first room program in January 2011. The main users' units were surgery, emergency duty, rehabilitation, social work, radiography, laboratory tests, and the ward for patients with acute illnesses. The functions in the units were mainly related single patient treatment, which needed consulting rooms for each staff member. The user functions required the floor area of 8000 sqm2.

Architects generated the second room program in January 2014. The main users' units were the same as in the room program generated in January 2011. The functions needed the same amount of total floor area (8000 sqm2). However, the room program was changed radically. In effect, the functions in several units were changed from single patient treatment to dynamic group work. The interaction requirements between the units were changed as the patient flow between the units was changed. The function changes were accelerated by a new healthcare process that focused on patient self-care and group treatment. As a result of the users functional changes during three years 27 % of the room program was updated. In other words, significant proportion of the facilities did not support the functions after a relatively short period of time.

4. Design alliance

Based on the literature review results, the authors developed the first version of a new procurement method for design, design alliance (DA). Following that, the DA was further developed by professional group work that utilized a risk management approach. The risk management approach consist of three phases: 1) identification of the risks related to design flow and value-in-use for the user, 2) planning of management actions, and 3) integration of management actions into the DA model. The risks related to design flow and decrease of value-in-use were identified. Here the flow refers to the perspective of the customer of the design work (building owner) and how the customer perceives the progress of design work. Moreover, the value-in-use refers to the fit between the facilities and user's functions. The identified risks and management actions related to design flow are presented in the Table 2. The identified risks and risk prevention actions related to value-in-use are collected in the Table 3.

Table 2. The identified risks and prevention actions related to design flow

Risk	Risk prevention actions for DA
The changes in user functions delays the design progress and increases costs	Integrate the users to the design process with flexible room program, set milestones for the design process, separate procurements of the infill and base building, and set target cost for infill and base building
The design solution does not fulfil the requirements of the brief	Divide the design work of design alliance into milestones i.e., functional solution (M1), conceptual solution (M2) construction permit designs (M3), and contracting offers (M4) and verify that the design solution alternations fulfil the requirements in each milestone with audits and financial incentives.
The users do not have enough motivation to participate in the design process	Users participate in the design alliance procurement process. Utilize 3D and 1:1 ratio to illustrate the design solutions and their operative impact to the users. Integrate the users only to the design tasks that they consider interesting with open building approach.

Table 3. The identified risks and prevention actions related to value-in-use

Risk	Risk prevention actions for DA
The user functions change after the design phase	Set measurable requirements for flexibility of the building in the project brief (e.g. service flexibility and modifiability) and test the flexibility of the design solution in virtual environment and in separate test sets.
The users cannot fully articulate the requirements they have to the designers	Utilize building information modelling (BIM) i.e., use virtual 3D modelling to illustrate the design solutions and simulation to illustrate the user processes in the facilities Build test facilities i.e., build concept rooms where users can test real functions and improve the design solution and procure the infill construction work so that the users are able to test the fit between facilities and functions before the final acceptance of the construction work.

The DA is responsible of all design and design management work in the project. The parties of the DA agreement are designers, user and owner. The contractor is not involved in the early phases of DA as only the parties that have the greatest influence on project success in early phase are involved. However, the contractor may be involved in later phases.

The main features of the DA design management process are open building approach, virtual and physical occupancy and target cost method. The design work and decision making is divided into different design packages according the open building principles. Therefore, the users and designers are able to test whether the design solution fulfils the functional requirements by virtual 3D occupancy, 1:1 modeling and physical testing.

In the design phase, the design solution is analysed by internal and external auditors in four milestones i.e., functional solution (M1), conceptual solution (M2) construction permit designs (M3), and building contracting offers (M4). Financial incentives are an important part of the DA concept. In effect, strong financial incentives are used as approximately 40 % of the compensation of the designers are based on reaching targets in each milestone. Moreover, the designers and building owner share the positive and negative risks of the project. In the DA compensation model the designer gets 20 % sanction or 20 % bonus according to the evaluation in each milestone.

The following key factors are analysed in each milestone:

- Quality: Does the design solution fail to meet, meet or exceed the functional, quality and flexibility requirements set on the infill and base building in the brief?
- Costs: Is the design solution in line with the investment and maintenance budget set on the brief?
- Time: Have designers generated alternative solutions for design problems and are all designs produced on time and in good quality?
- Collaboration: Are users and owners satisfied with the collaboration and integration between designers, user and owner?

To gain bonuses all key factors must satisfy minimum requirements of the brief. If some of the factors do not satisfy the minimum requirements, the designers face sanctions. Moreover, it is extremely important to carefully design the user collaboration process as the collaboration evaluation is one of the key factors: if users are not satisfied to the participation in the designing the facilities, the designers will have sanctions. In the final milestone, the target building cost is compared to the actual building costs i.e., contracting price. If the building contracting prices exceed the budget, the designers receive sanctions instead of a bonus.

5. Results from managing changing user functions with DA

The performance of the DA approach is evaluated through a milestone analysis of two milestones that are completed i.e., functional solution (M1) and conceptual solution (M2). The evaluation was made by an evaluation group that contained experts from the area of cost management, BIM and open building. The main information sources for the evaluation were designs, BIM models, satisfaction survey for users and building owner and benchmark cost data. The results of the milestone analysis are presented in Table 4. The key factors are quality, cost, time and collaboration. Summary of milestone success is evaluated in three categories, which are comprehensive success (full or nearly full bonuses), Good, Normal (no bonuses / sanctions), Failure, and Comprehensive failure (full or nearly full sanctions).

Table 4. Results of the M1 and M2

Key factor	**M1: functional solution**	**M2: conceptual solution**
Quality	The design solution exceeded functional, quality and flexibility requirements.	The first version was not accepted due to conflicting design documents. However, after the audit and development period of three weeks, the design solution achieved functional, quality and flexibility requirements.
Costs	The design solution is within the investment and maintenance budget	The developed design solution is within the investment and maintenance budget
Time	Alternative solutions (9) have been generated and all designs have been made in time and were of good quality	Alternative solutions (3) have been generated and the developed designs were made in time and were of good quality
Collaboration	User and owner are very satisfied with the collaboration	User and owner are extremely satisfied with the collaboration
In summary	**Excellent performance relative to targets**	**Good performance relative to targets**

According to the evaluation results, the DA has succeeded in the conceptual design phase. The DA approach is potentially highly beneficial for the building owner in projects where functions change. The DA was able to manage design risks related to functional changes as the design solution fulfilled the requirements and targets set in the brief. Moreover, the users and building owner stated that the co-working and user orientations in design process exceeded their expectations. The main reasons for the good satisfaction were the integration of user to design tasks of their interest, utilizing 1:1 and 3D visualization of design solutions and service oriented design process.

6. Discussion and conclusion

The functions of the facility user changes over time – especially in the healthcare sector. Current construction management practises in general are based on the assumption that functions are mainly fixed. According to earlier literature, new briefing practices and design management tools are needed to improve the value of facilities and managing the change. For example, target cost method and collaborative project arrangements have been discussed in the academia and applied in practise to address these issues.

The aim of this this paper is to introduce a new model to manage risks related to functional changes from building owner perspective. This case study increases the understanding on how to integrate users in the building design process through an open building and user-friendly design approach Design Alliance (DA). The main result of the study is that building owner can manage the risks related to changing functions by DA approach in the design phase of the building project. The benefits of the DA are promising. In the case project the functional changes were successfully managed in conceptual design phase. The major functional changes did not negatively affect the project budget, schedule, quality or co-operation between parties. Moreover, the users stated that the co-working and user orientations in design process exceeded their expectations. The main reasons for the excellent satisfaction levels were the integration of user to design tasks of their interest, utilizing 1:1 and 3D visualization of design solutions and service oriented design process. Furthermore, according to the auditions made in the milestones, the design process utilized successfully open building approach. The designers were motivated to take these actions and reach targets with financial incentives (bonuses and sanctions).

The ability of the DA to manage the functional change within the project targets is very valuable for building owners. For example in hospital projects in Finland, it is common that the functional change usually increases the scope of the project. While the room program is fixed in the brief phase, the functional change is managed by adding more rooms into the program and increasing the project cost budget.

In the future it would be pivotal to study the progress of the case study and further analyse the implications of the DA. Moreover, it is important to evaluate how the targets of the flexible room program are enabled to manage the functional change in the use of the building.

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On the definition and assessment of organizational health

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Abstract

The organizational status, in terms of competitiveness, employee morale, and efficiency of internal processes is a primary issue of concern for top management. Determining this status has been an issue of extensive study in various contexts, such as organizational performance, organizational behavior and culture, and, recently, organizational resilience. The research question is whether these contexts are significantly different or, in fact, they describe the same property of an organization, i.e. its inherent ability to perform and react efficiently in a dynamic business environment. A consequent question is whether this organizational property could be uniquely contextualized and used for organizational monitoring and decision-making. This paper's first aim is to define the new term of organizational health, which integrates existing concepts and largely expands the content of the term, as it is currently used in the literature. A second goal is to suggest an assessment method for organizational health that will be able to provide a metric of an organization's capacity to perform and adopt to a dynamic internal and external environment. Literature review is used to: a) identify the great number of parameters involved in the analysis, and b) integrate the various contexts where these parameters are met into the single context of organizational health. Once the definition of the new concept is provided, the appropriate theoretical background of the assessment method is investigated; this method should encompass all critical dimensions and provide a quantitative measure to indicate the specific organizational improvements required per case. The theory of entropy is selected in this context and its appropriateness is presented and justified. Overall, the research proposes a new, innovative and holistic framework for evaluating an organization's status and constitutes the first step of building a new theory with an anticipated significant effect to the organizational management body of knowledge.

Keywords**:** assessment; entropy theory; organizational health; organizational performance; organizational resilience

1. Introduction

The ability of an organization to perform efficiently is a fundamental issue irrespectively of its field of activity. Especially, for-profit organizations, such as construction industry organizations, need to ensure organizational efficiency at, considerably, high levels, in order to succeed in a very competitive environment. This is the reason why extensive research has been conducted on the issue of organizational efficiency. However, the literature presents considerable differentiations in the terminology, content and, most important, assessment methods of this organizational feature (Yukl and Lepsinger 2005, Aubry et al. 2007, Hyvönen 2007, Yukl 2008, Gregory et al. 2009, Zheng et al. 2010, etc.), thus leading to a fragmentation of approaches that prevents from deciding on a single measure for its assessment. In this paper, the term organizational health is introduced to integrate the various terms used so far to describe organizational robustness. Firstly, the term is conceptually described and literally defined to become distinct from other term's uses, which are met in some literature sources. Then, the theoretical background of the entropy theory is suggested for the measurement of organizational health.

This theory-building work emanates from the need to provide to the construction industry organizations a framework to assess, evaluate, and take action with regard to those organizational components, which are linked to its robustness, to ensure: a) proper function, b) quick response to internal or external loads (i.e., conditions that put in stress the organization), and c) success in achieving the required performance levels. The approach is creative, since it integrates concepts from several disciplines such as life sciences, physics, and systems sciences to produce a conclusive framework for application in management theory. The remainder of this paper introduces the conceptual framework of organizational health, which is still elaborated through ongoing research.

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2. Terms and concepts used for organizations appraisal

The Cambridge University Dictionary (2014) defines Organizational Capability (OC) as "*the ability of an organization to use resources, material or non-material, with an effective way, in order to achieve its goals*". Similar terms have been introduced in several research efforts with more or less significant differentiations from OC. For example, Chalker-Scott and Tinnemore (2009) present partially the features of Organizational Sustainability for an educational organization; Wicker and Breuer (2014) review the definition of Organizational Capacity, while Sobeck and Agius (2007) provide their literature review results on the same concept. Among the various terms, Organizational Performance (OP) and, lately, Organizational Resilience (OR) seem to be the most appealing and the most competing in the research community with regard to organizations appraisal, mainly, because their contexts introduce sets of quantitative indicators that measure the respective organizational features (i.e., performance and resilience).

Organizational Performance is a very common concept for an organization's appraisal. Compared to other concepts it is considered as more inclusive, since it reflects to various organizational components such as economy, human resources management, strategy, processes, etc. A broad literature analyzes the relations of these components to OP (Choi, et al. 2008, Turner et al. 2008, Tseng and Lee 2009, Katou and Budwar 2010, and Holsapple and Wu 2011). OP inherently includes various organizational components that address different organizational aspects and that has resulted to a huge number of proposed items to include in the OP context. As almost everything seems to reflect to performance, it becomes difficult to determine a single metric that would successfully integrate the number and nature of those contributing factors; therefore current OP measures are either partial or highly subjective in their estimation.

Organizational Resilience (OR) is another concept that recently has gained ground for organizations appraisal. OR is used to describe the ability of an organization to recover rapidly after crisis incidents or sudden environmental changes; therefore, it may be considered as a direct or indirect measure of organizational robustness. Riolli and Savicki (2003), Braes and Brooks (2010), Lengnick-Hall et al., (2011), Aleksić et al., (2013), Mamouni Limnios et al. (2014) provide, among others, an insight into OR components. The difference of OR to other conceptual approaches is that it can provide a measurement of an organization's reserves against unanticipated stress loads; therefore it provides a metric, which shows the potential for performance rather than performance itself. This is critical given that performance is measured *a posteriori*, i.e. based on what is done, while resilience can be measured *a priori*, i.e. showing what can be done.

Based on the review of the abovementioned research studies, it is evident that a great variety of concepts, approaches and methods exists for appraising organizations. Consequently, there is a variety of available measures and indicators that provide valuable input for the appraiser of an organization, who combines the available data and concludes about its status. The replacement of the various metrics with a single one that would represent directly the potential of an organization to succeed would constitute an important contribution both at the academic as well as the practical level. The new concept of organizational health, which aims to provide the basis for this development is presented in the remainder of this paper.

3. Definition of organizational health

Organizational Health (OH) is a term that currently exists in the literature to describe aspects of the working environment related to the employees' health. Miller et al., (1999) used OH to describe occupational stress, while Cotton and Hart (2003) interpreted OH more generally as the wellbeing of the employee in the working environment. While in academic literature there is no connection between OH and the management field, in the industry such a connection has been stated by Lencioni 2012, who defined OH as the state of convergence between management, operations, strategy and culture in an organization. In this paper Organizational Health is defined as the state of complete and unimpeded operation of all formal, informal, main and auxiliary organizational processes. This definition is actually an adjustment to organizational entities of the definition of health that the World Health Organization uses for humans, which states that "*health is the state of complete physical, mental and social wellbeing and not only the absence of a disease or a disability*" (World Health Organization 1948).

The reason for adopting a term from the field of life sciences to define as much of the organization's essence as possible is, simply, because the fundamental property of any organizational entity is being a living organism. This simple – yet absolutely accurate – idea allows the definition – for the first time – of a measure that captures, conceptually, the full state of an organization, i.e. its operational performance as well as its capacity (potential) to operate in anticipated or unexpected conditions. In other words, OH integrates the existing concepts of OC, OP and OR, thus providing a more effective tool for organizations appraisal.

OH as defined in this paper is a state of the organization that may be beneficial (healthy) or burdening (ill) for the organization. A healthy organization is the one where all processes are performed efficiently, while an ill organization is the one where some of the processes malfunction or even fail. It is important to notice that not all organizational processes are related to projects/products development; therefore, while organizational performance may seem satisfactory based on executed projects, the organization may still face issues that can be, timely, identified by the assessment of OH.

The organization appraisal framework that is proposed in this paper includes also for the sake of completeness an assessment method that is described in Section 4.

4. An assessment method for Organizational Health

Assessment of OH provides a metric of how healthy an organization is. Due to space limitations, the analysis of the process of deterioration of an organization's health is omitted and focus is given on the description of a formal method to assess OH. This method comprises four steps, namely:

- Identification of processes inside the organization.
- Identification of critical components in the processes.
- Assessment of critical components' health status.
- Identification of problematic components and processes and assessment of OH.

A detailed description of the implementation of these steps is presented in Sections 4.1-4.4.

4.1. First step: Identification of processes inside the organization

Each organization is characterized from its own processes; however, it is feasible to group these processes in certain categories that are similar for various organizations in various industries. Business Process Modeling (BPM) provides the framework for mapping organizational processes either to the formal groups of management, operational and supporting processes or to more or different groups that may be considered as more appropriate by the organization's analyst. Specific methodologies that may require a systems engineering or business re-engineering background are available to provide assistance for the implementation of this step. Malone et al. (2003), for example, have conducted an extensive work on organizing business knowledge that is included in a handbook for organization analysts. Despite the formal theoretical and practical frameworks that allow the implementation of the method's first step, this may be proved very challenging, especially, with regard to the informal organizational processes that are often difficult to identify and describe explicitly, in terms of content. Therefore, good knowledge of the organizational culture is, also, a prerequisite for the implementation of this step.

4.2. Second Step: Identification of critical components in the processes

The identification of the processes allows a further analysis concerning the components that constitute these processes. By definition, "*a process is a set of interrelated actions and activities performed to create a pre-specified product, service or result. Each process is characterized by its inputs, the tools and techniques that can be applied, and the resulting output*" (Project Management Institute 2013). The required actions, activities, inputs, tools and techniques to perform a process are its constituting components. Depending on the processes nature, type, and complexity they may comprise several components. Some examples are:

- Actions: assignments, reporting, outputs deliveries, etc.
- Activities: data collection, data analysis, information communication, etc.
- Inputs: Return-On-Investment (ROI), cash flows, resources constraints, etc.
- Tools: SWOT analysis, PESTEL analysis, FAST diagram, etc.
- Techniques: expert judgment, group decision-making, benchmarking, etc.

In this step, a categorization of the components is useful, since it facilitates the implementation of the method's next step. The criteria for this categorization may include: a) the type of the component (e.g., qualitative, quantitative), b) the level of control of the component (e.g. internal, external), c) the function of the component (e.g. leadership, productivity), etc.

The identification of the critical components, i.e. those components with the most significant impact on process performance depends on the capacity and resources of the organization's analysts. It is evident from the analysis so far that the successful implementation of this step lies in the analysts' knowledge and experience about the investigated organization's operations and culture; since, OH assessment may not be, necessarily, performed as an in-house activity, it is imperative that the analysts team and the whole method's implementation should involve some of the organization's key personnel.

4.3. Third Step: Assessment of critical components' health status

The assessment of health of each component and, subsequently the assessment of health of each process should be performed in a holistic manner, i.e. in a manner that would be able to express inclusively different aspects of the assessed item. A framework that supports such an approach is entropy theory.

Entropy theory that has its origins in thermodynamics has been suggested as a metric of disorder in a system, where a low entropy value indicates high order in the system and vice versa (Landsberg 1984). Considering disorder (or else randomness) as a deviation from the system's level of balance and considering the organization as a system of interacting processes, it is inferred that the assessment of entropy can be used as a measure of OH. The use of entropy theory outside the field of physics has already been tested successfully in many cases and various fields (Shannon 1948a, Shannon 1948b, Parunak and Brueckner 2001, Lin et al. 2010, Hirsh et al. 2012); however, any attempt to apply it in the field of business models has failed so far. The reason for these failures was that organizations as open systems, i.e. systems constantly interacting with their environment, require careful modeling to allow the application of entropy theory. Addiscott's research in ecosystems hierarchy entailed some valuable contribution concerning the use of entropy in open systems (Addiscott 2010); therefore, it could provide the basis for a proper use of entropy theory in organizations.

A more conservative approach is the one adopted in this paper, where it is suggested that it would be more effective to apply entropy theory at the process components level instead of the organizational level. This is because, organizational processes present stability or at least long periods when no changes occur to them, thus allowing to consider them as closed systems of components where entropy theory is more easily applicable.
Therefore, for the assessment of the critical components' health status, equation 1 is suggested:

$$F_i = \frac{(Q_{i,1} - Q_{i,0})}{Q_{i,0}} \quad (1)$$

In equation 1, F_i is the entropy value of component i, $Q_{i,1}$ are the losses of energy in the current state of the component (or the estimation of losses, if the losses cannot be quantified) and $Q_{i,0}$ are the losses of energy in the optimal state. F_i is basically a ratio between current losses and losses on the optimal state. An application example would be to consider communication as a component, which could be calculated by the real talking hours between employees ($Q_{i,1}$) and the minimum talking hours ($Q_{0,1}$) that would be efficient for the employees to achieve the same results. A numerical example would be to consider 120 hours of communications between employees, while based on: a) comparison with other organizations, b) calculations, and c) estimations, the optimal value of communications would be 100 hours. In this case, the calculated entropy is 20%, which signifies the need to intervene, in order to improve the entropy of the particular component.

4.4. Fourth Step: Identification of problematic components and processes and assessment of OH

The assessment of the health status of the processes components allows the identification of those components that operate below the acceptable performance/quality levels. The next step is to move from the components to the process level; however, not all components have the same impact on a process, while not all similar components have the same impact on similar processes. Therefore, proper weighting of the components is required to reflect the significance of each one of them to the overall process. This weighting could result from the nature of the process and the evaluation of the importance of the type (as presented in Section 4.2) of the component in executing the process. For example, in the case of a process where accurate data are required the weighting of inputs and activities may be greater compared to that of tools and techniques, while the opposite could stand for another process where a specific type of output (e.g. graphical) is required.

Once the weights of significance have been assigned by the analyst to the process components with the application of a more or less formal method, the process's overall entropy can be calculated by the weighted average of the components' entropies according to equation 2:

$$S_{prj} = \sum_{i=1}^{n} [\sum(w_i * F_i)]/[(\sum w_i) * n] \quad (2)$$

In equation 2, S_{prj} is the entropy value of a j process, w is the weight of each i component, F_i is the entropy value of each component and n is the total number of components linked to the process. Equation 2 calculates an entropy value for each process rendering them comparable, in terms of performance; the processes that present increased values of entropy need to be corrected.

Having calculated the entropy values of all processes, the final step is to calculate the overall organization's entropy by applying equation 2 at the organizational level. At this level, w would be the weight of each i out of n processes, while F_i should be replaced by S_{prj}. The final outcome, i.e. the organization's entropy would reflect the organization's health.

5. Conclusions

Organizations need to be constantly monitored, in order to, timely, identify malfunctions that prevent them from achieving their goals. Organizational theory encompasses many concepts and assessment methods that more or less successfully and inclusively attempt to evaluate the status of an organization at given contexts.
This paper introduces a new concept, namely Organizational Health. The new concept is defined according to the definition of health for living organisms, which is also appropriate - after slight adjustments - for organizations, considering that the latter are also living organisms by definition. This new concept unifies currently existing concepts such as organizational performance or resilience, since it reflects the organization's status, independently from any condition (e.g. project development, external load, etc.); it is a measure that reveals the wellbeing of an organization, in terms of conformity of internal processes performance to quality standards predefined by the organization.

Organizational health can be measured in the context of entropy theory, which has found applications in various disciplines. Entropy is a measure that allows the identification of an organization's status relatively easy, since by definition it reflects the status of order of a system. Therefore, the appropriate modeling of the organization as a system allows the application of entropy theory, thus providing with an adequate measure for a concept such as organizational health. This paper proposes a method of calculating entropy in an organization based on its internal processes regardless of type (formal/informal, main/auxiliary). The final output of this method is an entropy value that reflects the organizational health and is useful for:

- Deciding upon corrective actions, in cases of malfunctions of organizational processes
- Comparing the progress of the organization at different time periods
- Comparing the organization with other organizations (provided that their OH value is available)

Research on the organizational health concept is a newborn, therefore there are many issues to clarify and specify; however, it seems to be a worthwhile effort, since the anticipated outcome may have the potential of a very significant contribution to organizational theory and practice.

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An integrated framework for automated project risk management analysis

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Abstract

The article presents an automated and integrated risk analysis method for building projects which tracks the probabilities of occurrences of harmful events perceived by the owners from the conceptual phase to the end of the project. The risk management framework is built on the traditional risk modeling bases and integrated with financial aspects. This extension of the original concepts defines the project goal by the minimum requirements to be achieved, then objectively identifies risk factors with measurable financial variables. The objective of this paper is to provide the basis for developing a software prototype that is based on the proposed integrated framework of risk management by developing a flow chart. Based on this framework an automatized risk management process can be implemented, which will indicate if adverse processes start in the life of the project and action plans need to be launched. The automated procedure for risk analysis based on the integrated concept delivers a more effective practical tool to reduce liquidity risks and create value for the participants in the project, and opens new research areas in construction project management.

Keywords: automation of risk management; construction project; financial risk management; project success criteria.

1. Introduction

Automation is applied for many purposes in different professional fields related to management. One or more elements of the processes in the organization are operated automatically to reduce human intervention to a minimum. The automation of portfolio management processes is in the focus of recent research (Branke, Scheckenbach, Stein, Deb, & Schmeck, 2009; Metaxiotis, & Liagkouras, 2012). Automation saves time, reduces cost, and increases reliability and efficiency.

The general definition of risk in project management has undergone significant changes since the 1950s. At that time, risks were only regarded as the possible negative consequences of events or tasks (Rowe, 1977). Project management literature concentrated on specifying risk classes; thus, such research concentrated on how to manage risks based on those classes. Subsequently, the two-sided nature of risk was emphasized; positive consequences were also considered (Flanagan, & Norman, 1993). To address this, project management standards included the objective of maximizing the results of positive events and minimizing the consequences of adverse events. In accordance with these standards, many resources suggested methods for risk analysis that accounted for the probability and consequences of risks (PMI, 2013). Turner (2009) summarized the most relevant generic risk management processes and standards. Consequently, numerous industry-specific applications and research projects were established to make the efficient management of risks possible (Al-Bahar, & Crandall, 1990; Klemetti, 2006; Dikmen & al., 2008; Tserng, & al., 2009; Bevilacqua, Ciarapica, & Giacchetta, 2009; Chan & al., 2011; Kwan, & Leung, 2011). Zhang (2011) provided an extensive literature review of two schools of project risk analysis based on their objectivity, taking the different risk definitions and methods into consideration. Eventually, risk in project management became increasingly understood conceptually as the likelihood of an event occurring within a project (Baloi, & Price, 2003; Purnus, & Bodea, 2013); however, an "event" continued to cover a wide range of meanings. The principal methods of risk measurement have gradually spread from other scientific fields to project management applications. (E.g. for a summary of the most frequently used methods in the construction industry, see KarimiAzari et al., 2011).

The literature on project management typically divides the risk management process into steps: risk identification (and classification), risk analysis (including qualitative, and, if necessary and possible, quantitative ranking) and response (reaction) (i.a., PMI, 2013). Since the steps of risk management must be monitored in the

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realization phase, some authors regard controlling or tracking as an additional risk management step (see, e.g., Al-Bahar, & Crandall, 1990). The novelty of this paper is that it provides a revised integrated project risk-assessment framework enhancing the conventional risk category-based methods. Using the suggested method, risk analysis is conducted in the conceptual phase, and then finalized in the planning phase. By updating the environmental and project variables, automated forecasts on the need for intervention are conducted in the development phase, and in the operation and maintenance phases. Below we provide the basis for an automatized decision process with the integrated framework developed for project risk management in the construction industry.

2. Methodology

The purpose of the integrated risk management process proposed for the construction sector is threefold:

1) In the conceptual phase the purpose of risk management is to eliminate those risks where the investor has no comparative advantage. For instance, an agency specializing in building business centers has a competitive advantage in forecasting the rate of occupancy, and the rent in the coming years. In other words, this type of company should take risks in terms of the rate of occupancy and rent. Handling other risk elements is generally not included in the operator's management strengths, so they are removed through prior agreements, and pre-contracts. At this stage, only prior physical indicators based on cost and benefit forecasts are available. Risk management in this phase assists in preventing any participant from securing a position in which the possibility of losing financial interest, and thus exiting, is overly high. With risk analysis, the probabilities of potential losses and gains can be estimated. Based on this analysis, pre-contracts can be restructured until any risks without competitive advantage are reduced to an acceptable level.

2) In the planning phase the purpose of risk management is to identify and explore processes jeopardizing owner's interests, and to develop action plans for preventing them. At this stage financial data are finalized, and the complete business plan and financial model providing the basis for risk management are developed. The critical situations, scenarios, proxy factors, and break-even points are determined, and special action plans are developed to save profits or minimize losses. Such action plans contain the lossless transformation of project processes in the scenario or, if needed, the method for the consolidation of processes with the least amount of loss.

3) In the development, and the operation and maintenance phases the purpose of risk management is to provide continuous monitoring and, if necessary, to start the action plans. (These phases are optional. Sometimes a project is contracted only for one of these phases, sometimes for both of them.) Any intervention causes the redesign of the basic financial model. At this stage, the risk management processes can be automated, so we propose an application that provides visual feedback on the development of the critical variables and intervention points.

The basis for the risk management process in Figure 1 is the following standardized financial model of the project. Let us define value-driving parameter ($x_{n,t}$) as an arbitrary variable that can have any effect on the financial position of the owners of the construction project. $n = (1,\ldots,N)$ refers to the nature of the parameter (see below), and $t = (1,\ldots,T)$ refers to the given time period in years. Value-driving parameters are typically the following in the construction sector:

- parameters that are necessary for the calculation of the cost of capital: long-term nominal risk-free return, market risk premium, beta for the construction sector, and debt beta (the beta of a stock, portfolio or debt is a number describing the correlated volatility of an asset in relation to the volatility of the market as a whole); taxes: corporate income tax, business tax, land tax, building tax, VAT, and other taxes;

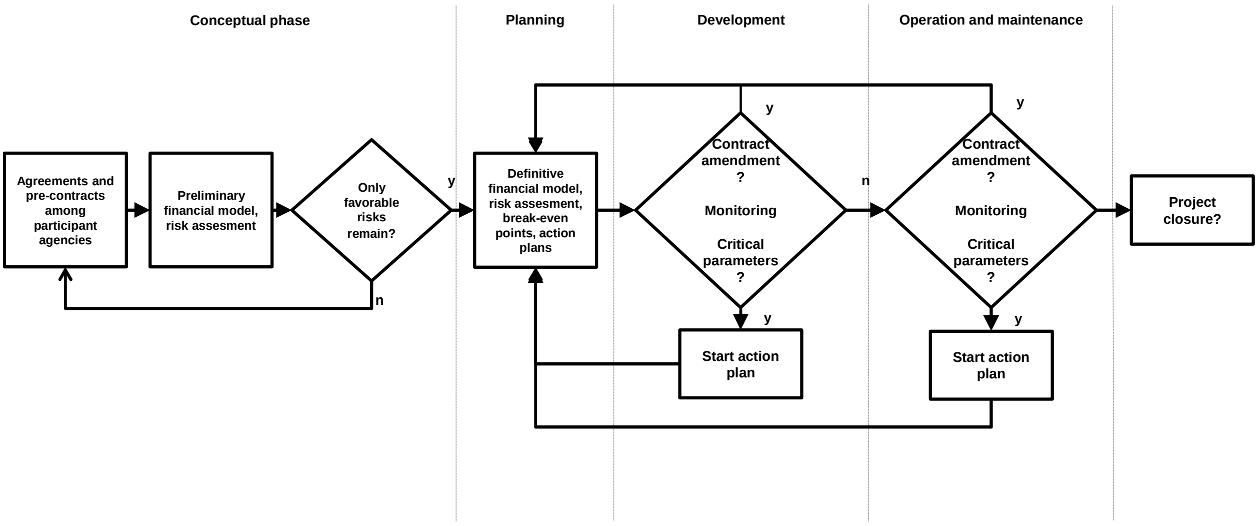

Figure 1. Automation of the risk management process in the integrated framework.

- parameters of a potential loan: the amount of the loan, base interest rate (often bound to a reference index), interest surcharge, other costs, spot exchange rates and expected inflation rates of relevant currencies);

- project-specific parameters (e.g., investment costs, components of expected operation costs and revenues, expected terminal value);

- parameters of unusual situations and acts of god (e.g. possible damage to the environment, potential occupational safety and health damages, and unexpected penalties).

Based on these value-driving parameters, the expected $CF_t = s(x_{1},t,\ldots,x_{N,t})$ annual cash flow in year t can be determined, showing the expected change in the value of the owners' equity related to the business idea for that period.

Costs include the expenses of all resources, including financial capital. In other words, the expected internal rate of return (IRR) of the business idea must be higher than the minimum rate of return requirement (r_{min}).

$$\sum_{t=1}^{T} \frac{E(CF_t)}{(1+IRR)^t} \geq r_{\min} \tag{1}$$

Although traditional project management concludes that achieving the predefined time, cost, and quality parameters ensuring expected profit is the primary goal, deviations from expectations do not necessarily lead to unbearable situations. In the following section we describe events whose occurrence is perceived harmful by the owners.

3. Risk assessment method for building projects

1. The primary aim of a project is to achieve a higher expected internal rate of return than is possible from capital market investments with similar relevant risk. So the primary harmful event is when the expected internal rate of return or the economic internal rate of return is less than or equal to the minimum requirements of the owners.

2. If a project is undertaken by a company specifically founded for the implementation of a project, the liquidity of the project must be maintained, that is, the cash balance (L_t) of the project must be positive in each year. If the company has many projects, then this constraint is not so important – more precisely, maintaining the liquidity of the whole company is the constraint then, which is a company-level resource allocation problem beyond the scope of this paper.

3. If debt is also involved in financing the project, the debt service coverage ratio ($DSCR_t$) cannot decrease below the value (C_t) that is specified by the loan contract in each year. This is an often-used heuristic rule of thumb by which creditors attempt to assure that borrowers will not succumb to bankruptcy. If these conditions are absent, the ex-post rate of return of a project can dramatically decrease as the transaction costs of a possible

financial distress may be unexpectedly high in an imperfect world. Failing to satisfy this condition is also considered to be a harmful event, which signals potentially more serious liquidity problems.

After the planned processes of the project are modeled by functions, the expected value of all possible financial variables can be calculated based on these basic data (e.g., expected project return, annual cash flows, net income, liquidity, dividends, working capital needs, debt service, debt service coverage ratio). For simplicity, the internal rate of return (*IRR*) capital budgeting method, which is calculated from the cash flow to the owners, is used here, but the approach can be extended to any arbitrary capital budgeting technique.

In the conceptual phase, a sensitivity analysis can be used to improve the structure of the project. By changing each variable ceteris paribus, those value-driving parameters whose deviation decisively determines the deviation of the project's expected return are presented.

$$\begin{aligned} &r(x_{i,t}) = IRR(x_{1,1},...,x_{n,t},...,x_{N,T}) \\ &x_{n \neq i,t} = E(x_{n,t}) \\ &\forall i \in [1,N] \end{aligned} \tag{2}$$

With a frequently applied simplification for conducting a sensitivity analysis, the variables of the same nature vary at the same rate in each year:

$$\frac{\Delta x_{i,1}}{x_{i,1}} = \frac{\Delta x_{i,t}}{x_{i,t}} = 1 + a_i \quad \forall t \in [1,T], \quad \forall i \in [1,N] \tag{3}$$

Thus, in Figure 2, $r(x_{i,t})$ is referred only to as $r(x_i)$. The critical value-driving parameters could be further analyzed; their estimations and calculations could be performed in a more precise and detailed manner for the project, and its contracts can be restructured. For instance, according to the example in Figure 2, the expected rate of return is not sensitive to marketing costs; therefore an increase in the amount allocated for marketing should increase the expected value or decrease the deviation of the rate of occupancy.

The r_{min} margin, the minimum requirement of the owners (the expected return of capital market investments with similar relevant risk), is highlighted in the diagram and shows how much the given parameter could change without causing the project's return to decrease below the acceptable minimum level. This value of a_i is the economic breakeven point ($B(x_i)$) at which the return of the project ($r(x_i)$) is equal to the minimum requirements of the owners, ceteris paribus

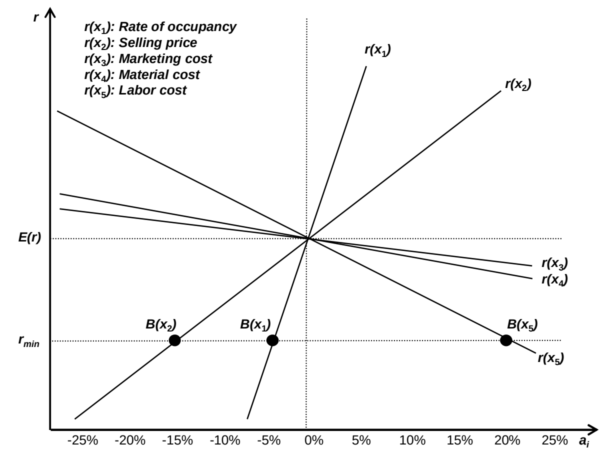

Figure 2. Sensitivity analysis.

More attention should be devoted to the more sensitive components because they could be responsible for the poor performance of a project or, conversely, could increase profits. However, sensitivity analyses are suitable only for filtering the most significant parameters describing the total risk of a project. To identify further consequences, one must determine the probability distribution functions of the value-driving variables using other methods.

As the example in Figure 2 shows, the probability distribution function of labor cost can almost be ignored because labor cost is an easily predicted parameter. Without any sophisticated quantitative calculation, it is easy to determine that in the realistic ±10% interval, the change in the project's return is not sufficient to reach the break-even point.

In contrast, the probability density function of the average rate of occupancy as a random variable is worth examining; its deviation can easily destroy owner's value. For example, 5% of the negative deviation from the expected value for occupancy must occur to reach the economic break-even point. If the probability density function of occupancy ($f(x_1)$) is known, then by integrating over minus infinity to $B(x_1)$, one can determine the probability (P) that the value-driving variable is less than the break-even point. Thus, the variable deviates enough in the negative direction to render the project value-destroying. If there is no continuous function available, for example, because the analysis of the process is empirical, then empirical probability is applied.

Sensitivity analysis must be conducted for the occurrence of all harmful events. Since a project company does not typically possess the competences that are necessary to manage risks other than project-specific risks, the project processes (e.g., the contracts with subcontractors, financing and dividend-paying conditions) must be modified and re-planned until the probability of the occurrence of the value-destroying conditions and bankruptcy becomes insignificant. The contracts of a well-prepared project can be restructured until only project-specific risks remain. In the planning phase all value-driving parameters and the financial model can be finalized.

4. Discussion and conclusions

The preparation of the financial model defined in our paper and filling it with the expected values require manual acts, but risk management in the monitoring phase can be automated. By substituting the actual data of past periods for the planned data in the financial model, parameters $E(r)$, $DSCR_t$, and L_t are automatically determined and continuously monitored. Moreover, before the occurrence of harmful events, dangerous trends can be observed, so the pre-defined action plans can be launched in time. Since there is usually no data available on the distribution function of project-specific value-driving parameters only subjective estimates, a special type of risk map is proposed to add to the risk management tools. For instance, if two project-specific value-driving components remain sensitive (e.g. occupancy and rent), the rate of return, the debt service coverage ratio and liquidity functions can be represented in terms of these variables. In Figure 3, all three variables and their margins are represented in year 0, 1, 2 and 3. If the value of a variable goes below its margin, it is harmful for the project.

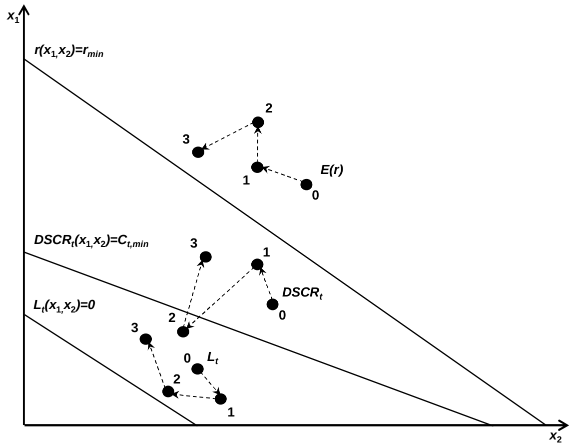

Figure 3. Risk map for two parameters.

The scenarios that are beneficial for owners in each variable fall above their margins, and there no action is required. If $E(r)< r_{min}$, the project becomes value-destroying. If $DSCR_t<C_{t,min}$ then problems with the loan contract arise, as the creditors perceive default risk; and if $L_t<0$, the project becomes bankrupt, and special transaction costs appear. In Figure 3 in the 2nd year, the $DSCR_t$ goes below the limit, so an action plan should be initiated to prevent potential liquidity problems, e.g., by raising new equity. In the third year this has beneficial effects on liquidity, but decreases shareholder return.

By developing this line of thinking further, a more complete and universal project management system could be established that is able to connect separate sub-systems, such as investment valuation, risk management, monitoring and control, and with automation it could also be more effective through saving time. The application of the suggested risk analysis approach provides deeper insight into the value-creating processes of projects, leads to higher added value, and provides a conceptual risk management framework for construction projects.

Based on the revised risk management framework and the automation of the process, this research will be completed with a software prototype using real data of a building project.

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Structure, function, behavior, meaning: Towards a reference model for creative construction

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Abstract

Since Aristotle we have been understanding “things” around us to have form, function, behavior, fit and working principle. Creating an engineering product (construction included) was about defining a form fitting together that would perform certain functions and behave, using a working principle, according to expectations. In the age of scarcity, customers were mostly looking for products that would perform their function satisfactorily. Mass automation of manual and intellectual works as well as increased capacity of the manufacturing industry, have been causing an abundance of such functional products. To perform the function, ceased to be a competitive advantage. However, the consumers and the industry discovered that meaning could still be made scarce.

Unlike function, meaning is not a solution to an existing and real problem but is constructed as an interpretation of products. If function is generally result of innovation, meaning is result of creativity. The paper claims that construction, civil and structural engineering in particular, can take part in the economy of meaning as well and not compete with the lowest price in saturated markets of function. It provides a theoretical definition of what is creative design in terms of structure-function-behavior and what is creative design in terms of structure-function-behavior-meaning. Engineering profession can be creative in both of the two models. The paper concludes that the creation of meaning is what engineers can do as well and does not have to be limited to designers, architects and marketing professionals. With increasing automation of engineering design this will in fact be essential.

Keywords: construction, information technology, automation, meaning economy, creativity, structure-function-behavior, reference model, conceptual model.

1. Introduction

Breakthrough technological innovations on one hand, and globalization of commerce on the other, are enabling an unprecedented abundance of food, industrial products and information, an overcapacity of global manufacturing industry and European food production (Pink, 2006). Abundance is an enemy of economy where the value of things is measured by the market and also an enemy of progress. Scarcity generates the motivation for innovation so that the scarce products or services can be offered on the market. This also generates jobs. Abundance is destroying jobs, drives down salaries and kills innovation.

In this world where the basic necessities – such as food, clothing and shelter are abundant, a scarcity of meaning was created (Hartley, 2004). Meaning is an increasingly important and valuable element of a product. Meaning is the difference between a no-name two dollar watch and one advertised by a Formula One driver, between a no name brown drink and one sponsoring the Olympics, between a cheap android tablet and an iPad, between a fair-traded coffee and a generic caffeinated drink, between a household cleaner that just cleans and one that also does something for the environment.

Meaning is the difference between an engineer’s work that just connected two banks of a river and a daring structure performing the same function but on the cover of Structural Engineering International magazine.

In every product or service one can find a distinction between a function such as “tells time” and meaning such as “formula one driver wears it too”. Functional products are abundant. Manufacturers of these products can only compete in price. Meaningful products can be made scarce.

Functional characteristics of products are a result of designing which was defined as a problem solving activity, “changing existing state of things into preferred ones” (Simon, 1992) and where the only problems were supposed to be “in the lack of information” (Negroponte, 1975). Functional designing is therefore typically (though not always) a routine or innovative problem solving exercise. Meaningful designing has to be creative in the sense that it has to create something that is does not emerge from the function of the product.

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The developed world in particular enjoys are relative abundance and high quality of civil infrastructure, office space, industrial and residential buildings. Indeed some of it needs a refurbishing and some new construction is always needed. Engineering designing is about fulfilling the functional characteristics of products; such as load capacity, earthquake safety etc. Industries and professions that have been in the business of providing function lack the scarcity power to maintain their levels of profit, innovation, salaries and jobs.

1.1. Research questions

In this paper we will try to answer the following questions:

- Is there more to engineering designing than designing for function?
- When is the engineering designing creative, both when designing for function and for designing for meaning?
- What kind of reference information models would explicitly support designing for meaning?

We claim that existing reference information models that are underlying the building information models and design software lack the support for the designing with meaning in mind.

1.2. Paper structure

In Section 2 we introduce the concept of reference information models. In order to study any phenomena, science introduces a model. To study building and build them, building information models were created. They are based, explicitly or implicitly on reference models that reveal fundamental conceptions on how to simplify reality into models. We will argue that function has been a core idea of these models, but not meaning.

In Section 3 we introduce the concept of meaning and provide an argument that while engineering functional designing *can* be creative, engineering designing for meaning *has* to be creative.

In Section 4 we describe an initial idea of a reference model of engineering products that would enable information models to include meaning.

In Section 5 there is a discussion and conclusions.

2. Reference models for construction

Since the broad use of paper and drawings in the construction profession, the description of the construction process as worded by William Shakespeare remains correct:

When we mean to build,
We first survey the plot, then draw the model,
And when we see the figure of the house,
Then must we rate the cost of the erection,
Which if we find outweighs ability,
What do we do then but redraw anew the model
In fewer offices, or at least desist
To build at all?

We draw the model, because creating models is a way in which humans deal with complexity. We abstract – remove – what is not important or essential for the study. A drawing is a model. The real thing is abstracted into a more or less complete and precise representation of geometry. Scientific theories are built on models. Through the simulation on models science predicts the behavior of real world phenomena.

2.1. Information modeling in construction

While the models were drawn on paper or used as a background of a scientific theory (like the structural models or building-physics models) the focus of the research has been on the theory for which the model was built. Only when digital computers started to be used to store, manipulate and visualize the models, some attention shifted towards the modelling itself, more precisely into conceptual modelling.

A "conceptual model of buildings" is a model of concepts that are useful to describe buildings and create software that will manipulate digital models of buildings. A digital model of a building is, for example, a digital representation of a design of a building to be built. A building information model (or BIM) is a kind of digital model of the building; that kind that relies on highly structured information. The data structures are derived from the concepts identified in the conceptual model of buildings. Conceptual models can be standardized. Industry Foundation Classes (IFC) is an attempt to standardize a particular conceptual model for construction. ISO-STEP standards were an example of another attempt.

Creating conceptual models is a process of choosing what is important and what not in the area studied (Turk, 2001). What we choose to select to put ahead of us is called "object". The etymologically of the term "object" means that. In the creation of conceptual models we also choose how object are related to each other. Related in the most generic sense.

2.2. Abstractions

Conceptual models are not created from scratch. When creating them we use certain methods and construct the models out of certain building blocks.

One method, **aspectification**, is to break the universe of discourse (UoD) into certain aspects: to observe the world from certain views, having in mind the context or process in which the model will be used and to separate concerns. For example we may observe a building from the aspect of an architect, a structural engineer, a building physicists, an HVAC designer etc. The result of this approach are several aspect models or views of the same UoD studied.

Another method is **abstraction**. The main building block in an abstraction is an "object" Further building blocks for creating models with abstraction include composition/decomposition (object is part of other objects or has parts), specialization/generalization (object is a-kind-of another object) and characterization (an object has certain characteristics). The characteristics (sometimes called attributes) can be of certain types as well, for example generic ones such as words, numbers, logical values or some other profession specific objects, such as color, material strength etc.

2.3. The four causes of Aristotle

With the tools and components listed above, just about anything can be described, in just about any way that could seem useful. However, philosophy, design science and computer science have provided tools and methods that assist us in creating models further but also narrow how we are able to see the world.

Aristotle (Falcon, 2008) made a lasting impact on the way how we choose to see the world with his the four causes that make things what they are. C*ausa materialis is what the object is made of. Causa formalis is what the shape of the object is. Causa efficiens* how it behaves. *Causa finalis* is the purpose or function of the thing.

2.4. Form and function

In essence Aristotle suggest we should look for material, form, behavior and function in products. Design scientists and researchers that though theoretically about designing and representing design, had to be influenced by that. Such references as to how to understand the world, we call in this paper a "reference model". Examples of Aristotelian reference models include Gielingh's (1988) suggestion to separate functional units (enable traffic across river) from technical solutions (a bridge, a tunnel). Aristotle's four causes are echoed in the principle that "form follows function". It is also echoed in the reference model popular in the design sciences that claims the existence of structure, function and behavior (de Kleer and Brown, 1983, Gero, 1990) and models the process of designing as creating a structure (a bridge) that will provide a function (enable traffic across a river) and have certain behavior (should a wind blow across the bridge it would not swing much).

The understanding is well suited for situations that focuses on functions because function is scarce.

3. Meaning: semiotic and existential

Models are symbolic representations, usually of real world things, existing, imagined or designed. Their relations with our thoughts are illustrated by the meaning triangle. Basic idea again goes back to Aristotle (Sowa, 1984). His idea was developed further by Ogden and Richards (1994). In the first apex of the meaning triangle is the real world object, in the second its symbolic representation and in the third the thought we hold about it in our mind (Figure 1).

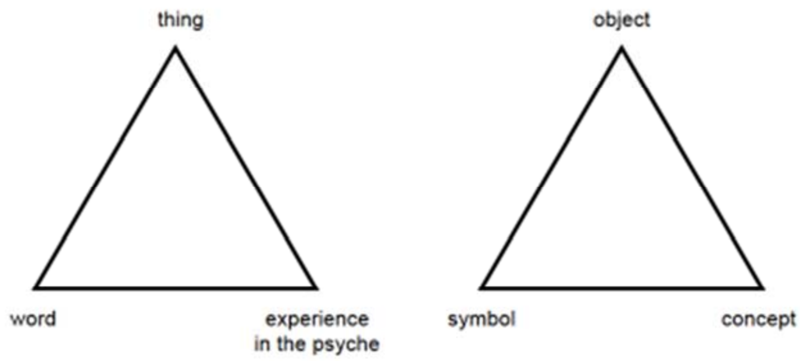

Figure 1. The (semiotic) meaning triangles of Aristotle (left) and Ogden and Richards (right).

In this context, the meaning is the relation between the symbol and the concept. If the symbol (read, heard, seen) evokes a concept that corresponds to the intended real world object, the symbol is meaningful. Such relations between symbols, real world objects and concepts are studied by semiotics. Design communication is the exchange of symbols about a to-be-build object – about its functional units or its technical solutions. Since people are always involved in communication, symbols should evoke the appropriate concepts.

3.1. Creative functional design

Functional designing can be routine, innovative or creative (Gero, 1990). In terms defined so far, creative design would be a design where either new symbols are being created or existing symbols are interpreted into novel concepts and objects. The author argued earlier (Turk, 1999) that BIM technology with a predefined set of high level symbols discourages creative design. The set of routine and innovative designs that can be composed with the predetermined symbols (BIM elements) is rather exhaustive but the high-levelness of the design language elements is a barrier to step out of what can be designed using those components. On the other hand, primitive symbols in pre-BIM tools, such as lines, enable much more creative interpretations of what the lines could stand for both and the designer is not limited with a predefined set of design components.

3.2. Existential meaning

In this study, however, we are interested in another kind of meaning. Not the meaning of symbols but the deeper and wider meaning of our activities, decisions and life. As Victor Frankl (1946) put it: “Life is never made unbearable by circumstances, but only by lack of meaning and purpose.” This kind of meaning is studied by psychology in particular logotherapy. This is the kind of meaning we look for in products and services once their function is not an issue any more.

A link between the required function and nice to have meaning is provided by the Maslow’s hierarchy of needs (Maslow, 1943). He claimed that the most basic needs are (1) physiological (the need for breathing, water, food, sleep etc.), flowed by (2) the need for safety (security of body, employment, health, property), for (3) love and belonging, (4) esteem (confidence, achievement, respect) and (5) self-actualization (morality, creativity, spontaneity).

One could argue that the functions of an engineering product cater for the lower levels of the Maslow hierarchy. Engineers are providing clean water, waste management, safe, healthy, private life environment. What we tend to think about the function of a product has little to do with clients esteem, morality or creativity. In fact it is the designers need for esteem and creativity that might push some designs beyond what would fulfill a function only. Why else would we see wonderful and daring bridges on locations where a simple beam or arch bridge would do. Creativity is a need of the designer, not just a client requirement.

The top layers of the Maslow hierarchy, self-actualization in particular, are related to the meaning in the existential sense.

3.3. Creative meaningful design

While the functional meaning of design is explicit through requirements or can be discovered by unintended uses of the object, the existential meaning of designs are always created. That a design caters to our high levels needs and causes feelings such as admiration, awe, confidence, satisfaction, righteousness etc. is a result of existential creativity.

4. Towards a reference model with meaning

Designing is a process of defining a form that would fulfill a function and exhibit a certain behavior. While function of a product can be exercised when used, the “meaning” of a product is “believed”, “judged”, “recognized”. Function is objective, meaning is subjective. That meaning can be recognized in a product it has to be designed in this way.

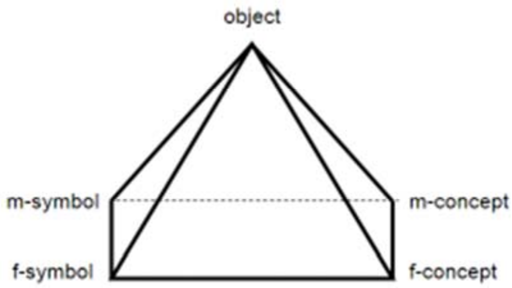

Figure 2: The meaning pyramid.

Two elements in the standard reference models must be modified for the non-function-focused designing. The meaning triangle should evolve into a structure like shown in Figure 2. It makes explicit that there are two kinds of concepts that we hold about real world objects – the firsts are rational and relate to what the structure, function and behavior of an object might be (functional or f-concepts). The others are emotional, what kinds of meanings and emotions the objects evokes (meaningful or m-concepts). This duality is reflected in the symbolic apex that breaks into symbols for representing and communication the rational aspects of the design and ones communicating the emotional aspects of the design. The first set of symbols are used by engineers to communicate the aspects of the design needed to manufacture or build what was designed. The second set of symbols is used to sell the design, convince the jury in an architectural contest, and make the end user desire the product for reasons that are beyond its function. A lot of marketing and sales information would use these symbols. The difference between architectural and engineering drawings is in the first using the m-symbols as well.

Similarly the Geilings “funtional unit / technical solution” schema would need to evolve into (Funcional+meaningful unit)/technical solution. The structure-function-behavior model of designing (Figure 3) would be augmented with the element of meaning.

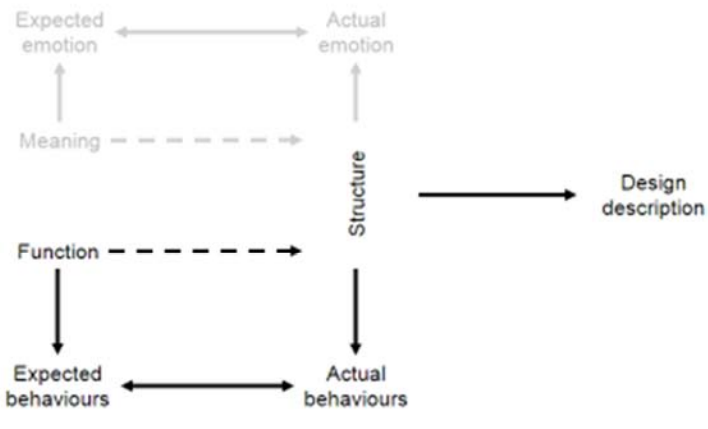

Figure 3: SFB model (black) augmented with meaning (grey)

5. Conclusions and discussion

Current understanding of designing was focusing on the function that the design should perform. This thinking was also present in how we understand communication in general and design communication in particular. In the paper some initial ideas as to where the interface to the non-functional aspects of the design would augment the reference models we use in designing.

With respect to the questions asked at the beginning of the paper and based on the arguments presented we can conclude: (1) there is more to engineering than designing for function. Although the architectural and industrial design is more often associated with designing that evokes emotion, several features of engineering work can respond to the upper layer of Maslow's pyramid. (2) Engineering designing with the goal for meaning is always creative because meaning is constructed while functions are interpreted. Designing for function can also be creative, but is more likely to be routine or just innovative. (3) In reference models for design and designing, the concepts can be broken into rational and emotional concepts, the first corresponding to function, the second to meaning. Meaning should be added in to the structure-function-behavior model of designing.

Further studies should formalize the understanding of meaning and develop the details of the MSFB model by exploring a more detailed model of how meaning affects models of designs and designing. As meaning is closely related to morals and ethics, the practical result of this would be an explicit attention to ethical dimensions of engineering work, for example in tackling environmental or social issues.

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Early warning system for detection of the crisis in construction projects

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Abstract

Construction projects are inherently high-risky. The crisis of the construction project is generated by gradually accumulated risks or by a sudden risk outbreak. Existing methods of construction risk management very difficultly distinguish the level of risk exposure to different segments of construction project management in the new conditions, in which construction projects arise. Because even small crisis can undermine the objectives of the project and subsequently damage the good-will of construction enterprise, an effective crisis management should be initiated as soon as possible. In order to improve the level of these procedures, it is necessary to search in the risk and crisis management systems a setting of an appropriate early warning system for detecting the symptoms of crisis of a project.

Early warning system for detection of the symptoms of the crisis is one of the most important factors in the success of proactive crisis management. Its essence lies in the monitoring of negative trends in the project. The early warning system allows the management of a construction company and management of construction project to monitor symptoms and indicators of crisis situations by using the management standard procedures. This system gives the control elements of the company and project the information about when the construction project is already in crisis, and when it is necessary to initiate the project crisis management.

The parameters of crisis state and defining the negative trends in the construction project, i.e. the setting of an early warning system in the various segments of the system matrix for the identification of the crisis depends on the contractual parameters of the construction project, and the system of management of construction projects and processes in a particular construction company, its strategy, its position on the market, financial stability and quality of human resources. Generally, in order to identify the symptoms of crisis, it is recommended to monitor the trends of changes, whether: Does the resulting trend correspond to dynamics of the project? Has the trend a positive or negative impact on the project? Is the trend a cyclical matter? Is the trend a consequence of another trend? Are there links between the different trends? For effective functioning of the system for the identification of the symptoms of the crisis, it is important to clearly set out who, when (at what period), where and how they will monitor the indicators and other signals, and to whom they will transmit the data.

Keywords: Early warning system; Crisis; Crisis management.

1. Different kinds of crises in construction projects, and ways of managing these crises

Products of construction contracting, i.e. construction projects, are defined by their high demands concerning financial sources, qualified network of suppliers, modern technologies, ecological and safety aspects. All these concerns together constitute a sum of conditions for the occurrence of critical situation during construction processes. Despite the fact that construction projects are liable to a number of crises due to their long-term character, current construction management is rather conservative, and does not admit that crises should arise. It is surprising that current management methods in construction projects or operational guidelines only deal with risk management, and not with the situations which arise when the risk becomes effective (Vondruška 2013). Such is the standard approach even in the largest companies. However, when a risk becomes effective and results in a crisis, the standard procedures of project management need to be stopped and replaced by crisis management. Construction project crises can be divided into four sub-groups, according to their characteristics. **Protracted crisis** is a slowly developing crisis with gradual risk accumulation and worsening of project status. It is extremely difficult to identify and diagnose this type of crisis because project managers expect the situation to improve soon. (Hujňák 2010) In construction projects such crisis is characterized by e.g. change of geological foundation during project realization, deteriorating quality of work, claims, temporary financial insufficiencies, etc. **Sudden crisis** of a project arises as a result of a severe risk outbreak, and it puts the whole project in serious danger. It can only be faced with timely counteractions. Cooperation of the whole project team is necessary in these cases, and it has to be focused on speedy effects. That requires preparations made beforehand in the form of a continuity plan. (Hujňák 2010). Ecological breakdowns, injuries, floods, and similar instances may be stated as examples of sudden crises. **Periodical project crises** – Loosemore (2000) mentions the existence of the periodical crisis category in his work. These crises occur repeatedly within intervals of various lengths. They may be caused by budget cuts, changes in company management, political or governmental changes. Moreover, we need to mention the category of Bizarre **and perceptional crises**, which – although generally considered marginal in sources – are very common in current construction contracting. These are crises arising from perception. They are caused by negative attitudes of the public and activists towards the project, usually supported by mass media, and based mostly on bizarre reasoning.

The efforts of any crisis-affected subject are to stop the effects of crisis as soon as possible, and eliminate its impacts. The ultimate goal is stabilization of the affected subject and its reestablishment to the level of operation before the crisis broke out. From this point of view, crisis management is considered as a set of precautions, measures, and methods whereby the affected subject actively proceeds (by their own means, or with external aid) towards minimization of the sources that led to the critical situation (i.e. **correction**), or whereby the subject prepares for activities needed in the state of crisis (i.e. **prevention**), whereby the subject averts the outbreak or escalation of critises (i.e. **contraction**), whereby the subject reduces the number of crisis sources, and their negative effects (i.e **reduction**), and whereby the subject removes the negative results of the given crisis (i.e. **restoration**). (Zuzák 2004).

Construction companies approach crisis management of a construction project in two different ways. The first approach deals with management of a crisis that is already effective and can be easily identified (natural disasters, accidents, injuries). Management of such kind of crisis is usually labeled as **consequential crisis management**, and it should logically have its place in construction projects only in cases of sudden and unexpectable crisis outbreaks. The second approach – **preventive crisis management** – focuses on predictions of potential critical situation, and on preventive elimination of impending crisis. Contrary to consequential crisis management, preventive crisis management actively predicts cumulation of potential risks or risks with substantial impact to see whether the project proceedings will be capable of facing the potential crisis viably. The major issue of proactive crisis management, when focusing on protracted, periodical or bizarre crises, is finding the fine line of division between risks and crises.

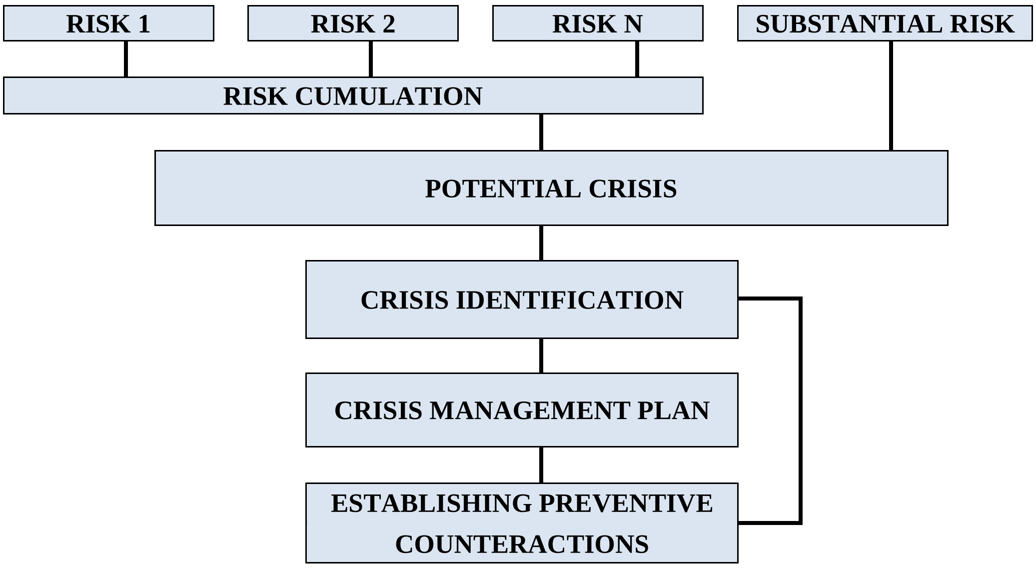

Figure 1. Proactive crisis management scheme

2. Structure of crisis symptom identification

Structure of the early warning system in a project which monitors negative trends within the project should be based on identification of symptoms within the project, and external symptoms which may influence the project. While establishing the structure of the early warning system, it is necessary to take into account identification of quantifiable and inquantifiable signals.

Crisis symptoms	*quantifiable*	*inquantifiable*

Within the project	**A**	**B**
External effects on the project	**C**	**D**

Figure 2. Matrix for identification of crisis symptoms (Lacko 2012)

2.1. Segment A of the symptom identification matrix

The matrix consists of four segments. Segment A accounts for quantifiable data arising from within the project. Data is assessed in consistency with past experience and is easily acquired. In construction projects, the four aspects that offer data are economic evaluation of the project based on accountancy, monitoring and evaluation of time for completion (schedule evaluation), quality evaluation, and work safety.

As each construction project in any company is a singular unit, evidence can be established for monitoring the obtained data. Individual indicators in such evidence would then be **crisis symptom indicators**. Such indicators need to be unequivocal, their values need to be complete and filed in a timely manner. There is also need for a qualified worker who will observe and evaluate the indicators in given intervals. Monitoring of crisis indicators is not based on observing the sum of their values but rather on the observation of trends. Therefore, while planning a construction project, it is necessary to lay down the parameters of observed indicators that would serve as guidelines for monitoring of the indicators and their proper evaluation. It is also necessary to establish initial values of the indicators that are to be used, critical values, acceptable values, and values which signify impending crisis. Design target plan may serve in this instance as both the tool for observation, and measure of evaluation of the indicators.

Using standard management procedures and company control systems

2.1.1. Managing accountancy

Progressive monitoring of project costs and comparing of these values with the planned indicators mentioned above is immensely important in any construction project. Nevertheless, the standard ways of billing and stating costs of project expenses does not offer reliable data to project management solely by the rules of standard accounting. Billing may misrepresent actual data on the grounds of securing supplies beforehand due to expectations concerning transport capacity of vendors. Contractor's costs may also be distorted on the grounds of inadequate estimate or intentional lowering of the volume of billed warks. Billing to the supplier may also be higher while lacking an adequate reason, or on the contrary intenionally lowered. This depends on a vast number of interlocked factors. We may say that the project manager disposes of a large number of mechanisms (or the manager may be forced) to influence progressive managing results concerning account balance. Moreover, the summarization of results and their final evaluation is usually carried out at the end of a very long period. A large number of cases is known when project managers profited from misleading financial data and caused severe complications to the employer or brought the whole construction company in crisis.

2.1.2. Schedule evaluation

Schedule evaluation, on the other hand, is a much more reliable indicator. How individual phases are carried out, the influence of delay on other actions, the trends towards due date of the project – all of this is easily quantifiable data. Monitoring the diviations from master schedule enables the controller to evaluate the trends of the project and indicate the symptoms of impending crisis. Deviation analysis uses standard management and evaluation procedures as described in project documentation. There is a vast array of methods for schaduling management which may combine financial management and schedule adherence evaluation. The results of these analyses are used in costs management, time management, and support risk and crisis management as well. The goal for project management is to establish a boundary when a given trend becomes a crisis.

2.1.3. Quality evaluation

Quality control is performed as a set of established tests, measurements, inspections, and control points. These all lead to evaluation of output quality. Quality control may be performed by the contractor, the client, or a third party – usually an independent inspection organization. Quality evaluation monitors specific characteristics of project quality, their deviations from quality standards, and finding the causes of insufficient quality including suggestions for improvement or removal od flaws. Quality control in a construction project starts immediately after site acceptance and progresses gradually according to quality control plan established for project execution phase. Quality control takes place both on site and on the premises of suppliers of chosen equipment. Quality control tests fall into three subgroups:

- On-site quality test (insulation test, concrete strength test, reinforcement test, etc.)
- Inspection on the premises of supplier (proper storage, cube tests at concrete mixing plant, etc.)
- Tests of functionality (elevator test, noise parameters, emissions etc.)

One of the essential documents that a contractor needs to hand in after signing the contract is a quality control plan which usually consists of:

- List of all equipment and building units to be tested
- List of quality tests for each piece of equipment or building unit
- Roles of both the contractor and the owner in each quality test
- Schedule of quality control tests
- Documentation details for each test
- Person responsible for individual actions on the part of the contractor
- Person responsible for individual actions on the part of the client

The control tests serve for comparison of actual values with the ones demanded by building standards, codes of practice, or contract specifications. The outputs of this process are quantifiable, and the number of deviations needs to be observed closely. If the number of deviations tends to keep rising, it may indicate impending crisis. There is no general rule of thumb for setting a viable limit for the number of deviations, due to the fact that every construction project is unique, and the numbers may vary greatly. Furthermore, it is not even possible to set a standard for the number of deviations in the same type of structure used in different kinds of buildings. Rising numbers of sub-par items in a concrete structure used for a transportation structure will lead to different conclusions than the same number of sub-par concrete items in a retaining wall for a warehouse. Maximal number of deviations which would already signify the project's tendency towards crisis needs to be stipulated for every individual project by the supplier's production engineer.

2.1.4. Work and environment safety

Construction contracting is increasingly oriented towards on-site safety and environmental safety of projects. Construction companies train their employees in prevention of on-site injuries and accidents, and project documentations lay down safety rules and environmental relations and impacts of the project. Work safety proposal is processed with regard to categories of work activities within the project. This proposal specifies a category of likely injuries, and strives to ensure the best help possible. Injury logs are kept and the number of injuries is monitored. Project documentation specifies the scope and frequency of safety checks carried out by commissioned safety supervisor. Fire protection observes the progress of securing fire protection and classifies on-site activities in relation to fire protection. This category of crisis identification also uses standard procedures of project management and classifies potential crisis symptoms according to project documentation. The maximal number of safety breaches or injuries should be established by the commissioned safety supervisor.

2.2. Segment B of the symptom identification matrix

Segment B includes inquantifiable data of the project. Signals from this category are softer, weaker, more related to interpersonal problems of a construction project (relationships: designer-contractor, contractor-subcontractors, client's attorney – project manager, project manager – workers, etc.). These signals, however, can also be processed into a checklist and their observation may be commissioned to top managers of the project (CEO, division executive officer, project manager). A checklist of crisis identifiers in segment B can consist of:

- Worsening communication with the client's attorney
- Worsening communication with the designer
- Worsening communication with subcontractors
- Decreasing level of communication with company (division) management
- Poor communication between on-site workers
- Lowering worker iniciative
- Low work discipline and morale
- Poor task distribution
- Rising number and length of staff meetings
- Centralization of decision-making
- Low respect for company standards, emergence of cliques

These symptoms develop slowly and influence the project over time. They are usually identified only when fully developed.

2.3. Segments C and D of the symptom identification matrix

Segments C and D focus on external factors which may influence project outcomes. These factors may be revealed not only by project managers, but also by stakeholders. Stakeholders in construction projects are usually banks, investors, public administration departments (Environmental Department), project participants, and activists.

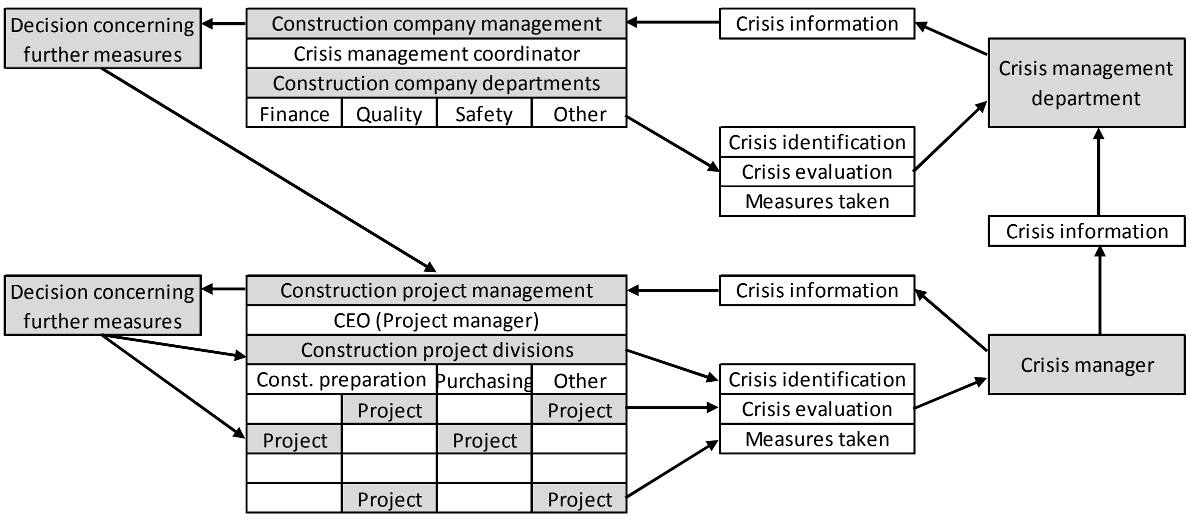

Figure 3. Early warning system for revealing symptoms of crisis in construction company structure (Vondruška 2013)

3. Conclusion

Early warning system enables the management of a construction company to monitor symptoms and indicators of impending crises through standard management procedures. This system informs the menagers of a company or a project about impending or full-fledged crisis in a project, and therefore about the need to turn to crisis management. Parameters of state of crisis and of negative tendencies within the project according to segment A of the aforementioned crisis are dependent on contract parameters of the given construction project. All four segments of the matrix link parameters of early warning system to project management standards within the company, to its strategy, market and financial stability, quality of human resources, and other like factors. Tendencies that may lead to crisis in one company may scarcely be noticed in the next. Keeping this in mind, it is therefore obvious that establishing crisis parameters is individual for each company and each project.

It is necessary for the early warning system to function properly to make it clear who monitors the individual signals, where, how often, and in what manner these will be evaluated, and who is going to be notified about the result of these evaluations. The system must be characterised by short and straightforward communication channels to the center or managing unit where evaluation is processed. Then a decision must follow swiftly about measures that need to be taken. There is no need for centralization, but if there are several centers of decision-making, cooperation is necessary so that the dividion are not mutually exclusive.

Acknowledgement

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Using LOD in structural cost estimation during building design stage: Pilot study

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Abstract

This paper presents a pilot study attempting to harness the power of Building Information Modelling (BIM), coupled with Level of Development (LOD), for practicing structural engineers to have greater understanding of design decisions on cost, and so give greater control of economy. This study aimed to exploit the wealth of BIM built environment data in a framework, matching building material data with cost information data, in the Microsoft Excel platform thereby allowing for a raw design cost to be automatically determined. Level of Development (LOD) is a standard which allows for comparison between BIM models by ensuring each model covers a specified scope. There are multiple LOD's and so by applying the framework at each of these, insight can be gained into the design cost over time as it is refined. Results indicate that similar structure types have similar design cost curves when data was standardised. The tool was employed on five separate structures: two blockwork medium-rise buildings and three reinforced concrete high-rise buildings. By employing the process over further studies, the empirical curves will be refined with greater certainty, allowing for eventual use as benchmarks to assess economic performance of design solutions.

Keywords: building information model; building; cost estimation; design stage; level of development.

1. Introduction

Despite being the largest sector in Australia, the Architectural, Engineering and Construction (AEC) industry has historically and persistently low levels of productivity. One of the recent advances within the AEC industry is the development of Building Information Modelling (BIM), touted as an IT-induced paradigm shift for the sector. According to Succar (2009), BIM represents a methodology to manage building design and project data in a digital format throughout the buildings' life-cycle. BIM is generally applied with the notion of decreased project costs, increased productivity and quality, and reduced project delivery time (Azhar 2011). These expectations of BIM provide grounding for the need to conduct research into how this may economically benefit structural design.

BIM provides a mechanism to assess structural designs in terms of economics by utilizing the latest, most up-to-date project information from all participants. By extracting relevant information from a model, this can be summarised in a form comprehendible by all industry across the board. Linking this with cost information can provide for a design cost estimate. It is possible to track the design cost as the structural solution is refined, and by doing so in many cases, provide a benchmark for design. Unfortunately BIM alone suffers from a lack of clarity in communicating structure definition for the correct uses as intended by the model author. The Level of Development (LOD) concept developed by The American Institute of Architects (AIA) addresses this issue with sufficient scope to allow for BIM to be used to track design cost estimation throughout all design stages. Since LOD is stringently defined in terms of what content is modelled at each stage, comparisons can be made between different structures. By standardizing this information, design cost curves can be derived for different structure types. It is intended that these, with further development, will be able to act as benchmark curves to allow project management to assess the economic performance of a design compared to a typical structure of similar construction.

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2. Theoretical Background

2.1. Material quantity takeoff using BIM

BIM-based quantity takeoff for cost analysis is only worthwhile when used in conjunction with rigorous, up-to-date and location specific, material cost prices. This information was used by Akbarnezhad et al. (2012) to calculate a design cost by extracting quantities from the BIM database and multiplying by the defined unit price. Provisions for construction, demolition, assembly, disassembly, transportation and the like were estimated automatically from the size of work required multiplied by respective unit cost factors. While a similar study was put forward by Fu et al. (2007), literature on BIM-based material quantity takeoff is scarce, most likely due to underutilization of the feature. However this could also be due to the lack of knowledge sharing in private enterprise (Monteiro & Martins 2013).

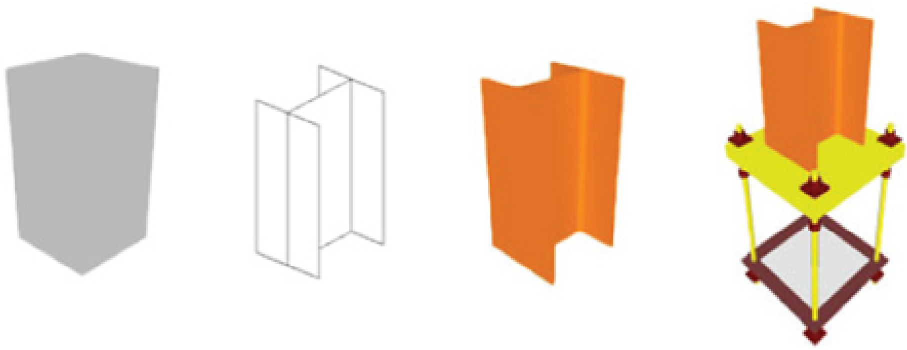
2.2. Level of development (LOD)

LOD has the ability to resolve an issue which stems from BIM material quantity takeoff – at what point should the process be implemented? It acts as a standardization which ensures the design cost is calculated at the correct time. A BIM model, by its very nature implies an exact quantity, whether it is intended to be or not (Reinhardt et al. 2013). This is the reason the Level of Development (LOD) concept was introduced by The American Institute of Architects (AIA) in document AIA E202 – 2008 (Bedrick 2008). LOD is useful to ensure the right amount of data is used in the cost estimation process and allow AEC practitioners to clearly articulate the content and reliability of a BIM model at various design and construction stages (Reinhardt et al. 2013).

There are five LOD's in the BIM context which reflect five standardised models allowing for comparisons to be made with confidence. These are listed as follows (Smith 2013):

- LOD 100 is the initial concept estimate stage,
- LOD 200 is the schematic design stage,
- LOD 300 is the developed design stage,
- LOD 400 arises as the information in the model is revised to produce construction documentation, cumulating in LOD 500 which is a BIM model reflecting the 'as-built' structure. Note that the aim of the study is to provide cost estimation at design stages, and so the 'as-built' structure is not as important, and not used in analysis.

While the AIA documents set out the standard practices, they do not provide specifics in terms of how they are practically implemented. The *BIM Forum* (https://bimforum.org) has developed a LOD specification to address this. The specification contains tables of particular BIM model elements, each showing what particular requirements should be incorporated at each LOD. The requirements listed in this document and by the AIA have been used as the basis for defining the LOD requirements for the BIM models developed in this study (Reinhardt et al. 2013). A graphical representation of this information for a typical steel section is shown below.



LOD 100 – Conceptual mass	LOD 200 – Preliminary Universal Column (UC) steel section	LOD 300 – Detailed 150UC37.2 steel section	LOD 400 – Construction details, including connection information

Figure 1. LOD progression of a steel column section (Reinhardt et al. 2013)

3. Research Method

3.1. Overview

Framework development to utilise BIM in cost estimation of structural designs revolves around two key concepts – material information from a BIM model, and cost information from an external database. Cost information includes provisions for material, labor, overheads, transport, and profit. The 2011 edition of Rawlinsons Australian Construction Handbook was used for this purpose, whereby a database was created for as many foreseeable commercial multi-storey building designs, using Brisbane, Australia as an arbitrary base location. Conversion factors are available in the guide for other locations (Rawlinsons Quantity Surveyors and Construction Cost Consultants 2011). To incorporate the LOD concept there obviously had to be some variation in the cost database to reflect the different levels of development of a BIM model. Not only is there greater certainty in a design as it progresses from one LOD to the next, but there is also a greater amount of elements that should logically be defined.

There are numerous alternatives to achieve material quantity takeoff from Autodesk Revit, the chosen BIM platform. These include Autodesk Quantity Takeoff (QTO), COBie spreadsheets, third-party software, and procedures inside Revit itself such as schedules and database links. COBie spreadsheets are mainly targeted towards facility management, however should be monitored into the future to assess whether they develop into an industry standard for material quantity takeoff under the context of this study. In order to keep things simple and accessible for users of the framework it was prudent to ensure that only the basic Autodesk Revit software is required. By elimination, the only option was to use schedules from inside Revit, referred to henceforth as Material Take-Off (MTO). MTO allows extraction of the following information through schedules, used at each specified LOD.

Table 1. Revit schedule capabilities

Revit Schedule	***Information extracted***	***Applicable to LOD***
Mass floor schedule	Building Gross Floor Area	100
Multi-Category Takeoff	Number of different elements, and the respective total volumes and areas	200 & 300
Structural Framing Schedule	Framing lengths	200 & 300
Structural Column Schedule	Column lengths	200 & 300
Rebar Schedule	Reinforcement mass	400
Fabric Reinforcement Schedule	Fabric reinforcement mass	400
Generic Model Schedule (using post tension family as instructed in Wood (2013))	Post tension mass	400
Structural Connection Schedule	Number of each connection type	400

With ground work achieved into preparing cost and material information for comparison, a function or script is required to match cost and material information together. Basically it needs to read the BIM object description, then look at cost object descriptions and select the best match. A best match is required as the nature of the databases mean the naming conventions are different. The platform to achieve this matching is inside Microsoft Excel – chosen for is universal acceptance and understanding throughout all industry. Several user-defined functions complete this stage of the algorithm as illustrated in Wood (2013).

The general details of the material information, cost information and matching technique have now been introduced, and so it follows that the framework must then handle the information to yield a design cost. This is based on a very simple and fundamental equation:

$$\text{Element cost} = (\text{Unit cost}) \times (\text{Element quantity}) \tag{1}$$

Clearly there must be consistency of units for this equation to hold true. With the element cost derived, the process is completed for all elements in a BIM model, and then summed to yield at design cost for the LOD.

3.2. LOD cost estimation

LOD plays a standardization role in the framework, however it also allows for useful analytical information to be gained, a direct result of the different BIM models which are developed at these predetermined stages over the temporal dimension. Applying the framework at each of these stages allows for cost information to be derived in the form of a curve varying with time.

In order to make comparisons between different design cost curves for different structures, some form of data standardisation is required. It was forward by the authors that for structures of similar structural system, material, and construction type, the design cost curves are the same shape, albeit out by a certain factor to account for the differing scopes of each building. This factor can be negated to allow for comparisons by creating relative figures calculated using the below equation:

$$Relative\ cost = \frac{Cost\ at\ specific\ LOD}{LOD\ 100\ cost} \quad (2)$$

In this context, LOD 100 can be thought of as a measure of the building scope as it is proportional to gross floor area. It is clear that relative cost is the dependent variable in design cost, however the independent variable requires discussion. LOD gives no indication of the effort required to create each model, and that is important in the narrative over a temporal dimension. The curves are plotted against a new variable, relative effort, which is defined in a similar manner to relative cost:

$$Relative\ effort = \frac{Cumulative\ effort\ to\ specific\ LOD}{LOD\ 400\ effort} \quad (3)$$

LOD 400 effort is used because it is the maximum effort expended over the course of the analysis, and so the relative value will always be less then unity. By establishing the effort to create a BIM model, this information can be used to allow for empirical relationships to be derived for final design cost, even when using data from the initial conceptual stage.

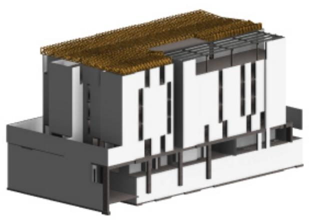
One question that may have arisen at this point is, wouldn't user experience have an influence on the design cost curve? It is shown by Wood (2013) that the influence effort has on the LOD 400 estimate from the design cost curve is often one order of magnitude less than the associated change in effort. In other words, if the effort changes by say 100%, the effect on the LOD 400 estimate would be ~10%. Furthermore, because the process uses relative effort, and it is relatively safe to assume that the ratio of time spent for each LOD would be similar between users, the overall impact is negligible for estimating purposes.

The design cost management process is envisaged to allow for empirical graphs to be derived for specific structure types providing a realistic forecast, with upper and lower bounds, for a design cost at construction, using early conceptual information. Obviously to yield these types of empirical curves, the framework would need to be employed over many different case studies of each type. Ultimately, it is expected that these curves would form a benchmark for future structures. This would give engineers and management the best chance to identify poor economic performance of a structure, and make subsequent improvements.

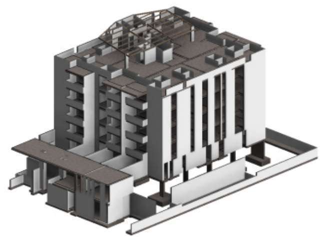
4. Results and Discussion

The framework was applied to five cases as shown in Figure 2. Both Cases I and II are very similar in terms of both the blockwork and reinforced concrete structures, but also in terms of scope. They should therefore produce relatively similar curves. A similar notion exists for Cases III to V structures.

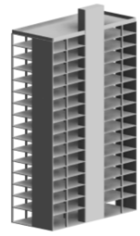
Figure 3 compares various curves of the relationship between relative cost and effort for all the five investigated cases. It should be noted that the blockwork structures (Cases I and II) use a logarithmic regression analysis, while the 16 storey office structures (Cases III to V) use a power regression analysis. This reflects the aspect that for different types of structures, the design cost curve can have a different shape, and so a different regression analysis function is required to best fit the data. Applying this process to many other structures of the same types would verify whether these choices are truly appropriate for the wider, general empirical curves as the benchmark for economic evaluation of designs. This decision is governed by the R^2 values.



Case I: Five storey reinforced concrete /blockwork office.



Case II: Six storey reinforced concrete/ blockwork apartments.



Cases III, IV and V: Sixteen storey reinforced concrete office buildings with 6m, 8m and 10m shear wall lengths, respecitvely.

Figure 2. Case studies

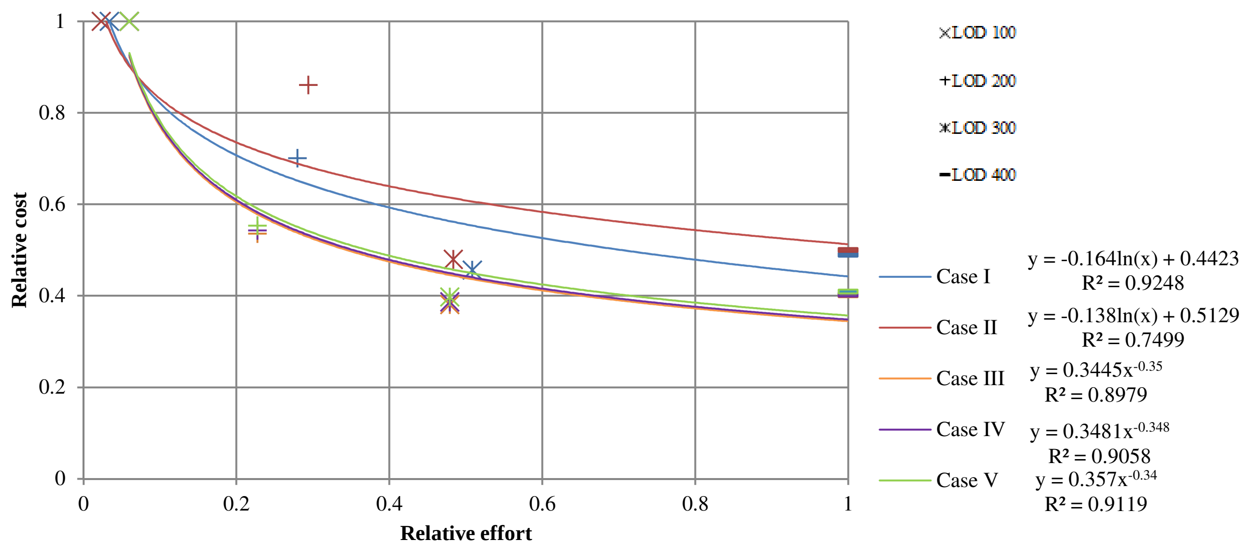


Figure 3. Design cost curves of the five investigated structures

The two functions derived for the Case I and II structures predict LOD 400 relative costs of 0.44, and 0.51 respectively. If an average for this structure type is taken, the LOD 400 relative cost prediction would be 0.475±0.035. This is an illustrative range, and confidence would increase as more structures of a similar type are put together under analysis.

While the design alternatives for Cases III to V (16 storey structures) do have changes in relative cost, it is far less than those for different structure types. It is worthy to analyse that the apparent confidence for the 16 storey structure is greater than for the blockwork structures, when predicting LOD 400 using the modelled equations. This is perhaps best explained as the office structures are predominantly similar. The aim of this analysis is not to expect the curves to be identical, however they should be similar enough that an average of many examples of the structure type reveals a different curve than for another structure type. A further explanation could be because the model for Case II is a relatively poor fit ($R^2 = 0.75$).

Discussion is warranted to the shape of the design cost curves. For example, note the asymptotic behavior of the curves. The downward curvature is best attributed to the increasing definition of a structure. At LOD 100 it may be known to be an office building. This could be of many different materials and construction types. The LOD 200 cost has an idea of this information, and it would be expected that the designer would choose a system which is cheaper than the average of all types of systems, which is why the curve goes down. The same analogy can be used for higher LOD's.

It must be stressed these figures are only for the structural system modelled. This in no way reflects the cost of the building to a client, and should be used only as a tool to evaluate the effectiveness of a structural engineer to minimise costs of only the structural system.

It would be worthy to implement the framework into a real-time project to analyse what time saving benefit the framework offers over traditional economic evaluation procedures. While from literature this is expected to be a significant saving, quantifying it in terms of the actual framework is useful information, something which could be used to attract potential users and research collaborators.

The framework was developed solely to satisfy the need for an enhanced costing mechanism of structural designs. In the changing global climate, one where sustainable design is becoming a critical element of projects, this offers an additional application of the framework – environmental impact assessment. The environmental footprint of a building can be quantified in terms of embodied energy and carbon, and if a database can be made to quantify each of these with respect to each structural element, a carbon database can be constructed, analogous to the cost database. This information would be invaluable in accounting for, and comparing sustainable designs. It would also assist in providing to a client what effect prices on carbon, such as an Emissions Trading Scheme, would have as a result of decisions by the structural engineer.

The eventual goal of the developed framework is to provide an automatic economic evaluation and optimisation procedure for structural design. It is envisaged the developed framework could lend weight to structural optimisation procedures, especially given the holistic building view BIM offers.

5. Conclusion

This study developed a framework to utilise the power of BIM in performing cost estimation of structural design options. In practical implementation this will allow for an enhanced interactive design process between all stakeholder parties, resulting in more efficient and economic solutions. The general approach taken by the framework was to extract material information from BIM, and then provide an algorithm to fuzzy match BIM objects with cost data. Multiplying both data sets together, after assessing for correct units, allowed for a total design cost to be made. By using the LOD concept, economic information could be determined over the temporal dimension. While only a few structures were tested in this study, it is envisaged that empirical relations will be derived for certain structure types. This will give framework users a benchmark to assess the economic performance of a structural design. Furthermore it will give an indication of where the design cost is likely to head, and how much the design needs to be refined to get there. Further testing of the framework is required to ensure the approach is valid in a greater selection of design alternatives. With future industry collaboration and development, it is envisaged the framework will have a role to play in the design process to ensure design solutions stand up to economic scrutiny.

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Development of key performance indicators for organizational structures in construction and real estate management

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Abstract

Construction projects as well as comprehensive projects of Real Estate Developments are evolving more and more as a matter of complex interacting networks driven by means of coordination and motivation.
Profound analysis of networks is done since several years with remarkable success in particular by sociologists. By modelling social networks through methods provided by Linear Algebra and matrix calculation, some very interesting general parameter can be formulated, which characterize the networks solely based on its structure.
Social networks are developing on a background of personalities and the interaction specified by sociology in general and in particular a subset of interaction means given by e.g. software restrictions on respective platforms.
Such procedures turn out to be useful and directly applicable to networks formed by participants in construction projects like trades, subcontractors, workers, departments, hierarchical groups and other involved parties. The generalized personalities are also given by their tasks and their according interests and motivation, where the interaction is defined by legal dependencies and contracts.
Not much diverse from this situation are the markets in real estate development, where players and their rules are given accordingly.
In this research we propose to define network parameters for project interaction structures in construction as well as in development situations and analyze these for the a priori elaboration of well supported interaction schemes. Furthermore already existing parameters are to be identified and mapped on this parallel world in order to improve the understanding and thus the definition of an organization plan as an inevitably required precondition for thoroughly prepared projects.

Keywords: Construction Management, Key Performance Indicators, Organizational Structures, Project Management, Project Delivery Systems

1. Introduction

The classical solution to the present situation of projects starkly increasing in size and complexity is Division of Work (Picot et al. 2008) awarding subtasks to respective specialists. This solves the demand for interdisciplinary skills but induces the new requirement of motivation and coordination of third parties to share the common goal (Principal Agent Problem). Yet, as the main task becomes divided into pieces interfaces need to be defined and information to be transferred to give the executive units the best possible means to to carry out their segment. Therewith complex strongly interacting projects are mapped on networks of primarily independent players which are connected by contracts determining aspects of motivation – remuneration and other incentives – as well as coordination – information, design and plans. On this background conducting complex projects thus extends classical risk management regarding unknown facts to the view on the uncertainties of the network structure itself and the connecting ties. The connections are formed by contracts and therewith suffer principally from incompleteness. Lack of perfectness ranges from the description of tasks, properties and required results in quality, time and consumption of resources to the uncertainty of the efficiency of the implemented incentives (e.g. Zimmermann, Eber 2011, 2014). This raises the question of the role of the network itself and of whether stability can be obtained by constructing secure and flexible, probably self-repairing or at least failure tolerant network-structures to ensure a positive result.

2. Networks

2.1. Networks in Construction and Real Estate Management

Network structures in conducting projects in Construction or in Real Estate Management mostly comprise different interaction classes and contents at the same time and thus form a set of multiple interleaving structures.

Elements would range from single persons to departments, companies, authorities and administrations. Different elements would be activities, work packages and tasks producing results but requiring pre-products and resources as well as the mentioned products, pre-products, resources and information. As numerous in type and character the elements are, as multiple are their possible interactions.

Thus conducting large projects is first of all solidly based on the fact that there are specialists and methods capable to fulfill the requirements of the single tasks. Under this precondition large projects focus on the singular challenge to find and combine them by coordination and motivation and make them on the one hand accomplish the task and on the other hand form the network to encourage or force them to do so successfully and efficiently. This implies the careful analysis of each singular element and furthermore of the local interactions with its direct neighbors. Secondly the network itself needs to be analyzed respectively designed providing the overall partial and total developments and results as emergent values. On this background the network needs finally to be optimized according to (Malik 2003, 2008, Wiener 1992) by controlling and steering the flow of information i.e. the contracts that form the network.

Traditionally relevant networks are in a first approach built by the use of the classical work break down structures (WBS e.g. Kerzner 2003, Lewis 2002, Schelle et al 2005, Schulte-Zurhausen 2002). The project task is broken down along a graph theory tree-structure to finally work packages. Since a tree-structure can only follow one singular characteristic WBS are constructed vertically while distributing responsibility. Thus elements are tasks and subtasks, often correlated with products and sub-products created within the tasks. Finally work packages are leading to activities as the final level on the tree. Correspondingly to the only vertical tree-structure all horizontal interactivity is so far neglected for the purpose of unambiguity. Further interrelations are only introduced at the very bottom level of the activities where classical networks structures allow for time and resource related interactions. These are according to the theory of graphs only restricted to the existence of a starting node, an ending node and most of all to being loop-less which is a very artificial requirement, never matching reality. Nevertheless the restrictive network of strong preconditions and post-conditions of production activities can be modeled only here.

2.2. Social Networks

Social and behavioral science has shown considerable interest in investigating social networks during the last decades (Wassermann, Faust 1994). In recent times a new type of huge social networks has come up as a fairly new phenomenon and has been studied widely. These are dependent on computer networks for easy access and model social interactions of participants based on their free decisions to share personal information and interest. Therewith structures are formed which are subject to no predefined graph-theoretical rules but on purely object-related short-path communication. They are not purposefully modelled from outside, yet, model themselves nevertheless for a general purpose of forming communities within higher order communities and thus serving a higher unspoken goal driven by local motivation. So to say, structures are formed to perform some sort of a common task, thus creating and optimizing itself, probably also terminating itself if not matching or just losing the commons interest. The software behind social networks only provides the means of interaction i.e. the definition of dependence and allows the participants to form the network appropriately.

The constructional counterpart to this is the installation of project platforms offered to conduct large projects where a number of participants share a goal and the interfacing information. These are well established in Construction and Real Estate projects. In contrast to purely social networks the project managers try to handle the interaction on such platforms very restrictively and channel the required information and communication along well defined network paths in order to keep the structure itself efficient and targeted. Typical applications are given by modeling business processes very accurately in order to force participants to follow the predefined structures. Yet again only the means of communication are provided, the motivation to share the goal is determined by the underlying contracts. Therefore, construction of structures is merely a matter of to which extent hierarchical vertical structures were to be replaced by horizontal self-organizing structures.

On any account coordination and motivation demands are modeled by the definition of interaction which is comparable to the efficiency automatisms found in social networks. This raises the question of how to define means and degree of interaction to make a network function and lead to a predefined result. Furthermore measures need to be found to judge the efficiency and safety of a predefined or to some degree self-developing network. Therefore a thorough analysis of the network key parameters is expected to reveal typical characteristics of project structures as well as of social networks.

3. Matrix calculus

3.1. Cross-Impact Approach

Operability and predictability of linear networks has been elaborated under the notification of Cross-Impact approach (Gordon 1968, 1970) and to some extent used and modified as the Sensitivity Model (Vester 2001). Basically the impact of a number of aspects or variables (equating network nodes or participants) on each other is denoted as probability estimation [0..1], later in a more qualitative view as strength ranging from 0 to 3 (none to strong impact) and listed on a square matrix where each participant is assigned a row as well as a column. The horizontal sum of elements for each row is named the active sum AS and represents the activity role of a participant indicating of how actively its influence on all other network members would be. Simultaneously the vertical sum throughout a column yields the passive sum PS , indicating the degree of reactivity of the respective member to all other players. The combination of these two values allows characterizing the criticality $P=AS\cdot PS$ of a node. If active-sum and passive-sum are both high small modifications would lead to high positive feedback effects which likely would destabilize a closely coupled system. On the other hand both parameters being low stand for participants ready to stabilize a system by damping modifications. The ratio $Q=AS/PS$ denotes the parameter of control ranging from actively in control of the system if high to reactive on the low side if strongly responding to modifications.

3.2. Adjacency Matrix

The common approach starts with modelling all participants on a network as nodes on a graph (sociogram) and all interactions as edges (e.g. Wassermann, Faust 1994). In order to access graphs by mathematical means they are denoted as matrices (sociomatrix). In an unweighted adjacency matrix A each node is represented by a row as well as a column, a connecting edge independent of its direction or weight is denoted as a 1 at the crossing position. If the strength of interaction needs to be analyzed this unit value is replaced by the preferably normalized weight of a directed interaction $w_{i,j}$ and leads to the weighted adjacency matrix A_w . Then the mentioned characteristic $\overline{AS}$ and $\overline{PS}$ values defining the role of a player are easily obtained from A_w as left or right sided product with a one vector. This corresponds to well-known structural parameters of social and other networks and allows extending them:

- For unweighted adjacency matrices the vector AS equals PS and yields the particular degrees as components and averaged nodal degrees as length. Otherwise appropriate weighted in-degrees and out-degrees are defined accordingly and represent the local impact on members of the network or the influence a member has on its adjacent neighbors.
- The average active sum exactly mirrors the impact parameter ς as well as the parameters of influence ξ of a network according to Zimmermann/Eber (2012), within a closed network $\xi = \varsigma$ also reflecting the parameter of connectivity $\nu=(\xi+\varsigma)/2$:
- The density (Wassermann et al 1994) of a directed graph thus becomes the ratio of the existing interactions to the maximum interactions, possibly including their weight.

Yet this linear understanding does not take into account the repetitiveness of interactions in a system during its development or more importantly, its convergent or divergent behavior. Therewith the number of (possibly weighted) paths through a network and the more of closed path loops and feedbacks gains importance. However, the approach can easily be extended to handle multiple interactions by making use of the power of the adjacency matrix. According to e.g. Katz (1953, p. 40) we obtain

- $A_{i,j}$ to the power of k as the number of paths with length k from node i to node j,
- the sum over $A_{i,j}$ to the power of $k=1..m$ as the number of paths with length $<=m$ from node i to node j and
- the sum over $A_{i,i}$ to the power of $k=1..m$ as the number of closed loops with length $<=m$ where node i is involved.

Making use of this we obtain higher order active and passive sums as well as a parameter indicating the degree of recursiveness of the graph. These can be treated equivalently to AS and PS to determine the role which an aspect or participant plays within the system but include the behavior of the system up to the m^{th} step of time-development. Thus true long-term roles can be determined from higher powers of A:

- the normalized active as well as passive sum of degree m, taken from $A_{i,j}$ to the power of $k=1..m$, and

- the sum of weighted loops with length $<=m$ where i participates. From this an indicator of recursiveness –yet not equal but correlating to the definition of (Zimmermann, Eber 2012) can be derived as the trace of the respective matrix.

3.3. Long-term behavior and stability

Since networks are operated mainly far away from equilibrium long-term evaluations may be questionable in detail but nevertheless characterize stability providing useful indicators. Therefore the mentioned degree m needs to be observed to infinity by giving every aspect/participant an arbitrary initial weight and applying A an infinite number of times to obtain the influence of adjacent nodes with their actual weight. Proceeding to infinity the vector of weights yields the stable final relative weights of participants independently of the initial weight choice.

This procedure is identical to the evaluation of Eigenvectors of A. At the first glance being just a final distribution of weights after stabilizing the Eigenvector turns out to be a classical means to measure centrality of a node. Centrality of a node and respectively Centralization of a graph are fairly important parameters characterizing functionality of social networks. However temporal project networks can be measured and judged by the same. Well-known centrality parameters are e.g. (Bolland 1988, Landherr et al 2010, Freeman 1977, 1979, 1991, 1980):

- Degree-Centrality, where the number of In/Out-Edges measures the importance of a node (Bolland 1988).
- Closeness-Centrality is given by measuring the average distance of a node to each other (e.g. Beauchamp 1965).
- Betweenness-Centrality counts the number of geodesics between each pair of nodes the considered node sits on and therefore claims influence (Freeman 1979)

The Bonacich Power Centrality (Bonacich 1972, 1991) states that the power of a node is determined by the average of the powers of the adjacent nodes which is identical to the Eigenvector algorithm described before. The complete Bonacich approach includes a controllable soft transition to the degree-centrality which is of no further interest here. The Page-Rank Algorithm (Page et al 1998, 1999) used to evaluate the power of a webpage is based on a similar mechanism.

From the point of view of Theory of Systems Eigenvalues have a very specific meaning for the stability of system (Bertalaffny 1969, Haken 1983) which is of interest for designing operatively working networks. In the long-term development each node is per time unit modified by a linear function of the actual state of all adjacent nodes. Then the system can be expressed as a set of linear differential equations. Any (weighted) adjacency matrix denotes the (linear) influences of a state given by a state-vector on the future state by its modification during one progression step. Such systems can be solved if A is diagonizable. In this case the Eigenvalues λ_i form the values on the diagonal. Solutions would thus be concatenated from exponential functions, where the Eigenvalues are a factor on the time argument. Thus possible interpretations for the resulting set of Eigenvalues regarding the stability of the overall network taken from sign, value and possibly imaginary components would range from exponential stability to exponential growth respectively stabilizing to destabilizing fluctuations.

In the case of Cross-Impact-Matrices mapping interactivity of participants in a social or temporary organizational system we derive therefore: As long as a pure adjacency matrix is analyzed, all values are 0 or 1 and A is symmetrical. Making use of the Cross-Impact-mechanism weighted adjacency matrices occur with positive strength values e.g. $[0..1]$. Then all Eigenvalues are of real type and systems of this kind are rarely stable (EW<0) but developing. Thus we have in any case exponential growth, probably decrease as well. Therefore the only point of interest is which item would dominate the growth where all others are reduced by continuous normalization (Perron 1907, Frobenius 1912, Rheinboldt et al 1973). According to the Frobenius-Perron Theorem a dominating positive Eigenvalue and an associated positive Eigenvector can be derived which determines the long-term behavior of the system and therewith serves as characteristic property of the network.

3.4. Laplace-Matrix

The transition from dominant Eigenvalues to strictly dominant Eigenvalues rests on the condition of the existence of at least one singular path between any two nodes corresponding to the property of irreducibility of the graph, i.e. the graph does not decompose into components. Therefore means to measure the degree of decomposition, i.e. the connectivity are required and given by the Laplace-matrix $L=D-A$ (Diagonal matrix of node degrees D minus adjacency matrix A) in accordance to e.g. Chung (1991, 1997) or Spielman (2012). Hence, the multiplicity of the smallest Eigenvalue $\lambda_0=0$ reveals the number of components a graph decomposes into (Bollobas, 1998, Chung 2006, Fiedler 1973, 1975, Mohar 1991, Trevisan 2009). This can be calculated easily by solving the characteristic equation for L for roots at $\lambda_0=0$ and eliminating them consecutively until no more are obtained at position zero. Therewith the number of elimination steps yields the number of connectivity components of the network. Since this works well on weighted graphs the degree of decomposition of a network can be directly observed and used as key indicator for the development of independent subgraphs.

4. Conclusion

From these considerations we propose the careful analysis of the spectrum of a network mapping the scope of participants and their interactivity or the better the construction of such networks according to such aspects. This would apply e.g. to

- Communication within social networks as well as in participants interaction in construction projects
- Trading in economy, interaction of players on markets, analysis of locations and quarters
- Flow of Decisions and Reports, failure progression, distribution of risk and uncertainties in projects
- Cooperation within consortiae, stakeholder analysis, analysis of influence in rental contracts

Within such scenarios nodes weights and appropriate equilibrium scenarios would possibly be formed by

- Rates of financial flows, where the equilibrium is the final distribution of capital
- Weighted degree of decision making, where the equilibrium will be the degree of responsibility
- Material flows would be modelled and the equilibrium will be the need for storage over given time frames
- Flows of abstract or real production factors. Then equilibrium weights reflect the the particular creation of value

Therefore we demand a so far constructed system to be at least stable on the long-time scale, i.e. a strongly dominant Eigenvalue and an associated Eigenvector which mirrors a fairly well preferred state. Then the Eigenvalue reflects the time constant we are to expect for stabilizing which required to be as large as possible since the characteristic time of convergence is obtained by $\tau = 1/\lambda_n$. If this is not possible which is unfortunately to be expected if the systems is not absolutely straight forward and small nevertheless the spectrum will reveal the main character of the network requiring more specific treatment. In particular all Eigenvalues and associated Eigenvectors need to be known in order to estimate and predict the networks future behavior. All possible states (=Eigenvectors) should be preferred ones and be reached within sufficiently short time $\tau = 1/\lambda_n$ as we would like to construct networks short-time stable.

The proposed constructional approach according to Zimmermann, Eber (2013) is implemented by the introduction of additional nodes (control processes), on the first hand increasing options of complexity. Yet if these would be strongly interacting with existing nodes (production processes) they would force their outcome into very small corridors which are precondition to subsequent production processes. Therewith the interconnectivity of production nodes is strongly reduced by the operation of the added control nodes. The main consequence would therefore be the falling apart of the most complex network into small world scenarios which are subject to only very few clearly assessable sets of Eigenvectors and respectively Eigenvalues determining their behavior. Thus the construction of appropriate networks with clearly predictable sort- and long-term stability and outcome is possible and can be proven easily.

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Creative Scheduling in Construction

A possible extension of modeling capabilities of network techniques

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Abstract

Existing and widely used scheduling techniques suffer from many shortcomings and drawbacks. These are mainly due to the oversimplifications made in the late 50s-early 60s to adjust these scheduling models to the available mathematical and IT tools. In this paper, these shortcomings of network techniques are collected and classified. Following this a new general model can be defined using a new representation system that allows for example:

- the use of loops for determining recurring activities,
- precedence relations with arrows at both ends for modelling the sequencing problem in construction,
- precedence relations that can be used to describe minimal and maximal spatial distances,
- decision nodes with or without probability, etc.

Resources are assumed to be unlimited throughout the paper unless otherwise is explicitly stated. The main result of this research is a more general scheduling model that better fits the needs of project planners than the existing methods.

Keywords: Network techniques, Precedence Diagramming Method, precedence relations, sequencing problem, loops in networks.

1. Introduction

Occam's (or Ockham's) razor devised by William of Ockham (1287-1347) is the principle of parsimony/succinctness used in the theory of problem-solving in many sciences. In mathematical modeling it can be interpreted as "as simple as possible, as complicated as necessary". (Lucko, 2014) However, this is not a term to easily interpret. Consequences of (over)simplification cannot be foreseen ahead, and the validity of the outputs is often questionable. Sometimes model makers oversimplify the problems just to make it solvable by using the available IT and mathematical tools. In the authors' opinion, widely applied network scheduling techniques – such as CPM (Kelley and Walker, 1959), Precedence Diagramming (Roy, 1959), (Fondahl, 1961) and PERT (Malcolm at al, 1959) – suffer from the same problems. At the time of their birth, decision making theory and information technology were not ready to solve those complex problems which can easily be solved by using those available tools that have been developed recently.

The authors state that weak modeling capabilities cannot result in adequate plans; consequently, the project control process that compares the facts to non-adequate plans is usually misleading. The magnitude of getting false information from these processes is hard to estimate but cannot be denied. The aim of this paper therefore is twofold:

- to collect and classify those shortcomings of the widely known and used network techniques that could not be ignored,
- to propose a general model and an adherent graphical representation that makes the tools of the new model to use in planning practice.

A serious limitation of this research is that resources are ignored throughout the paper. The main reason for that is the size limit given for this paper.

2. Literature review

2.1. Program Evaluation and Review Technique (PERT)

PERT was developed during the cold war at the end of the 1950s. (Malcolm at al, 1959). The task to be solved was to determine the distribution of the project duration. The main simplifications/hypotheses of the original model were the followings:

- activities follow a beta distribution, and correlation in activity duration among activities does not exist
- three-point estimation can be used to model the activities' pdf function,

- only one critical path exists and no other path can candidate to be critical,
- activity calendars are ignored in the PERT model.

Regarding the distribution of the activities Clark stated (Clark, 1962) that “The author has no information concerning distributions of activity times; in particular, it is not suggested that the beta or any other distribution is appropriate”. Despite this many other distributions were introduced over the decades, e.g. the lognormal distribution (Mohan et al., 2007), the double truncated normal distribution (Kotiah and Wallace, 1973), the mixed beta and uniform distribution (Hahn, 2008), the triangular distribution (Johnson, 1997), and the Parkinson distribution (Trietsch, 2012) among others. Thorough justification of the applicability of these pdf functions from engineering point of view is still missing. On the other hand, some authors (Kamburowski, 1997) (Hajdu and Bokor, 2014) argue that due to the significant uncertainty and imprecision reflected in the estimates, the application of new pdf functions does not result in more realistic distribution for project duration.

The original three-point estimation has also received great many critiques. This estimation only gives precise results for the expected value and the variance, if the beta distribution is symmetrical, that is both the optimistic and pessimistic activity durations are at the same distance from the most likely value. However, it was shown (Farnum and Stanton, 1987) that under some conditions, the magnitude of the inaccuracy can be accepted.

It was soon realized that the original calculation is very optimistic. These optimistic results were the consequences of the hypothesis regarding the one possible critical path. Solutions for a better determination of the distribution of the project duration were developed over the decades. These can be divided into three groups according to the classification by Adlakha (Adlakha, 1989) and Elmaghraby (Elmagrabhy, 1989) from estimations (Dodin, 1985) through Monte Carlo simulation (van Slyke, 1963) to analytical solutions. (Fischer at al., 1985)

2.2. Critical Path Method (CPM)

The original CPM method developed in the ‘50s (Kelley and Walker, 1959) was a cost optimization problem, which was solved by parametric linear programming. Dozens of sophisticated algorithms and embellishments were developed over the decades but none of them has dealt with how to improve the internal logic of the projects.

2.3. Precedence Diagramming Method (PDM)

Although Precedence Diagramming is the prevailing technique of today’s construction practice, its birth was not as radiant as the birth of CPM or PERT. Even the date of birth and the name of the parents are hard to define. The pioneering work of John Fondahl (Fondahl, 1961), who suggested the activity-on-node notation instead of the activity-on-arrow notation, and Roy (Roy, 1959), who introduced the SS and maxSS relations, could be considered as the forerunner of today’s Precedence Diagramming Method. Even the algorithm of the simple time analysis changed a lot over the decades. The introduction of the SS and FF relations caused a lot of problems for those researchers who were socialized on the CPM or the PERT technique. It was strange for the planners that shortening of the duration of a critical activity can increase the project duration and vice versa. This observation has led to the characterization of critical activities and to the definition of splittable activities. (Wiest, 1981) It must be noted that the definition of the split was not a real split as it assumed also continuous intensity without interruption, but with lower speed. Today this activity type is called elastic. The four types of critical activities originally defined by Wiest (Wiest, 1981) has been extended to six by Hajdu (Hajdu, 1997) .

3. Main classification of problems in planning and scheduling

Problems that hinder the creation of “good” project plans (although it is hard to define the term “good plan”) can be classified as follows:

- Problems and limitations of the scheduling software,
- Lack of knowledge on the planner’s part,
- Shortcomings of the existing models

Problems and limitations of the available scheduling software is a huge topic, which requires the detailed and thorough knowledge of the available applications. In this paper we do not have the possibility for listing these problems and limitations, so the list below is just to indicate the magnitude of the problem:

- some software cannot handle maximal relations,
- different software gives different project duration for the same network,
- some applications allow more than one precedence relation between two activities, some of them do not,
- different activity types are used in different applications,
- calendars cannot be assigned to precedence relations, sometimes the software automatically assigns calendars to precedence relations,
- projects created in an application cannot be converted into another.

Very often planners do not have the necessary knowledge to create a reliable schedule. This could be the consequence of the lack of necessary theoretical knowledge or the lack of information about the project. E.g. planners are usually not aware of one of the most important hypotheses of the Precedence Diagramming model that activities in PDM are assumed to be carried out with the same intensity without interruption. (Hajdu, 1997). Sometimes they are not even familiar with the rules of the time analysis.

Lack of knowledge about the project can also be the cause of non-reliable plans. Preparing a detailed and reliable plan is a huge work that requires a lot of time, creativity, and the evaluation of different options. It can be said that the necessary sources are very rarely allocated to the planning process and planners usually suffer from the pressure of time and cost, which, of course, has a negative influence on the quality of the project plan.

Addressing the shortcomings of the existing models is the main issue of this paper. These can be classified as:

- Problems with activities, activity durations
- Modeling problems that hinder the correct definition of the logical interdependencies within the project, between activities.

4. Shortcomings/problems regarding activities

These types of problems can be classified as follows:

- Adequate list of activities is hard to define
- The accuracy of the estimates of the activity durations is always questionable
- Modelling the changing intensity and breaks within activities is very awkward
- The effect of calendars on activity durations cannot be handled with the models
- Correlation can exist among the durations of some activities

4.1. Adequate definition of activities

Planners usually work under serious time pressure, which often leads to the omission of some important activities. These mistakes can result in serious delays in the project. Models and methodologies that completely ensure the definition of activities without failure do not exist. Knowledge-base and expert systems that contain the lessons learned from previous and similar projects could help.

4.2. Accuracy of the estimates of activity durations

Activity durations (either deterministic or stochastic) have great influence on project duration; therefore the exact definition is extremely important. Today's techniques are based on simplified calculations – e.g. 100 workdays is necessary so with 10 worker it will be 10 days, but with 20 workers it will be 5 days – that lead to wrong estimates. In case of stochastic models the definition of the probability distribution of the activities is almost impossible. However, it was shown (Hajdu, Bokor, 2014) that the precise estimation of the most likely, optimistic and pessimistic durations have much greater importance than the exact estimation of the pdf functions.

4.3. Changing intensity of activities

Scheduling practice uses Precedence Diagramming in 99%. The most important hypothesis of Precedence Diagramming method is that activities are carried out with the same intensity without interruption, which almost never happens. Generally in scheduling it is assumed that two-day work provides twice the performance as the performance in a day. However, this is not true, even if the same resources are allocated to the task each day. To start the work, some preparations are required, e.g. studying the site and the working conditions etc., which result in a slower start. This phenomenon can be described by using learning curves.

Mathematical learning curve models can be used in construction for the prediction of the time/cost required to perform a future repetitive activity. The time required to perform a given activity is decreasing in a repetitive construction work. Learning curve theory is applicable to predict the cost/time of future work based on the assumptions: there are repetitive work cycles with the same or similar working conditions in terms of technology, weather, workers as persons, without delay between two consecutive items. According to Wright (Wright, 1936) the reduction in time follows a monotonically decreasing function. Recent studies show that the work also has a forgetting period (Lam, 2001)

4.4. Effects of calendars on activity durations

The duration of activities sometimes depends on the weather. Cold, rain, wind, decreased visibility – which is more frequent during late autumn and winter – can slow some types of works by as much as 20%. At the time of the estimation of the duration the planned start and finish is not known; therefore the need is obvious for defining the activity durations as some function of the calendar.

4.5. Correlation among activity durations

Sometimes the durations of two tasks depend on each other. This means that some kind of function exists (either stochastic or deterministic) between two or among more activities regarding their activity durations. If plaster works were finished in high quality than paintworks can be faster, and vice versa, a poor quality plasterwork will require longer paintworks. Dozens of similar dependencies can be defined; however these problems were not addressed in the traditional network techniques.

These kinds of dependencies can either be positive or negative. Tasks are correlated positively, if an increment of the duration of an activity will result in longer durations of the correlated activities. To the contrary, in case of negatively correlated activities longer duration will result in shorter duration of the correlated activity and vice versa. In the literature, most of the cases, linear relationships are investigated with correlation coefficients.

5. Shortcomings/problems with the creation of the projects' logic

These types of problems can be classified as follows:

- Sequencing problem
- Models usually allow the definition of relations between the start and finish point of the activities. How can we define relations between activities and not between their start and finish points?
- Spatial distances cannot be modelled
- How can recurring activities be modeled in a network?

5.1. Sequencing problem

Let a small project be given. (Fig. 1a) Activities A1, A2 and A3 have to be carried out in three different streets, which require the temporary closing of the streets. However, the authorities only allow to close one street at a time. This will result in 6 different options for the sequences of activities A1, A2 and A3. Different sequences will result in different project durations. The task to be solved is to find the shortest project duration. This well-known problem of operational research can be incorporated into the network as it is shown below. (Fig 1b) The relation with two arrowheads means that an FS0 has to be satisfied in one direction.

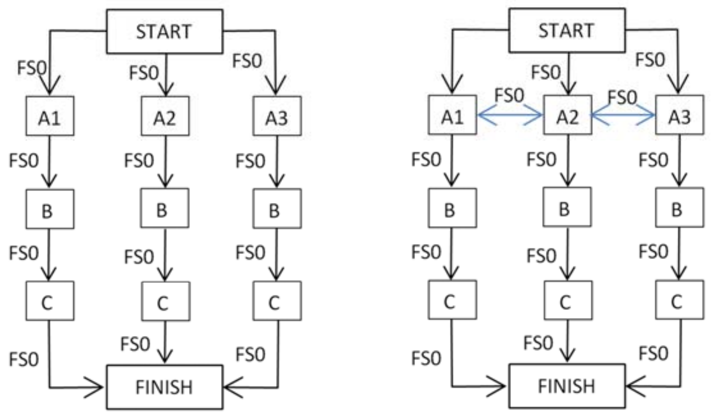

Figure 1. a) The project modeled in a traditional way b) The new type of precedence relations

5.2. Relations between the activities

Traditional network techniques allow the definition of relations between the start and finish point of activities. That is why the assumption of PDM on the same intensity and no interruptions is so important. Applying this hypothesis, the difference can be defined between every section of the connected activities. However, if the intensity of the activities can change, then another type of precedence relation will be necessary. With this new type of activity, the necessary minimal time can be defined between every section of the connected activities. (Fig. 2)

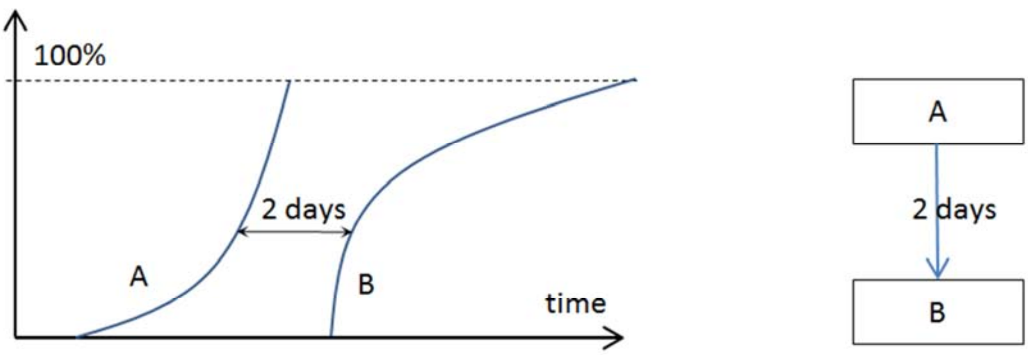

Figure 2. Defining minimal allowable time between activities

5.3. Defining spatial requirements

Site layout planning is a continuous reorganization of the construction site during the project. Site layout planning has a large impact on construction safety, productivity and area needed. It has a deep relationship with other planning tasks such as scheduling, procurement, equipment planning, and financial planning. Failure in site layout can cause inefficiency in construction and can increase operational costs. For correct site layout, safety issues, etc. it is necessary to define the minimum and maximum allowable (spatial) distance among activities, and incorporate some scheduling techniques, such as line-of-balance method (or linear scheduling, cyclogram) allowing to consider spatial issues in construction (Shabtai, 2013), however, it is restricted to linear or repetitive-unit construction sites, where the geometry can be simplified to one dimension.

5.4. Recurring activities

Some activities must be repeated during the project. (E.g. The application for building permit is denied by the building authorities due to some reasons, therefore some parts of the design and documentation process must be repeated.) This requires the possibility of defining relations that can form loops, and decision nodes where probability could also be defined.

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Creative Construction Conference 2014

Increasing the accuracy of a prefab building design process simulation using simulated annealing

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Abstract

Monte-Carlo simulation analysis has been discussed in project management literature as tool for proactive scheduling and to gain better insights into projects which are characterized by a high level of complexity and uncertainty, such as the design phase of prefab building projects. The application of simulation as proactive scheduling tool in construction projects is hampered by limited accessibility of proper input data, though, because of long project duration, the often temporary organization and multidisciplinary nature of such projects. In this study we use simulated annealing to adjust parameters of a simulation model for which the simulation outcome is sensitive to data perturbation by making use of data from related parameters which is easier to estimate. The applicability of the approach was demonstrated on a real life project, the construction of a 1100 m^2 residential building in Sweden. More precisely, we used Design Structure Matrix simulation, i.e. an activity network based Monte-Carlo simulation technique with which stochastic project evolution (deviations from the planned activity sequence due to unexpected iteration of sub-processes) can be simulated, to model the workflow of the design process of the observed project. Then, by means of the simulated annealing approach, we adjusted the rework probabilities (model parameter) such that the frequencies of executed activities in simulated activity sequences fitted the frequencies as observed in the real project. Adjusting input data by using prior knowledge of the dependencies of the project activities and cross analysis with related data that is easy to estimate would help to increase the accuracy of simulations when access to statistical data of the input variable in question is limited. The suggested approach is interesting for practitioners who work with standardized design processes (e.g. as part of standardized building systems) and continuous improvement.

Keywords: building design process; continuous improvement; design structure matrix; model calibration; proactive scheduling.

1. Introduction

Precise design and accurate scheduling of the design phase are crucial success factors in managing prefab building projects because of the high production rate of the standardized building elements (usually manufactured off-site) and their interdisciplinary nature. A high production rate implies that once the production has been started design errors will be multiplied. The interdisciplinary nature implies that inaccurate scheduling will further complicate the cooperation between the project members. As one of the major factors that adversely affect design and scheduling precision, iteration induced by design changes have been identified in numerous studies (e.g. Love et al. ,2008; Hwang et al., 2009; Olawale and Sun, 2010). The design process of building projects is often complex, which implies that already a small change during execution can cause significant effects on the project outcome (Austin et al. 2002, Pektas and Pultar 2005). The complexity together with uncertainty about project conditions makes it a challenge for project managers to predict the effects on the project outcome of any design change during the execution of the project.

An established means in engineering design to get insights into and to develop robust design processes of projects characterized by a high level of complexity and uncertainty is Design Structure Matrix (DSM) simulation (e.g. Cho and Eppinger, 2005; Karniel and Reich, 2009). DSM simulation is an activity-network based technique with which variation in project duration is simulated to origin both from variation in activity duration and variation of the activity execution sequence. Usually, the execution sequence is modeled to follow the activity dependency logics as defined by an activity network. But the logical sequence is randomly perturbed in that sub-processes have to be iterated (Cho and Eppinger, 2005). By iterations it is simulated that, as consequence of an unforeseen information change during the execution of a design project, successor activities that have already been carried out have to be reworked (Yassine, 2007; Srour et al. 2013). It is obvious that the quality of process optimization which is based on a numerical model significantly depends on the quality of the numerical model used, and consequently of the accuracy of the model input data. As indicated above, the

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probability with which iteration of a sub-process is triggered (i.e. the rework probability) constitute a core input parameter of a DSM simulation model. Usually rework probability is estimated by using historical data or, if not accessible, by expert interviews. Also indirect interview techniques have been applied to facilitate the estimating for practitioners (e.g. Yassine, 2007). However, the use of historical data or expert interviews to assess the rework probability for the design phase of building projects is often hampered by the temporal organizing and long project durations, i.e. a lack of accessible data.

In this paper we propose a new approach to assess the rework probabilities of a DSM simulation model. The idea is to reduce estimation uncertainty by making use of related data that is easier to access than the rework probabilities, i.e. the mean frequencies of activities of observed project execution sequences.

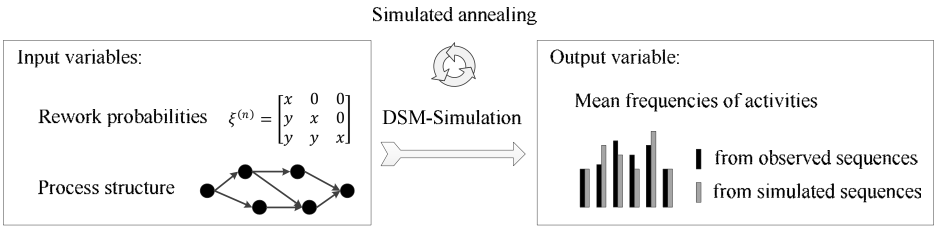

Figure 1. Estimation of rework probabilities by making use of related data (inverse analysis)

The mean frequency of an activity depends on the underlying process structure (which defines the precedence constraints) and the rework probabilities. The task is to find a configuration of the rework probabilities such that the activity frequencies of the simulated execution sequences fit the observed ones. Because the stochastic nature of DSM simulation it is not possible to find an analytical solution for this problem. However, DSM simulation can be used itself to generate the frequencies (by generating execution sequences) and then simulated annealing (a Monte Carlo optimization technique) can be used to iteratively fit them to the target frequencies.

The applicability of the approach was demonstrated on a real life project; the design process of a 1100 m^2 residential building in Sweden.

2. DSM-based simulation

Different models using DSM-based simulation have been presented in literature. The following description relates to the model created by Cho and Eppinger (2005), which is basically a discrete event model that makes use of DSM to define the rework probabilities.

The basic concept in DSM-based simulation considers variations in project costs and time largely a function of the iteration required in the project's execution (Yassine, 2004). Figure 2 shows the activity sequence of a sampled project and the underlying process structure. The process structure is represented by a digraph; the activities of the process are depicted by the vertices A1 to A6 and the precedence constraints by the straight arcs. A process structure defines the order in which activities should be carried out and whether activities can be carried out concurrently. The project sequence is represented by the bold arcs. It represents the order in which a project was carried out.

Theoretically, the project in figure 2 requires only 5 transitions from start to finish. But because a change in activity 2 after the 5^{th} transition occurred (first order rework) 8 transitions were required instead. Since A3 depends on input from A2 it had to be reworked too (second order rework). The progression of the project sequence is defined by the dependency logics, the rework probabilities, and a priority role. The rework probabilities are represented by a matrix, where the i,j^{th} element gives the probability that if activity i is the current one activity j will be carried out next. The duration of a project is simulated by interlinking the chronological arrangement of the activities (i.e. concurrent or sequential execution), and the sampled duration of each activity. A more detailed description of DSM-based simulation can be found in e.g. Cho and Eppinger (2005).

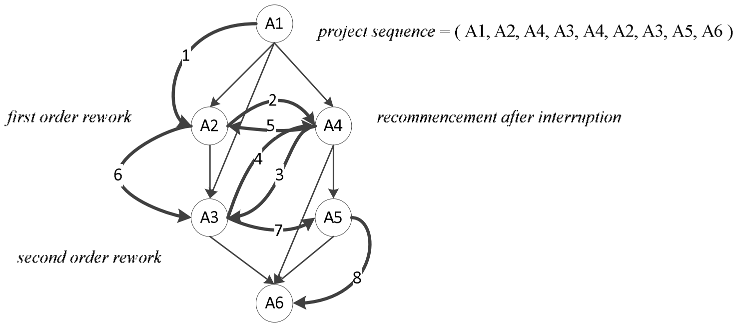

Figure 2. Schematic of sampling a project sequence

3. Simulated annealing

Simulated annealing is a probabilistic numeric method utilized to find a global minimum over a discrete search space $S = \{ s_1 , \ldots , s_n \}$ by iteratively improve a candidate solution $s_i \in S$ with regard to a quality measure $f: S \rightarrow \mathbb{R}$, called the energy function. That is, to find a $s_i \in S$ which minimizes $f(s_i)$. The method was inspired by the annealing process in metallurgy and first presented by Kirkpatrick et al. (1983). The basic procedure is that s_i is altered until the global minimum is reached, or until $f(s_i)$ is sufficient small. The alteration of the candidate solution is often called 'picking a neighbour' and is done systematically. The altered candidate solution will be accepted with the probability

$$min\{exp(\frac{f(s_i)-f(s_{i+1})}{T}), 1\}, \quad \text{where} \quad T \in \mathbb{R}^{+}. \tag{1}$$

That means, the new solution is accepted: in any case if $f(s_i+1) \leq f(s_i)$, and only with a certain probability if $f(s_i+1) > f(s_i)$. The acceptance rate depends on the temperature T which is decreased towards 0 with the number of iterations; the lower the temperature the lower the acceptance rate. A deeper theoretical background is given in e.g. Häggström (2002) and Kincaid and Cheney (2012).

4. Rework probability estimation

As conclusion from the preceding discussion we propose the following approach to estimate the rework probabilities (figure 3):

- *Objective*: The objective is to find a configuration of the rework probability matrix such that the average frequency for each activity of the simulated sequences will fit the frequencies from the observed sequences. In other words, we want to find a configuration of the rework probability matrix ξ such that $f(\xi) = \|\boldsymbol{h}_{sim} - \boldsymbol{h}_{obs}\|_2^2$ gets minimal, where $\boldsymbol{h}_{sim}$ is a vector with the average frequency for each activity of the simulated projects as its elements and $\boldsymbol{h}_{obs}$ the corresponding frequencies of the observed projects.
- *Required input*: When starting the approach, observed activity sequences of several projects as well as their underlying process structure (common, standardized process) must be available. Methods to derive a DSM-model of the underlying process structure are described in e.g. Steward (1981) and Yassine (2004).
- *Initialize*: The first steps are to calculate $\boldsymbol{h}_{obs}$ from the observed projects and to do an initial guess $\xi^{(0)}$ for the rework probability matrix. $\xi^{(0)}$ is derived from the observed activity sequences by simply recording the number of transitions from a certain activity to the next in an adjacency matrix (figure 4.b) and then dividing each matrix row by its own sum (we require the sums of each matrix row to be 1). $\xi^{(0)}$ corresponds then to the lower triangular entries of the adjacency matrix.
- *Loop*: Now the simulated annealing approach can start. The first step is to choose a new neighbour (see section 3). This is done by changing some of the elements of the current rework probability matrix: $\xi \rightarrow \xi'$. In order to restrict the search to the neighbourhood we allow only elements bigger 0 to change. The next step is to simulate sufficient many project activity sequences (sufficient many in terms of Monte-Carlo simulation) and calculate thereof $\boldsymbol{h}_{sim}$, and subsequently $f(\xi')$. Finally, it has to be decided whether ξ' is accepted as the new current configuration (equation 1). Repeat these steps until $f(\xi)$ is sufficient small.

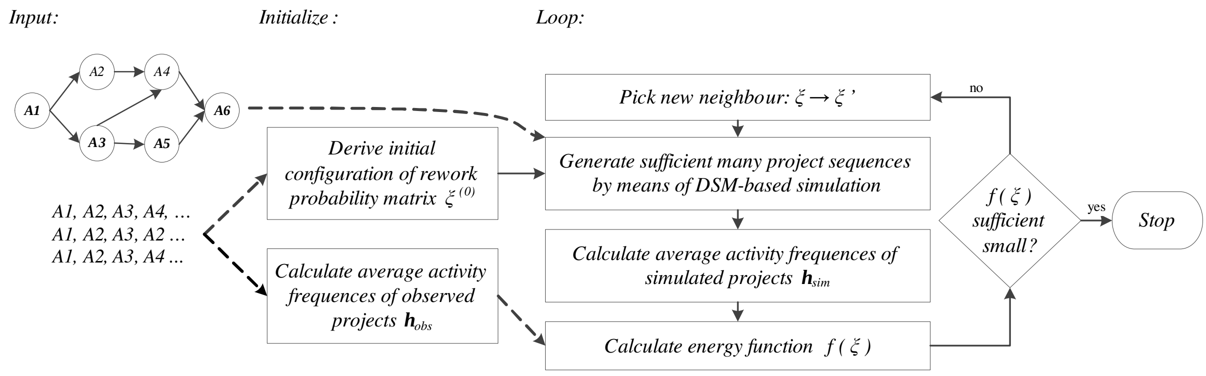

Figure 3. Schematic diagram of the rework probability estimation algorithm

5. Prefab building design process application

In order to test the applicability of the suggested approach, it was applied on a real life project. The data for the underlying process model originate from a design-build construction project i.e. the construction of a two storey apartment building with an area of 1100 m^2. The structural frame of the apartment building consists of prefab timber frame system elements (Masonite's Flexible Building system MFB®). The design was drawn up by a project team of SME technical consultants.

Data collection and the compilation of the process model were conducted iteratively between September 2009 and September 2010. In line with the recommendations outlined by van der Aalst (1999; 2011) the project was mapped at the work step level, i.e. all activities in which information (in the form of documents and agreements or material) was transferred between at least two of the main actors were logged. The log file of the project activities provided descriptions of each activity undertaken, their dates of execution, the number of hours worked, and the required inputs. In order to triangulate these data, the contents of the log file were discussed with the project leader over the course of 10 meetings. To further ensure the correctness of the logged activities, further information on the proceedings was gathered from 14 project- meetings. Finally, based on the information about required inputs a topological sort was generated by means of a DSM partitioning algorithm. Note that the process structure model was compiled iteratively. It was presented (in parts) to the main actors during three project meetings to confirm its correctness. The resulting network model (figure 4.a) consists of 98 activities with 376 dependency relations. It spans the process from the compilation of the client's specifications through the pre-tendering phase to the completion of the building plans. A detailed process description is given in Haller (2012).

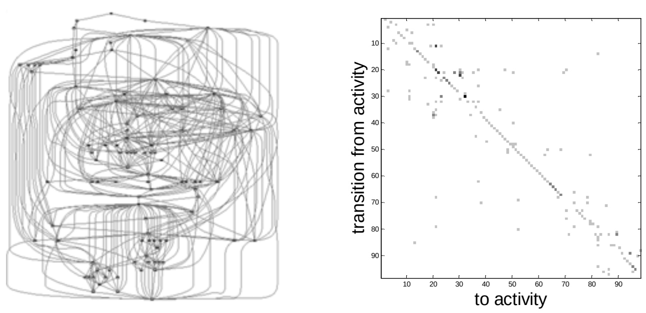

Figure 4. The modelled process structure (a) and the observed transitions (b)

Once the required input was compiled, the rework probabilities were estimated by means of the approach described in section 4. Figure 5 shows the residuals i.e. the differences between the activity frequencies from the simulated execution sequences and the observed activity frequencies.

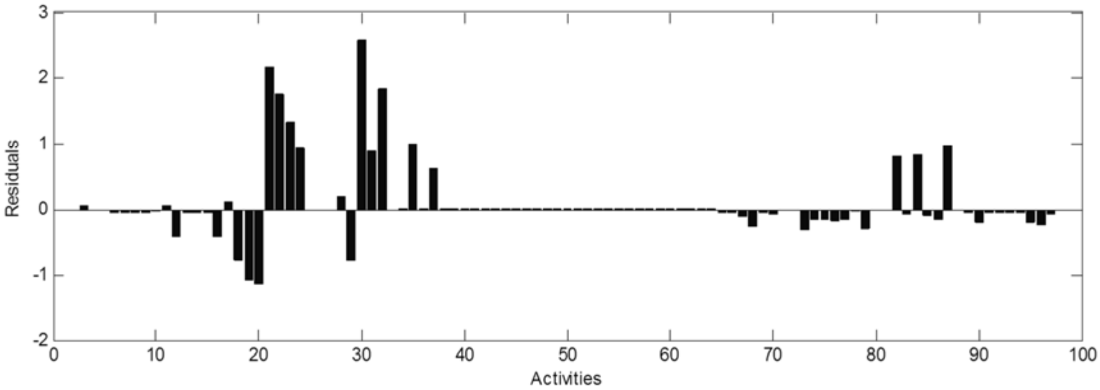

Figure 5. Differences in activity frequencies between observed and simulated sequences

A positive residual means that the simulated frequency was higher than the observed one. The closer the residuals are to 0 the better is the estimation. Note the residuals between activities 16 and 33 (planning of technical details in the pre-tendering phase). A possible explanation for the peaks could be that the main actors did not completely agree about how the process structure of this phase should be modeled. There was some uncertainty about the dependencies of the activities. Thus, perhaps the model partly does not match the real structure. Another explanation could be that it was quite difficult to catch all transitions between the project participants during this phase (figure 4.b), since many technical details were discussed via telephone. These transitions were not recorded but had to be reconstructed afterwards. That means that there is also some uncertainty about the correctness of the observed activity sequence in this phase.

Figure 6 shows the length of the simulated activity sequences (in number of activities). The mean length of 10 000 simulated sequences is 207.5, which is close to the length of the sequences of the observed project (202 activities). In contrast, the mean length of 10 000 simulated sequences generated by using direct observations, i.e. without fitting, was 148.6. The distribution of the simulated project lengths is right skewed, which is in line with Banks (2001) and Robinson (2007). Considering the results of this study, we assume that by using the proposed approach we could increase the plausibility of the project outcome.

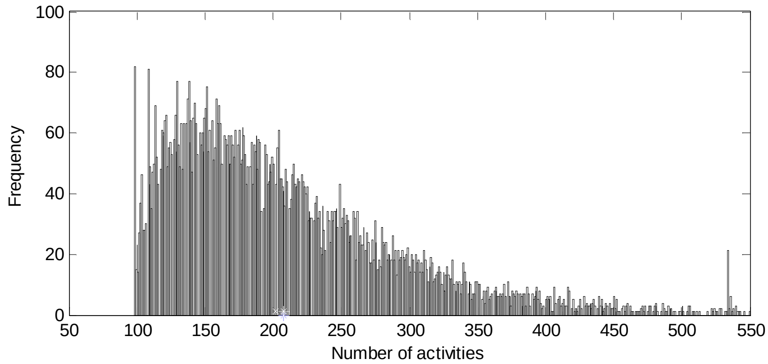

Figure 6. Frequencies of simulated project lengths

6. Conclusions

A core component of DSM simulation models is the rework probabilities. Rework probabilities are usually estimated by direct observation or expert interviews. However, the application of these methods in construction projects is often hampered by limited accessibility of proper input data, because of long project duration, the often temporary organization and their multidisciplinary nature. This study presents a new estimation procedure for rework probabilities that can be used in DSM based simulation models. It is an iterative, activity network based approach where use of related model data is made i.e. the underlying process structure and the activity frequencies of observed project sequences. The suggested approach proceeds in three phases. First, the underlying process structure has to be derived by means of DSM sequencing algorithms and a first guess of the rework probabilities by inference from the observed project sequences. Then, project execution sequences are sampled by means of DSM based simulation and the activity frequencies of the simulated sequences are compared with the activity frequencies derived from the observed sequences. Finally, the first guess is improved by a Monte-Carlo optimization technique, i.e. simulated annealing, until the simulated activity frequencies are sufficient close to the observed frequencies.

The approach was tested on a real life project, the construction of an 1100 m^2 residential building in Sweden. The results of the study indicate that by applying the approach it is possible to receive more accurate rework probability estimates than by direct observation. Adjusting input data by using prior knowledge of the dependencies of the project activities and cross analysis with related data that is easy to estimate would help to increase the accuracy of simulations when access to statistical data of the input variable in question is limited. A prerequisite is, though, that the observed project sequences are resulting from a common underlying design process and that this process must be well defined. The suggested approach is interesting for practitioners who work with standardized design processes (e.g. as part of standardized building systems) and continuous process improvement.

In this study it was assumed that adjusting the rework probabilities with reference to the observed activity frequencies will increase the accuracy of the model. However, preliminary additional tests indicate that this is not always the case. Rules have to be developed that will help the practitioner to assess the potential efficiency of the estimation procedure for a given problem in advance.

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Singularity functions as new tool for integrated project management

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Abstract

Construction managers must actively plan and control the plethora of quantitative and qualitative aspects of their projects in a coordinated, judicious manner to achieve successful performance. However, current managerial techniques are compartmentalized into modeling and analyzing time, budget, resource utilization, equipment operations, and others. Therefore, the objective of this research is to explore how such very disparate aspects, here limited in scope to quantitative ones, can be integrated into a cohesive and versatile model. Its methodology is to adopt and adapt a traditional model from structural engineering called singularity functions. Generalizing elements of conventional algebra, they activate the non-zero behavior of their dependent variable over a specific range of one or several independent variables. Thus it is possible to model different relationships of project performance. Yet this accomplishment in analytical capability has left unsolved the issue of interfaces between said compartmentalized aspects. To address it, interactions between the pairwise work quantity, time, cost, and resource variables are explored and conversions between their respective input and output data are derived. The contribution of this research is threefold: First, the mathematical models of linear schedules, cash flows, and resources are aligned. Second, interactions between those models are extracted and formalized based on a common irreversible variable, which is time. Third, the possibility of integrating elements into a 3D or indeed *n*D quantitative model for project management is discussed. In conclusion, such integrated model based on singularity functions opens new possibilities for holistic planning and management of construction projects. Linking its various quantitative elements thus enables a customizable and easily adoptable approach and facilitates comprehensive analysis and multi-objective optimization toward minimum duration and cost and maximum resource utilization.

Keywords: Cash flows; integrated project management; quantitative performance measures; scheduling; singularity functions.

1. Introduction

Construction project management is a complex system, as it is driven by multiple objectives; "[t]hese objectives and their relative importance vary from one project to another, and they often include minimizing construction time and cost while maximizing safety, quality, and sustainability" (Kandil et al. 2010, p. 17). The term 'objective' can also be used interchangeably to the term dimension, as traditional project management is commonly defined as a three-dimensional (3D) cost-schedule-technical system (Gransberg et al. 2013). To handle the characteristics of such a complex system, previous studies divided construction projects into various subsystems. They typically focused on one compartmentalized subsystem as their research purpose, while simplifying or even omitting interfaces to other subsystems. For example, Gantt bar charts are a graphical scheduling method that is oriented exclusively toward the time dimension, ignoring others such as work quantity, cost, and resources. The well-known Critical Path Method (CPM) was developed for the requirement that "[t]he plan should point directly to the difficult and significant activities – the problems of achieving the objective" (Kelley and Walker 1959, p. 160). CPM may be described as a one-and-a-half dimensional method, because it primarily applies an algorithm to schedule time, while a separate later time-cost tradeoff analysis could consider direct cost, but not indirect cost (Kelley and Walker 1959). More recently, additional dimensions (often three) are brought into multi-objective models. They were solved "using a variety of methods, including linear programming, integer programming, dynamic programming, and genetic algorithms" (El-Rayes and Kandil 2005, p. 477). However, CPM still dominates as their limiting foundation, to the detriment of other dimensions. Yet construction projects are integrated systems that unfold in a complex interplay subject to a plethora of factors, which requires using a more integrated model to generate realistic analyses and efficient optimization. A need therefore exists to explore novel approaches toward such an integrated systems view of project management.

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2. Literature Review

Traditional research "selected [the] most important objective while either neglecting the less important competing objectives or imposing them as known constraints in the optimization formulation" (Wu et al. 2012, p. 1411). Such studies on single objectives usually explore a detailed *subsystem*, e.g. scheduling (Harris and Ioannou 1998) or cash flows (Cui et al. 2010). But construction projects are complex systems and thus it is deplorable that there exists "a plethora of "control" techniques that cannot provide any insight into the interactions among the many components of a construction engineering project" (Kalu 1990, p. 494). To manage multi-objective problems, studies seek to create "tools and strategies that can simultaneously improve project performance in multiple dimensions" for *integrated systems* (Ford 2002, p. 30). Yet "[m]ultiobjective optimization formulations have clear theoretical advantages but increase the complexity of the mathematical formulation" (Wu et al. 2012, p. 1411). In most cases, researchers make approximations to simplify the problem. Ammar (2011, p. 67) for the example of a time-cost tradeoff optimization explained that a "[d]iscount factor in the exponential form…, is too complicated to be handled in a mathematical optimization model… Instead, a simplified form… will be used." Such approach is common in multi-objective research for reasons of simplicity, manageability, and brevity of a model and its description, but clearly undesirable.

Furthermore, such studies typically follow very similar steps: First, selecting objectives from project performance parameters to be minimized or maximized, e.g. time, cost, or resources. Second, using a multi-objective optimization algorithm. However, an important intermediate step is often short-changed, that of creating a model whose nature is ideally suited to its challenge. It logically occurs between establishing the objectives and performing an optimization and is crucial for an efficient and reliable optimization. Models must be *versatile* yet *accurate* to the maximum extent that input data allow, without imposing extraneous restrictions from modeling assumptions. Previous studies have focused extensively on optimization algorithms (Geem 2010), but appear to overlook this modeling challenge.

2.1. Research Need and Objectives

Abridged objective functions to minimize or maximize dependent variables radically simplify reality: Duration is determined by factors such as productivity, crew size, resource availability, shifts, lead/lag durations, buffers, etc.; multi-objective studies omit most such details. Cash flows must consider direct and indirect cost, bill-to-pay delay, prompt payment discount, credit limit, interest, time value of money, etc. Objective functions typically simplify these details, focusing instead on algorithms to identify or compare solutions. One may argue that it is overly complicated to maintain the same level of detail as local *subsystems* when moving to modeling a global *integrated system*. But per the paradigm of Ockham's razor, who advocated 'as simple as possible, as complicated as necessary' for models, one should not reduce realism if a system becomes more complex, which limits the validity of its output and may mislead decision-makers. This research thus raises the fundamental question of how to bridge local and global views, while remaining efficient and accurate as determined by the quality of available data, not model assumptions. **Singularity functions**, defined in the following section, offer the unique features of *detailability* (can reflect any desired level of detail within their mathematical expressions), *extensibility* (can incorporate any number of interacting dimensional variables), and *convertibility* (can extract pairwise performance parameters to examine their relationships in detail).

Three sequential **Research Objectives** will be addressed by this research, which together contribute to its overall goal of ultimately gaining a single comprehensive yet customizable approach to construction project management:

- Exploring interactions and conversions among singularity functions for merging subsystems into a global model;
- Aligning subsystem models of schedule, cash flows, and resources in cumulative and non-cumulative expressions;
- Visualizing the integrated 3D project model and assessing its potential contribution as a novel management tool.

3. Singularity Functions

Singularity functions were initially used in structural engineering to analyze the problem of beams that are loaded with diverse types of loads, which are located at discrete or distributed locations on said beams. The basic term of Equation 1 was historically known as the Föppl symbol (1927) or Macaulay brackets (1919). This operator performs a *case distinction* for the given cutoff value a of the independent variable x: The functions yields zero if x is smaller than a, while evaluating the pointed brackets as round ones if x is equal to or larger than a. The strength s amplifies the value of the function, while the exponent n modifies the behavior to linear or nonlinear growth of the function.

The virtue of singularity functions is that they can easily model influences that are located at or distributed along a dimension (e.g. time), which fulfills requirements of various key applications in the construction management field. For example, in linear schedules, activity progress is represented as a curve with start and finish date, whose slope is the productivity. Moreover, for cash flows, a cost profile also has a start and finish; its slope is the rate at which the cost grows. Furthermore, for resources utilization, a profile can be derived analogously. Of course, multiple effects of the same type can be expressed jointly, which generates a staggered profile over its respective time period. All of such phenomena can be modeled with the basic term of singularity functions by inserting the respective appropriate independent and dependent variables per Table 1. This feature enables the conversion per **Research Objective 1**: Introducing a new variable, e.g. a cost factor for work units into a linear schedule, transforms the model as desired.

$$s \cdot \langle x-a \rangle^n = \begin{cases} 0 & for\, x < a \\ s \cdot (x-a)^n & for\, x \geq a \end{cases} \quad (1)$$

Table 1. Variables for singularity functions.

Type of problem	Independent	Dependent
Linear schedule	x = work unit	y = time unit
Cash flows	y = time unit	z = cost unit
Resource utilization	y = time unit	r = resource unit

3.1. Linear Schedule Model (cumulative and non-cumulative forms)

Most construction projects, whether pipelines or multi-floor buildings, contain many repeating activities (Harris and Ioannou 1998). CPM can only guarantee that sequential relations between those repeating activities are obeyed, but cannot directly represent constraints for resource continuity (Harris and Ioannou 1998), nor exploit the repetitive nature for the model itself. On the other hand, the Linear Scheduling Method (LSM) and closely related approaches with similar names, e.g. repetitive or location-based scheduling, which "analyze projects that are characterized as geometrically linear or repetitive in their operations" (Lucko 2008, p. 711), are able to take advantage of prevailing repetitiveness to derive a more intuitive model. It was widely considered to be merely graphically-based scheduling that "is presented graphically as an *X-Y* plot where one axis represents [repeating] units, and the other time" (Harris and Ioannou 1998, p. 270). Such graphical, non-mathematical focus was a severe limitation of LSM and has hindered its computerization and broader application in the construction industry. However, that situation has changed through the introduction of the Productivity Scheduling Method (PSM) that is based on singularity functions. They "provide a flexible and powerful mathematical model for construction activities and their buffers that are characterized by their linear or repetitive nature" (Lucko 2008, p. 711). Yet the fundamental mathematical connection between CPM and LSM remains largely unexplored, and – once understood – could facilitate broadening the capabilities of PSM.

Lucko (2009) described the steps of PSM as activity and buffer equations, initial stacking, minimum differences and differentiation for consolidation, which generates revised activity and buffer equations, and criticality analysis. Details of these steps are omitted in this paper for brevity. *Stacking* generates a feasible but extremely conservative and thus lengthy schedule, *consolidation* overlaps as many activities as possible within the sequence constraints. The approach of PSM is to convert all inputs about activity sequence, durations, leads or lags between activities, and any time or work break into the mathematical model that is composed of singularity functions. The schedule (start and finish of each activity in the initial and final versions) and its criticality characteristics are outputs. Time (y) is the independent variable in PSM per Equation 2, x is work, U_i is the number of repeating work units, D_i is the duration of activity i, a_{Si}^* and a_{Fi}^* are its start and finish, whose asterisk indicates that they may include a shifted start (prior delay d_1) or extended duration (new delay d_2). Note that time is better measured on the y-axis, because it should be minimized by the algorithm. An analogous form with time as the dependent variable can be derived by switching the axes. An example with activities A, B, and C per Table 2 is shown in the $x(y)$-oriented linear schedule of Figure 1.

Figure 1 shows the schedule in a *cumulative* form, which means that the work quantity of each activity (vertical axis) increases with time that passes (horizontal axis). According to calculus, calculating the derivative of a function yields its rate of change (Strang 2010). Thus differentiating the cumulative Equation 2 returns the *non-cumulative* Equation 3. Figure 2 shows this non-cumulative form. Interestingly, the profile of non-cumulative activity equations is similar to a traditional bar chart. It differs from a bar chart only in that the vertical axis represents productivity and not just an activity name or label. It thus displays more information than a bar chart. The activity with the highest productivity is placed at the top, and the smaller the productivity the lower the height where activity bars are placed.

$$x(y)_i = \frac{U_i}{D_i + d_{2i}} \cdot \left[\left\langle y - a_{Si}^* \right\rangle^1 - \left\langle y - a_{Fi}^* \right\rangle^1 - (D_i + d_{2i}) \cdot \left\langle y - a_{Fi}^* \right\rangle^0 \right] \quad (2) \qquad x'(y)_i = \frac{U_i}{D_i + d_{2i}} \cdot \left[\left\langle y - a_{Si}^* \right\rangle^0 - \left\langle y - a_{Fi}^* \right\rangle^0 \right] \quad (3)$$

Table 2. Schedule, cash flow, and resource input for example.

Name [-]	Successor [-]	Duration [months]	Work Unit [count]	Time Buffer [months]	Shift d_1 [months]	Delay d_2 [months]	Cost C [$1000]	Markup M [% of cost]	Bill-to-Pay Delay b [months]	Resource Rate [workers]
A	B	3	3	1	0	1	100	15	1	10
B	C	9	3	2	1	0	200	10	1	20
C	-	6	3	1	1	1	100	10	1	10

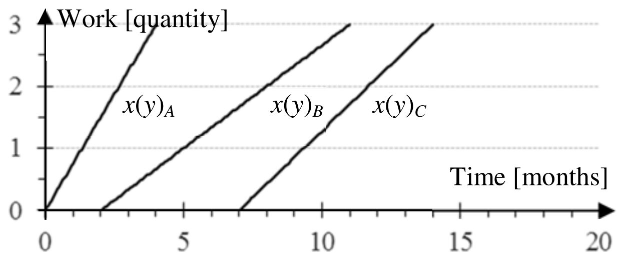

Figure 1. Cumulative linear schedule for example.

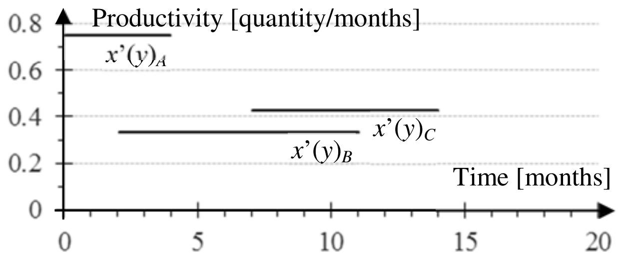

Figure 2. Non-cumulative linear schedule for example.

Overall, PSM with its systematic application of singularity functions provides a mathematical model that unifies compartmentalized concepts and project performance parameters, as used e.g. in minimizing the project duration and determining the criticality of activities under CPM, displaying graphically their start and finish dates as in bar charts, and representing the starts, finishes, sequence, and productivity of activities as under LSM. The cumulative and non-cumulative forms of the equations enhance scheduling research in that it becomes apparent that concepts whose relation was previously arduous to express can indeed be explicitly modeled in such integrated quantitative manner.

3.2. Cash Flow Model (cumulative and non-cumulative forms)

The success or failure of construction projects strongly depends on cash flow management. Therefore, modeling cash flows is a crucial problem in construction management. However, it is a thorny problem, because the interaction of cash outflows and inflows generates a zigzag-shaped balance that used to defy modeling attempts until recently (Lucko 2011a). Moreover, some phenomena related to cash flows exhibit a distinct periodicity (Su and Lucko 2013), which should be modeled. Furthermore, Time Value of Money (TVM) can be considered explicitly (Lucko 2013).

Expanding the example from the previous section, assume that cost for each activity grows linearly (Elazouni and Metwally 2005). Table 2 lists the cost (C), markup (M), and bill-to-pay-delay (b) for each activity. Whereas the slope represented productivity in the linear schedule, the scale factor ($C / (D + d_2)$) in the singularity function per Equation 4 represents the rate of cost growth, which is the slope of the cost profile. Adding the markup to the cost yields a bill function per Equation 5. As bills are sent to the payer at the end of each period, an operator $\lfloor\ \rfloor$ that rounds down the operand to its nearest integer is applied to the independent variable y. Such rounding operator can easily express the "periodicity [that] occurs both in cash outflows and inflows that have a specific frequency and amplitude, e.g., overhead, billing, and payment functions" (Lucko 2011a, p. 528). The pay function per Equation 6 is derived from the bill function, but subtracts the bill-to-pay-delay b from each y, which has the effect of moving the bill profile to the right to become the pay profile per Figure 3. Note that the cost, bill, pay, and balance profiles in Figure 3 model the entire project, adding the cash flows of the three activities accordingly. The balance is the difference between the sum of the cost functions (outflows) and the sum of all pay functions (inflows) per Equation 7. In a real project, b will be approximately 30 to 90 days; here it is assumed as one month. It is assumed that the balance function does not consider TVM. Its value depends on the period over which it is assessed, e.g. for financing interest or an unused credit fee, as analyzed in detail (Lucko 2011a, Lucko 2013, Su and Lucko 2013), but is excluded here for brevity.

Previous cash flow models are *cumulative*, yet the *non-cumulative* form of such cash flow models can also exist per Figure 4. Differentiating Equation 4 yields the non-cumulative cost function per Equation 8. A cumulative pay function has a stepped profile per Figure 3. Differentiating it would generate a bar chart-like profile, which would be incorrect, because the non-cumulative pay function should only be active at each pay. Su and Lucko (2013) solved this problem by introducing customized pay and signal functions for a non-cumulative bill per Equations 9 and 10.

$$z_{cost}(y)_i = \frac{C_i}{D_i + d_{2i}} \cdot \left[\left\langle y - a^*_{Si} \right\rangle^1 - \left\langle y - a^*_{Fi} \right\rangle^1 \right] \quad (4)$$

$$z_{bill}(y)_i = \frac{C_i(1+M_i)}{D_i + d_{2i}} \cdot \left[\left\langle \lfloor y \rfloor - a^*_{Si} \right\rangle^1 - \left\langle \lfloor y \rfloor - a^*_{Fi} \right\rangle^1 \right] \quad (5)$$

$$z_{pay}(y)_i = \frac{C_i(1+M_i)}{D_i + d_{2i}} \cdot \left[\left\langle \lfloor y - b \rfloor - a^*_{Si} \right\rangle^1 - \left\langle \lfloor y - b \rfloor - a^*_{Fi} \right\rangle^1 \right] \quad (6)$$

$$z_{balance}(y) = \sum z_{pay}(y)_i - \sum z_{cost}(y)_i \quad (7)$$

$$z'_{cost}(y)_i = \frac{C_i}{D_i + d_{2i}} \cdot \left[\left\langle y - a^*_{Si} \right\rangle^0 - \left\langle y - a^*_{Fi} \right\rangle^0 \right] \quad (8)$$

$$z_{each\_pay}(y) = \sum \frac{C_i \cdot (1+M_i)}{D_i + d_{2i}} \cdot z_{pay\_signal}(y) \quad (9)$$

$$z_{pay\_signal}(y) = \left(\left\langle \lfloor y \rfloor - (a^*_s + b) \right\rangle^1 - \left\langle \lfloor y \rfloor - (a^*_F + b) \right\rangle^1 \right) - \left(\left\langle \lceil y \rceil - (a^*_s + b + 1) \right\rangle^1 - \left\langle \lceil y \rceil - (a^*_F + b + 1) \right\rangle^1 \right) \quad (10)$$

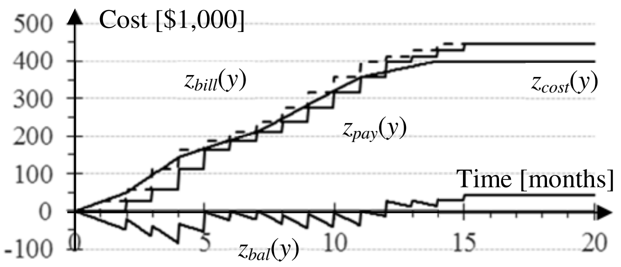

Figure 3. Cumulative cash flow profile for example.

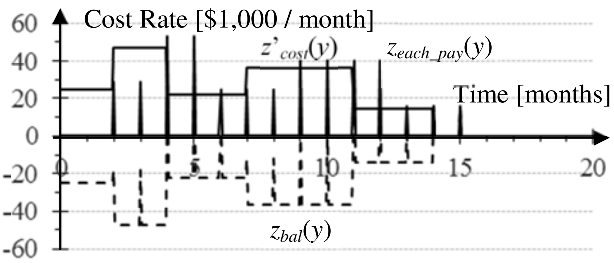

Figure 4. Non-cumulative cash flow profile for example.

3.3. Resource Model (cumulative and non-cumulative forms)

The same approach as described for linear scheduling and cash flows can also be adopted for resource utilization. Its scale factor per Equation 11 represents the rate of resource consumption *r* (Lucko 2011b), typically for general or specialized labor. Continuing the previous example, Table 2 lists the resource rate for each activity. Equations 11 and 12 express the cumulative and non-cumulative resource functions, respectively, which are shown in Figures 5 and 6.

Aligning these subsystems in their cumulative and non-cumulative forms fulfills **Research Objective 2**. Note that additional refinements can be added to reflect the aforementioned factors such as shifts d_1 (that move the start) and delays d_2 (that move the finish, i.e. expand duration) (Lucko 2008) to enhance its realism. This can be accomplished by adding them to the cutoff of the singularity function. Equation 13 links subsystems via the scaling factors of their pairwise variables for proportionality, notwithstanding further the moving and rounding the cutoff in bill equations.

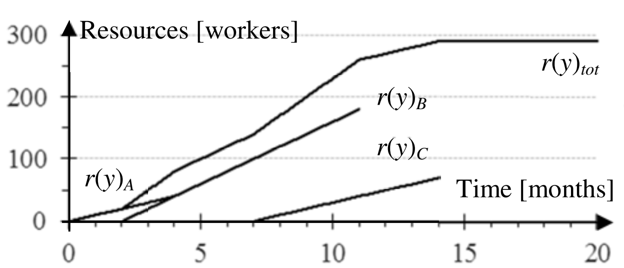

Figure 5. Cumulative resource profile for example.

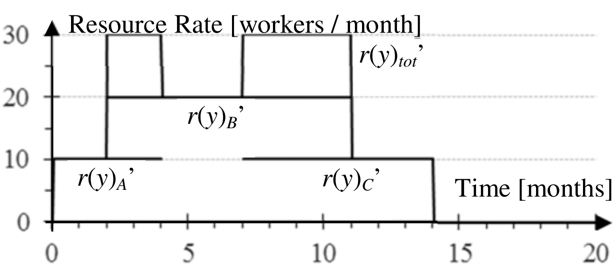

Figure 6. Non-cumulative resource profile for example.

$$r(y)_i = s_i \cdot \left[\left\langle y - a_S^* \right\rangle^1 - \left\langle y - a_F^* \right\rangle^1 - (3 + d_{2i}) \cdot \left\langle y - a_F^* \right\rangle^0 \right] \quad (11) \qquad r'(y)_i = s_i \cdot \left[\left\langle y - a_S^* \right\rangle^0 - \left\langle y - a_F^* \right\rangle^0 \right] \quad (12)$$

$$f(x, y, z) = \left\{ z = \frac{C_i}{U_i} x, \quad z = \frac{C_i}{D_i + d_{2i}} y, \quad x = \frac{U_i}{D_i + d_{2i}} y \right. \quad (13)$$

4. Integrated Model for Multi Objective Research and Conclusion

Using this approach, local models are integrated into a global one without diluting its level of detail. Since time is an irreversible dimension, other project performance parameters are expressed based on it by default. Figure 7 projects the 3D curve per Equation 13 onto the planes. It creates familiar 2D profiles of linear schedule and cash flow in top and side view. Project performance parameters of work quantity, cost, and resources can have cumulative or non-cumulative form to ideally suit a given purpose of analysis or optimization, which thus fulfills **Research Objective 3**. Singularity functions even enable *n*D models; offering a new avenue toward the goal of holistic quantitative project management for future research work.

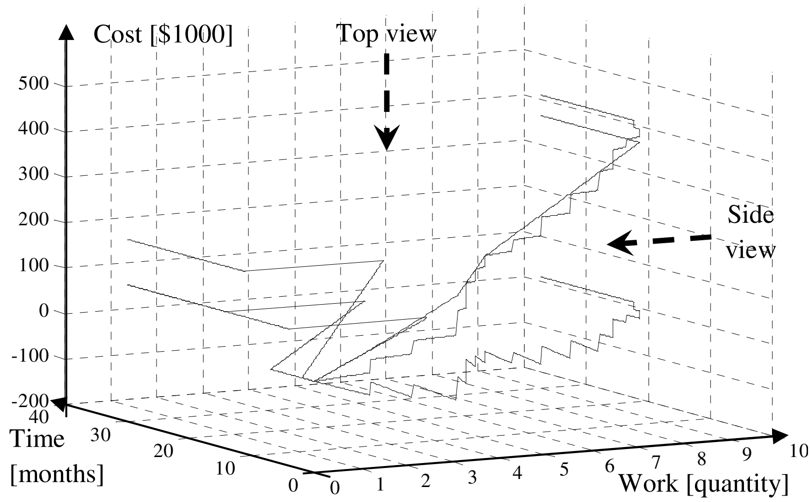

Figure 7. Cumulative 3D profile for example.

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Correlation between time and cost in quantitative risk analysis in construction projects

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Abstract

The increasing constraints which construction companies face due to the prolonged financial crisis and the contracting construction market impose more and more realistic and efficient approaches related to the planning, scheduling and monitoring of their projects.
A project deterministic approach, with preset parameters of time and cost and with the decisions taken based on the independent analysis of time or cost, even they are interrelated, has a low likelihood to be successfully. Usually the construction projects are confronted with delays and over costs which reduce the company profit and leads to its bankruptcy. Therefore, a more efficient approach should take into account the risk events and uncertainties and the resources limitations in construction projects planning, scheduling and monitoring and also, the correlation between the parameters time, cost and the resources limitation.
The paper provides a practical approach of quantitative risk analysis using Monte Carlo Method and highlighting the correlation between the parameters time, cost and resources limitations in construction projects. The project execution is analyzed not only by the current probability to achieve the parameters time and cost together, but by the trends of their combination, integrating the scope, time, cost, resources and risks and providing a better tool in decision making. To demonstrate the advantages of this approach, a case study of a construction project is analyzed using Spider Project software.

Keywords: management by trends, Monte Carlo method, project planning and scheduling, quantitative risk analysis, risk index

1. Introduction

The construction projects are considered having high risks due to the numerous stakeholders, long production duration and open production systems (Taroun, 2013). The increasing constraints which construction companies face due to the prolonged financial crisis and the contracting construction market impose even more the application of structured approaches related to the planning, scheduling and monitoring of their projects. Unfortunately, the construction industry has a poor reputation in risk management comparing with other domains such as finance or insurance (Laryea, 2008), even if the risk management provides a solid basis for decision-making in projects and brings important benefits, such as: reduced costs, increased engagement with stakeholders and better change management (Bayati, Gharabaghi & Ebrahimi, 2011).

Different project risks management approaches were defined in standards and guidelines (ISO, 2012), (IPMA, 2006), (AS/NZS, 2004), (PMI, 2008), (Liberzon & Lobanov, 2000). In order to offer flexibility and space to manoeuvre for the application of different project risks processes, standards usually provide only a very generic description of the processes, focusing on the high level characteristics and not on the details on how it should be done. "Tailoring the process model should take into account the sector and organisation specific requirements as well as the requirements derived from the specific types and/or categories of projects performed in that organisation" (Wagner, 2012).

An efficient risk management lies in the ability to quality and quantifies the risk elements. *The project quantitative risk analysis* is usually considered as the hardest part of the risk management (Makait, 2011), (Andersen, 2011), mainly because it is based on advanced statistics and mathematics methods.

A project deterministic approach, with preset parameters of time and cost and with the decisions taken based on the independent analysis of time or cost, even they are interrelated, has a low likelihood to be successfully. Usually the construction projects are confronted with delays and over costs which reduce the company profit and leads to its bankruptcy. Therefore, a more efficient approach should take into account the risk events and

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uncertainties and the resources limitations in construction projects planning, scheduling and monitoring and also, the correlation between the parameters time, cost and the resources limitation.

Many probabilistic methods were developed over time and made available, especially through software implementation (Bodea & Purnuş, 2012a), (Purnuş & Bodea, 2013b), (Archibald, Liberzon, & Souza Mello, 2008). But these methods are usually not properly applied, or not applied at all. The main reasons for this are the complexity of methods, the lake of expertise, difficulties in collecting historical data and in communicating with the relevant stakeholders, especially line managers and/or resources from the functional departments. In (Galway, 2004) the results of several unstructured interviews with researchers and practitioners in the field of project risk analysis are presented. Regarding the general utility of quantitative project risk analysis, the answers were that it is clearly useful, mainly because it is so widely recommended, even if there was little empirical evidence of how useful these quantitative techniques really were. But the answers were followed by comments that project risk analysis is not well-understood, not well-integrated into project management, and not easily explainable to senior decision-makers.

The literature points out the difficulties that affect the ability of practitioners to carry out a project cost or schedule risk quantitative analysis (CIOB, 2008), (Bodea & Purnuş, 2012b), (Purnuş & Bodea, 2013a). Some of the most relevant are the following:

- Deciding the proper level of detail for the risk analysis (the level of aggregation of tasks or costs);
- Assuring relevant data in order to determine the probability distributions for task durations and the component costs. Particular distributions, such as the triangle one are usually used based on mean and variance estimation of the experts.
- Dealing with the correlations between task durations and costs. These correlations should be taken into account when specifying probability distributions. To elicit multivariate distributions is far a more difficult task than in the case of univariate one. In addition, the duration and cost random variables can only take positive values. The constraints on correlated positive random variables are more difficult and far less intuitive than in the case of normal distributions, where the correlations between an unlimited set of normal random variables can be specified arbitrarily.

The paper provides a practical approach of quantitative risk analysis using Monte Carlo Method and highlighting the correlation between the parameters time, cost and resources limitations in construction projects. The project execution is analyzed not only by the current probability to achieve the parameters time and cost together, but by the trends of their combination, integrating the scope, time, cost, resources and risks and providing a better tool in decision making. To demonstrate the advantages of this approach, a case study of a construction project is analyzed using Spider Project software.

2. A Project Risk Analysis Method considering duration and cost

Let us consider 5000 pairs of duration-cost values as a result of Monte Carlo simulation. If we consider the different order of magnitude of the two dimensions, it is necessary to normalize the values both for duration and cost, on the same interval, e.g. [0, 1]. Using this process, the pair of values (x, y) will become (x_n, y_n), applying the formulae (1) and (2):

$$x_n = \frac{x - x_{\min}}{x_{\max} - x_{\min}} \tag{1}$$

$$y_n = \frac{y - y_{\min}}{y_{\max} - y_{\min}} \tag{2}$$

After the normalization, the 5000 normalized values are represented as points in the space XoY, where X = duration and Y = cost.

All the 5000 points forms a cluster for which we compute the centroid C(x_c, y_c). The centroid coordinates may be considered as *the most probable values*, for duration (x_c) and cost (y_c).

Let us consider a point T(x_t, y_t), representing the target dates we want to analyze from the risk perspective. We compute the **euclidian distance** between C and T, $\mathbf{Dist_{C\text{-}T}}$ with (3):

$$Dist_{C-T} = \sqrt{(x_t - x_C)^2 + (y_T - y_C)^2} \tag{3}$$

In this case, the parameter $Dist_{C-T}$ indicates the deviation of the analyzed values relative to the most probable values.

For a correct interpretation of the parameter $Dist_{C-T}$, it is necessary to take into consideration the distance between the points which form the cluster. Therefore, we propose an index for risk analysis I_R, as a function of the ratio between the parameter $Dist_{C-T}$ and the position of target pair of values relative to the position of centroid, defined as following (4):

$$I_R = f\left(\frac{Dist_{C-T}}{Thr_p}\times 100, Position\right) \quad (4)$$

where: Thr_p is the upper limit (Threshold) of the distance to controid, with p% of the cluster points included while the position is a qualitative parameter.

Let us consider a parameter **p** which model the risk tolerance. If p value is set closed to 1, the risk tolerance is high. If p value is closed to 0, than the risk tolerance is low. The risk index I_R values which are higher than the p parameter values ($I_R > p$) will represent a high risk.

In order to exemplify the interpretation of risk index I_R, several experiments were made (table 1).

Table 1. Experiments with different T point coordinates and p parameter

Experiment	Coordinates of point T	Parameter p [%]	$\frac{Dist_{C-T}}{Thr_p}\times 100$	Risk Index I_R
1a	(50, 330000)	50%	61.9978	high risk
1b	(50, 330000)	75%	43.89951	low risk
1c	(50, 330000)	100%	14.16787	low risk
2a	(58, 340000)	50%	368.0186	high risk
2b	(58, 340000)	70%	260.5872	high risk
2c	(58, 340000)	100%	84.10038	low risk

The results of the experiments 1a and 2a are presented in Fig. 1and Fig. 2.

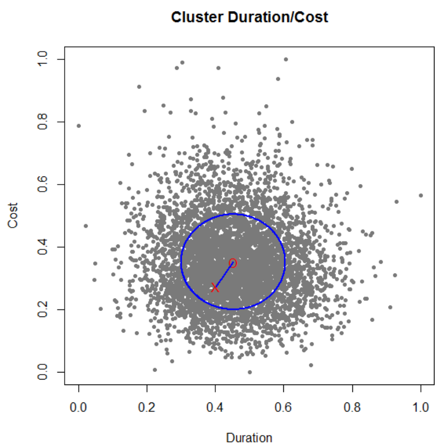

Figure 1. Experiment 1a - T(50, 330000), p=50%, I_R=high risk

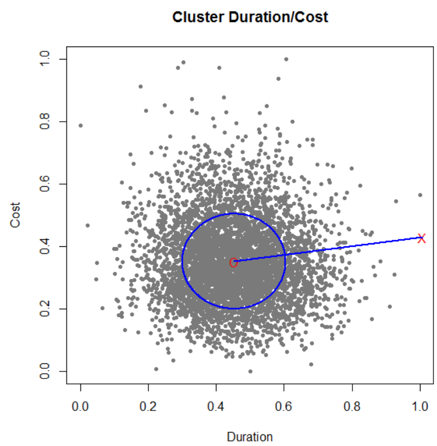

Figure 2: Experiment 2a - T(58, 340000), p=50%, I_R=high risk

3. A Case Study

The quantitative risk analysis was made for a construction project in the field of the implementation of new technologies for the recovery of recyclable materials from the contractor perspective. It consists in the construction of a technological warehouse, two reservoirs, fencing, access roads and platform. The project model was developed taking into account the execution level of detail of the activities, containing 643 activities, 46 resources (manpower and equipments), 124 multi-resources, 92 types of materials, 8 calendars, 15 cost components and 6 cost centers. The risk events and uncertainties were identified and prioritized according their potential impact on the project duration and cost using the regular approaches in qualitative risk analysis. As result, there were developed three scenarios: optimistic, most probable and pessimistic for the initial data (duration, volume of work, productivity, calendars, resources), which were used in the risk analysis with Monte Carlo method. The optimistic scenario includes the risks with probabilities exceeding 90%, the most probable scenario includes the risk events with probabilities exceeding 50%, and all selected risk events were included in the pessimistic scenario (Liberzon, V., Souza Mello, B. P. 2011).

In the case of limited project resources, the probability curves for project duration, cost and other project parameters created using Monte Carlo method, are valid only if resource leveling heuristics that is used in risk simulation process is the same as used for project scheduling and management (Liberzon, V., Shavyrina, V., Makar-Limanov, O, 2012).

The quantitative risk analysis for the construction project was performed using the software Spider Project which has in place the module for Monte Carlo method. For the purpose of risk simulation, the project model was analyzed performing 5000 iterations, with resource constrained scheduling and the log-normal shape of probability distribution curve. The project execution phase was monitored with a 2 weeks frequency for 9 different stages in order to identify early signs of risk events occurrence and to take the best decision to mitigate their impact. The risk simulation was performed for each update, analyzing the trends of probabilities for project duration, project cost and the combined probability duration-cost.

In the initial stage the probabilities for both project duration and cost were computed. Based on the organization risk tolerance and the contractual terms, the target dates were set at 84.64% representing 206 days for project duration and 73.90% representing 2,702,000 Euro for project cost (Fig. 3, Fig. 4).

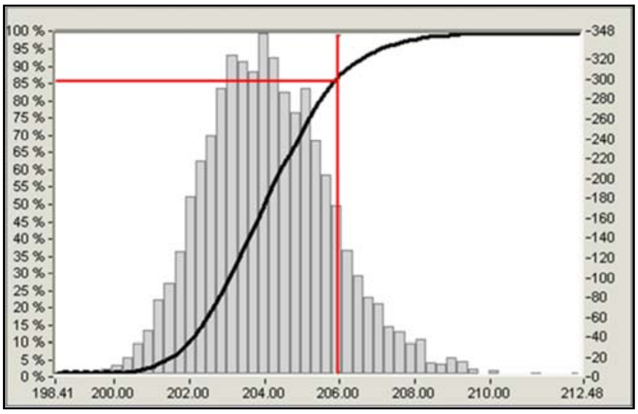

Figure 3. Probability curve and target date for project duration

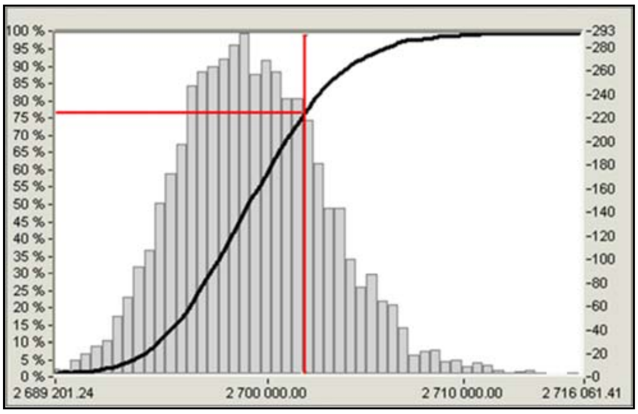

Figure 4. Probability curve and target date for project cost

If we consider that activity duration and cost estimates do not depend on each other the probability to meet both targets will be the multiplication of the probabilities to achieve the targets. However these parameters are correlated and setting multiple project targets will require multidimensional risk analysis. For this reason, our analysis took into consideration the following parameters variation during execution: the duration and cost buffers, the position of the pair of values representing the target duration and cost related to the centroid of the iterations results, the distance between the centroid and the target dates, the correlation between the project duration and cost and the proposed risk index (Fig. 5).

During the project execution, risks events like delays due to the lack of resources, weather, over costs and unforeseeable events occurs, impacting the current probability to achieve the target duration and cost. The variation of probabilities for target duration, cost and combined probability duration-cost is presented in the table 2.

Table 2. Probabilities of targets parameters in different stages of the project execution

Probabilities	0	1	2	3	4	5	6	7	8	9
Duration	84.64%	0.04%	0.22%	3.14%	32.76%	88.40%	94.96%	34.20%	56.90%	70.56%
Cost	73.90%	29.28%	42.00%	45.20%	47.36%	51.64%	53.30%	55.82%	58.92%	27.42%
Duration-Cost	70.20%	0.04%	0.22%	3.04%	28.18%	51.36%	53.28%	31.02%	48.76%	27.34%

While the duration and cost buffers are in a descendent trend as the result of the risk events impact (table 3), an important aspect of the risk simulation was to identify the position of the target dates relative to the position of centroid. It resulted that in different stages of the project execution, the position of the target dates may belongs to one or another quadrant relative to the position of centroid (Fig. 6).

Table 3. Variation of the duration and cost buffer

Buffer	0	1	2	3	4	5	6	7	8	9
Duration	100.00%	90.58%	85.61%	80.50%	75.97%	71.14%	65.94%	64.57%	59.64%	54.68%
Cost	100.00%	38.22%	50.77%	50.77%	50.77%	51.14%	50.83%	48.95%	44.53%	8.51%

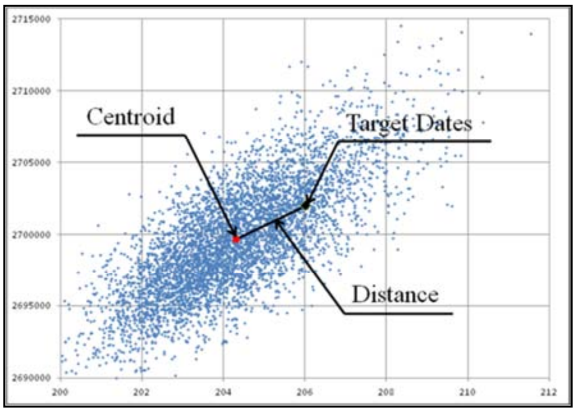

Figure 5. Scatter diagram for the initial stage

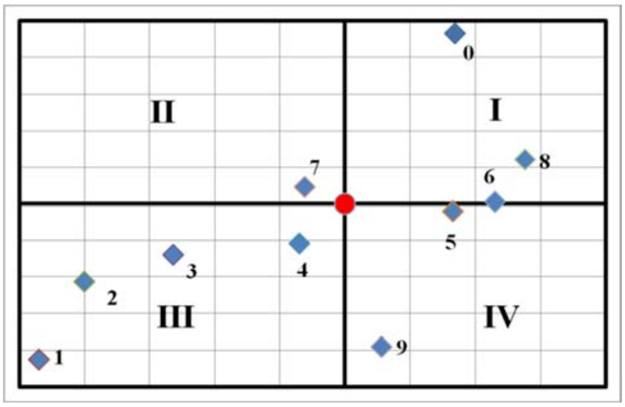

Figure 6. Relative position of the target dates to the centroid

The risk index I_R variation as a direct function of distance $Dist_{C-T}$ has to be correlated with the target dates position relative to the centroid position (table 4).

Table 4. Variation of the distance and the position of target dates in different quadrants

	0	1	2	3	4	5	6	7	8	9
Distance	36.09%	100.00%	85.04%	56.19%	14.92%	35.27%	48.99%	13.08%	61.68%	11.84%
I_R	medium	high	high	medium	low	medium	medium	high	low	high
Quadrant position	I	III	III	III	III	IV	I	II	I	IV

As time as the position of the target dates is in the 3rd quadrant, the trend of risk index I_R will be opposite to the trend of combined probability duration-cost. If the position the target dates is in the other quadrants, than the trend of risk index will be in accordance with the trend of the combined probability duration-cost, providing an additional tool for decision taking.

4. Conclusions

The quantitative risk analysis with applications in construction projects represents an important asset for the construction companies which are facing with continuous delays and cost overruns. The paper provides a practical approach of quantitative risk analysis using Monte Carlo method and highlighting the correlation between the parameters time, cost and resources limitations in construction projects. The project execution is analyzed not only by the current probability to achieve the parameters time and cost together, but by the trends of their combination, integrating the scope, time, cost, resources and risks and providing a better tool in decision making.

The application of quantitative risk analysis using Monte Carlo method becomes increasingly easy due to the development of software solutions. However, a special attention should be given to the limited project resource which is typical for most of the construction projects. In this case, the probability curves for project duration, cost and other project parameters created using Monte Carlo method, are valid only if resource leveling heuristics that is used in risk simulation process is the same as used for project scheduling and management.

A risk index taking into account the distance between the target dates (duration-cost) and the centroid of the solutions cluster resulted from Monte Carlo simulation, together with their relative position as a combined qualitative-quantitative index was proposed. Its trend variation become an additional tool for decision taking, as time as the quality of input data in the Monte Carlo simulation is never good enough.

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Sustainable Construction, Health and Safety

The effects of unsatisfactory working conditions on productivity in the construction industry

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Abstract

The construction industry has been experiencing chronic problems such as poor health and safety (H&S), inferior working conditions, and non-achievement of quality, which have had an adverse effect on construction productivity, overall performance, and image.
A descriptive survey was conducted among medium to large general contractor (GC) members of the East Cape Master Builders Association (ECMBA).
The salient findings include: construction workers are exposed to excessive noise levels; material shortages affect productivity more than other related factors; time delays are attributable to poor specification; unsafe working conditions such as an untidy site are the most common cause of injuries on construction sites; the non-achievement of quality negatively affects the image of the construction industry more than other factors; construction worker morale and satisfaction is substantially affected by inadequate supervision; hourly wage rates affect construction worker quality of life to a major extent; the quality of life of construction workers is rated between poor to near poor, and working conditions on construction sites are rated as poor to average.
It can be concluded that unsatisfactory working conditions negatively affect productivity in the construction industry. Furthermore, the image of the construction industry is tarnished.

Keywords: Construction Industry; Health and Safety; Productivity; Working Conditions.

1. Introduction

Construction work is dangerous according to Hawkins and Wells (2013), and the Construction Industry Development Board (cidb) (2009) states that in industrialised countries, more than 25% to 40% of work-related deaths occur on construction sites despite the fact that the global construction industry only contributes 10% of the total employment. There are a variety of H&S hazards and risks that construction workers are exposed to, which may have an adverse effect on working conditions, productivity, time delays, injuries on site, and lost time injuries (International Labour Organisation). These factors further affect the image of the construction industry, construction worker morale and satisfaction, work related musculoskeletal disorders (WMSDs) and the quality of life of construction workers (International Labour Organisation, 2001). In terms of WMSDs, the cidb (2009), states that approximately 30% of all construction workers suffer from back pain or other musculoskeletal disorders.

Employers within the construction industry view H&S as a financial burden, however the related costs of occupational accidents and disease to employers are abundant and include; property damage, lost production time, lost skills as well as increased costs associated with recruiting and retaining replacements (Department of Labour, 2003).

According to the University of KwaZulu-Natal (2009), welfare facilities are a major problem on South African construction sites, which often result in unhygienic conditions and impact on worker morale and job satisfaction. The image of the South African construction industry is viewed in a negative light by the public and construction work force due to reports of buildings collapsing, large scale collusion and corruption, the dangerous nature of construction, and unsatisfactory working conditions (ILO, 2001).

Due to the fact that work-related illness and injuries within the construction industry are among the highest of all industries (HSE, 2012), and that racial inequality within South Africa is among the worst in the world (Industry Insight, 2012) construction workers therefore experience a poor quality of life.

2. The Review of Related Literature

2.1. H&S Compliance

Statistics arising from a national construction blitz conducted by the Department of Labour across South Africa indicate that of the 1 415 work places inspected only 759 (47.5%) of employers complied with regulations, and 829 (52.5%) of employers were non-compliant. This resulted in the issuing of 1 388 notices - 86 (6%) improvement, 1 015 (73%) contravention, and 287 (21%) prohibition (cidb, 2009).

2.2. Working Conditions

Construction workers are exposed to more H&S risks than many other industries. The variety of H&S hazards that construction workers are exposed to include noise, irritant or sensitising materials, dusts, fumes and gases, and other hazardous materials such as asbestos which result in adverse health risks (Danso, 2012).

Employers therefore have a common law duty to ensure that working conditions are healthy and safe, and do not cause harm to the H&S of employees and third parties (Basson, Christianson, Dekker, Garbers, le Roux, Mischke and Strydom, 2009).

2.3. Productivity

Production and productivity are affected by variables such as site conditions, the weather, organisation factors, H&S and personal problems, which should be considered when completing the activity and calculating productivity, as they may adversely affect production and productivity (Panas & Pantouvakis, 2010).

Construction productivity can be improved through, *inter alia*, H&S measures, positive worker relations and supervision, and hygienic welfare facilities. Lastly, various personal factors can influence construction productivity, which include the H&S of employees, domestic relations, nutrition, over exertion, and wages (Sugiharto, 2003). Other factors such as poor H&S procedures and culture, poor site conditions, unsatisfactory working conditions, inadequate supervision, organisation factors, personal factors, and climatic factors may also lead to a loss in construction productivity (Jergeas, 2009).

2.4. Time Delays

According to Emsley and Makulsawatudom (2001), time delays on construction sites may be as a result of material shortages, incomplete drawings, inspection delays, incompetent supervisors, instruction time, lack of tools and equipment, poor communications, poor site conditions, H&S issues, on site injuries, and rework. Poor site conditions result in major time delays as poor site conditions cause difficulties and unsafe working conditions, which pose H&S risks as they increase the probability of incidents and accidents occurring or workers becoming injured on site, which will result in further time delays (Emsley and Makulsawatudom, 2001).

2.5. Lost time injuries

According to the Department of Labour (2003), employers often view OH&S as a cost to be avoided if at all possible, however the costs of occupational accidents and diseases to employers include property damage, lost production time, lost skills as well as the cost of recruiting and retraining replacements.

There are both indirect and direct costs to employees who incur occupational injuries and diseases. The direct costs suffered by employees include; permanent disabling injuries, loss of employment, and income (Department of Labour, 2003). The indirect costs suffered by employees affect their families as a result of a loss of the household's 'breadwinner' and increased dependence on governmental support and grants (Department of Labour, 2003).

There are many associated costs which are not covered by a construction firm's insurance policies which include medical fees, sick pay, damage or loss of product and raw materials, overtime and temporary labour, production delays, investigation time, and fines for non-compliance or unsafe working conditions (Health & Safety Executive, 2012).

2.6. Construction Image

Reports of buildings collapsing due to poor construction techniques, and an increase in large scale collusion and corruption has resulted in a negative image of the construction industry as a whole. This negative image is mirrored by the workforce due to the dangerous nature of construction work, and the fact that workers are often exposed to unsatisfactory working conditions on construction sites (ILO, 2001).

2.7. Construction worker morale and dissatisfaction

The various factors that can lower worker morale and attitude are increased conflict, disputes, excessive hazards, overtime, over-inspection, multiple contract changes, disruption of work rhythm, poor site conditions, absenteeism, and untidy site conditions (Intergraph, 2012).

Jergeas (2009) states that incentive programmes can improve productivity and morale through the following: incentives for achieving milestones on schedule; bonus schemes across all work groups; performance based incentives; recognition for quality work and reaching milestones; H&S awards / rewards for no lost time accidents or incidents, and H&S competitions to promote healthy and safe competition between trades. Optimum labour management can further improve job satisfaction and productivity, and improved labour relations results in increased job performance.

2.8. Work-related musculoskeletal disorders (WMSDs)

Work-related risk factors are the major causes of WMSDs which may include physical demands of the job such as handling heavy materials, repetitive movements, and working positions or stances, physical exertion, vibrations, and working while maintaining awkward postures (Baril, Dion-Hubert, Lapointe, Paquette, Sauvage, Simoneau, Stock, and Vaillancourt, 2005). WMSDs are a major cause of disability in industrialised societies and result in enormous human and economic costs (Baril *et al.,* 2005).

According to Kew (2011), in addition to WMSDs, construction workers also experience numerous occupational diseases, which may include noise induced hearing loss, silicosis, asbestosis, and lung cancer. Construction workers are further exposed to manual tasks which contribute to WMSDs which include muscle strains and sprains, ligament or tendon rupture, prolapsed intervertebral discs, tendonitis of the shoulders and elbows, and carpel tunnel syndrome (Queensland Government, 2007).

2.9. Quality of life

It is important to note that the physical health of construction workers affects their quality of life (Queensland Government, 2007). Musculoskeletal injuries can result in permanent injuries that can have a significant impact on a person's working ability, and quality of life (Queensland Government, 2007).

According to the Health and Safety Executive (2012), the construction industry has a poor reputation for, inter alia, being an unhealthy industry to work in. This is due to the fact that its rate of work-related illness is one of the highest of all industries (HSE, 2002).

3. Research Method and Sample Stratum

A descriptive survey was conducted among 50 medium to large general GC members of the ECMBA using a self-administered questionnaire, which was distributed by post and by e-mail. Responses were returned via post, e-mail, and facsimile which consisted of two sections. 14 Completed and returned questionnaires were included in the analysis of the data, which equates to a response rate of 28%.

4. Research Findings

Table 1 indicates the extent to which seven factors effect productivity on construction sites in terms of percentage responses to a scale of 1 (Minor) to 5 (Major), and MSs ranging between a minimum value of 1.00 and a maximum value of 5.00. MSs > 3.00 indicate that respondents perceive that the frequency that the factors affect productivity is major as opposed to minor. It is notable that 1 / 7 (14.3%) of the MSs > 3.00, namely material shortages. Although the other factors have MSs ≤ 3.00, and thus the extent can be deemed minor, the MSs ranked second to joint fifth are > 2.60 ≤ 3.40 (near minor to some extent / some extent) - poor maintenance of plant and equipment resulting in idle time, poor H&S culture resulting in increased incidents and accidents, unsatisfactory working conditions, unattainable deadlines or time constraints, and negative worker relations and poor supervision.

Table 1. The extent to which certain factors impact productivity.

Factor	Response (%)						MS	Rank
	U	Minor..Major						
		1	2	3	4	5		
Materials shortages	0.0	14.3	21.4	21.4	21.4	21.4	3.14	1
Poor maintenance of plant and equipment resulting in idle time	0.0	28.6	21.4	7.1	21.4	21.4	2.86	2
Poor H&S culture resulting in increased incidents and accidents	0.0	21.4	28.6	7.1	35.7	7.1	2.79	3
Unsatisfactory working conditions	0.0	21.4	28.6	14.3	21.4	14.3	2.79	3
Unattainable deadlines or time constraints	7.1	21.4	7.1	28.6	28.6	7.1	2.71	5
Negative worker relations and poor supervision	0.0	28.6	14.3	21.4	28.6	7.1	2.71	5
Incorrect use of PPE	0.0	35.7	14.3	14.3	28.6	7.1	2.57	7

Table 2 indicates the extent to which certain factors negatively affect construction worker morale and satisfaction in terms of percentage responses to a range of 1 (Minor) to 5 (Major), and MSs ranging between a minimum value of 1.00 and a maximum value of 5.00. It is notable that two (25%) MSs > 3.00, which indicates the extent that inadequate supervision and poor worker relations do so is major, as opposed to minor. The remaining six (75%) MSs < 3.00, which indicates that the extent the factors do so is minor, as opposed to major. However, the MSs ranked first to fourth are > 2.60 ≤ 3.40 (near minor to some extent / some extent) - inadequate supervision, poor worker relations, unhealthy and unsafe working conditions, and inadequate welfare facilities.

Table 2. Extent to which certain factors negatively affect construction worker morale and satisfaction

Factor	Response (%)						MS	Rank
	U	Minor…..Major						
		1	2	3	4	5		
Inadequate supervision	0.0	21.4	0.0	21.4	35.7	21.4	3.36	1
Poor worker relations	0.0	14.3	14.3	21.4	50.0	0.0	3.07	2
Unhealthy and unsafe working conditions	0.0	14.3	28.6	21.4	28.6	7.1	2.86	3
Inadequate welfare facilities	0.0	14.3	28.6	35.7	21.4	0.0	2.64	4
Lack of incentive and bonus schemes	0.0	21.4	21.4	35.7	21.4	0.0	2.57	5
Excessive and extended working hours	0.0	28.6	21.4	28.6	14.3	7.1	2.50	6
Over exposure to harsh environmental conditions resulting in dehydration	0.0	28.6	28.6	21.4	14.3	7.1	2.43	7
Labour intensive construction techniques	0.0	28.6	35.7	28.6	7.1	0.0	2.14	8

Table 3 indicates the respondents' rating of construction workers' quality of life and working conditions on construction sites in terms of percentage responses to a scale of 1 (very poor) to 5 (excellent), and a MS ranging between a minimum value of 1.00 and a maximum value of 5.00. The MS relative to quality of life is ≤ 3.00, which indicates that respondents perceive construction workers' quality of life as poor as opposed to good. However, the MS of working conditions is ≥ 3.00, which indicates that respondents perceive working conditions on construction sites as good as opposed to poor, however marginally so given that the MS is 3.07.

Table 3. Respondents' rating of construction workers' quality of life and working conditions.

Aspect	Response (%)						MS
	U	Very poor..Excellent					
		1	2	3	4	5	
Quality of life	7.1	14.3	35.7	28.6	14.3	0.0	2.29
Working conditions	0.0	0.0	7.11	78.6	14.3	0.0	3.07

Table 4 indicates the extent to which respondent's agree with the statement 'Unsatisfactory working conditions negatively affect productivity in the construction industry' in terms of percentage responses to a scale of 1 (Strongly disagree) to 5 (Strongly Agree), and a MS ranging between a minimum value of 1.00 and a maximum value of 5.00. Given that the MS is > 3.00 the respondents can be deemed to agree as opposed to disagree with the statement.

Table 4. Extent to which unsatisfactory working conditions negatively affect productivity in the construction industry.

Response (%)						MS
U	Strongly disagree............................Strongly agree					
	1	2	3	4	5	
0.0	0.0	21.4	35.7	35.7	7.1	3.29

A summary of the salient findings relative to the aims and objectives of the study are as follows: construction workers are exposed to excessive noise levels; material shortages are perceived by respondents to affect productivity more than other related factors; time delays are attributable to poor specification; unsafe working conditions such as an untidy site including trip hazards are the most common cause of injuries on construction sites; accidents resulting in a labour investigation occur more frequently than other lost time injuries; non-achievement of quality negatively affects the image of the construction industry more than other related factors; construction worker morale and satisfaction is affected by inadequate supervision; hourly wage rates greatly affect construction workers' quality of life; the quality of life of construction workers is rated between very poor to poor / poor; working conditions on construction sites is poor, and unsatisfactory working conditions are negatively affecting productivity in the construction industry.

5. Conclusions

Research has shown that productivity on construction sites is adversely affected by unsatisfactory site conditions. This may further exacerbate the problem as inadequate H&S will increase the probability of accidents and injuries occurring, which will result in time delays thereby decreasing construction productivity.

Research from this study has shown that the quality of life among construction workers is poor and that working conditions are unsatisfactory, the study further suggests that unsatisfactory working conditions are negatively affecting productivity in the construction industry.

It is therefore imperative that there is a paradigm shift from perceiving that quality and productivity on construction sites is more important than H&S. Employers within the construction industry should disregard the view that H&S is a financial burden, which can be avoided if at all possible to a more responsible and holistic approach addressing the positive effects that H&S has upon productivity, worker satisfaction, and morale.

Implementing a positive H&S culture within the organisation and ensuring that there are healthy and safe working conditions and welfare facilities on construction sites will ultimately provide a greater return on investment as a result of an increase in productivity.

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Creative Construction Conference 2014

Integration of life cycle assessment in a BIM environment

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Abstract

Currently, the construction industry is turning towards sustainability. Nevertheless, in order to achieve a sustainable performance, a balance between environmental, social and economic criteria has to be created. There are already different tools available which have the potential to reach this goal. It is necessary to identify them as such and find out how they can be integrated to obtain synergies and contribute to sustainable construction. These tools have to be implemented in early design phases so as to add value to the project. In the present paper, two powerful methods, namely BIM and LCA, will be highlighted. Such methods can be of great assistance in the context of sustainability. On the one hand, BIM supports integrated design and improves information management and cooperation between the different stakeholders throughout the different project life-cycle phases. On the other hand, LCA is a suitable method for assessing environmental performance. Both LCA and BIM should be integrated in the decision-making process at an early stage with a view to achieving a holistic overview of the project, including environmental criteria, from the beginning.

Keywords: Building Information Modeling (BIM); Construction Industry; Design Phase; Integration; Life Cycle Assessment (LCA); Sustainability.

1. Introduction

The construction industry is moving towards sustainability. At the same time, the sector is facing new challenges. Costs need to be reduced, while quality has to be improved. In addition, further demands, such as reducing energy and resources consumption, must be met (Sjøgren, 2011).

Sustainability is generally described as being based on environmental, social and economic aspects. Ideally, there should be a balance between these three pillars. In other words, sustainable construction may be characterized as having the lowest environmental impact while enjoying a high level of social and economic development (Hakkinen, 2008).

At present, the construction industry is inefficient, and there is a need of change. Such inefficiency is mainly caused by industry-specific features, such as lack of cooperation and wasted resources (Bundesministerium für Verkehr, Bau und Stadtentwicklung, 2013).

One of the aims of the construction industry is to profit from the knowledge and technology currently available for achieving a sustainable performance (Chong et al., 2009). There are already a number of assessment tools in use with regard to construction, but they do not provide universal evaluation. Such a tool must be able to evaluate construction performance based on various criteria and, at the same time, integrate the information in the design framework. In this way, it becomes possible to compare different alternatives (Hakkinen, 2008). Among the already existing tools and methodologies that can be applied in the construction industry are Building Information Modeling (BIM) and Life-Cycle Assessment (LCA). However, in most cases, these tools are not being used beneficially.

This paper will assess the properties of both methodologies, showing how and in which project phases they should be implemented so as to improve performance in the construction industry.

2. Change in the Construction Industry. Integration of LCA and BIM in the early design phases

The construction industry is turning towards sustainability. In order to achieve this aim, a balance between environmental, economic and social aspects has to be reached. Consequently, these criteria have to be taken into account during the design phase.

2.1. *Project's phases with higher capacity to influence the project (design phase)*

This section highlights the project phases which can have the greatest influence in terms of achieving sustainable construction.

The early design phases are the ones which have the greatest influence on the project as a whole due to the fact that project planning is more flexible at this stage. As the project evolves, flexibility is reduced, and the chance of making changes is smaller, or making changes involves higher costs. During the early phases, there is more potential for studying different alternatives, reducing costs, implementing changes and improving performance (Burke, 2001). The design phase can thus be considered as one of the key phases in achieving sustainability, as has been highlighted by the British government: "Good design is synonymous with sustainable construction" (HM Government, 2008).

Sustainable design has to be meticulous, with increased effort in the early phases due to the fact that decisions made during this time will significantly influence the project as a whole. At the same time, the entire construction life cycle has to be considered. It is important to view sustainable construction not as a complicated or expensive trend, but as a form of integrated design, where all components of a given project are seen holistically rather than individually (C-SanD, 2001). It can be said that integrated design is a key factor in achieving sustainability (McGraw Hill Construction, 2010).

Various alternatives have to be compared in the early design phases with a view to selecting the most suitable one, based on the three pillars of sustainability. For this purpose, a huge amount of information has to be dealt with. This is one of the main reasons why, at present, sustainable methods are often implemented in the later project phases, when the final solution has already been developed. However, at the point, the potential and capacity for influencing the project are greatly reduced (Hakkinen, 2008).

Thus it follows that sustainable methods such as BIM and LCA should be applied in the early phases so as to be fully integrated in the decision-making process.

2.2. *Information management (BIM)*

The use of Building Information Modelling (BIM) has the potential to improve the overall information flow, thereby achieving better project performance and quality. Moreover, this tool enhances transparency and collaborative work between the stakeholders. The resulting improvement in communication leads to waste reduction and helps to avoid future errors (HM Government, 2012).

BIM greatly supports integrated design due to improved collaboration between the stakeholders and a better overview of the project as a whole (McGraw Hill Construction, 2010).

With the help of BIM, both time and resources can be saved. In fact, it has been estimated that in the construction industry the same data may be entered up to seven times (Sjøgren, 2011). This could be avoided by using BIM models as an information source.

The particular features of BIM make it into an appropriate method for achieving sustainable construction. It has a positive impact on the three pillars of sustainability. Firstly, with regard to economic aspects, the better quality of information leads to cost reduction. Various alternatives can be analyzed in the early design phases of a project, which improves efficiency and decision-making. Secondly, with regard to social aspects, BIM-based analysis and simulation make it possible to assess different parameters, such as daylight, which leads to an improvement in working and living conditions. Such assessments are more complex without the use of BIM-based tools. Thirdly, with regard to environmental aspects, BIM software can be applied in different ways, e.g. energy analysis (Autodesk, 2005). It should be pointed out, however, that its capacity for evaluating environmental issues will be enhanced if it is integrated with LCA tools.

Generally, it can be said that BIM has a huge potential for achieving sustainability in the construction industry. However, it is currently underused mainly due to a lack of interoperability (Nisbet & Dinesen, 2010). By creating synergies with other methodologies, such as LCA, the overall scope of BIM could be increased.

2.3. *Environmental criteria in the early design phases (LCA)*

At the present time, there is growing concern about the environmental impacts of the construction industry. Life-cycle assessment (LCA) can be seen as one of the most suitable methods for assessing such impacts as a whole (American Institute of Architects, 2010).

LCA may be used as an assessment tool for decision-making in terms of sustainable construction (Ortiz, et al., 2009). However, it has some drawbacks that need to be solved before it is integrated in the design process.

One of the main drawbacks of LCA is that it depends on the quality and availability of the data. It is frequently the case that there are simply not enough data or the available data are not up to date or below standard. This will lead to assumptions which, in turn, make the assessment inaccurate (American Institute of Architects, 2010).

The lack of project information is an obstacle for LCA performance during the early project phases and, as such, one of the reasons why, in the majority of cases, LCA is performed after the design phase. As a matter of fact, in Europe, LCA is often only done for certification purposes after the building has been completed (Tritthart, et al., 2010). As mentioned above, the phases with the highest potential for influencing a project are at the beginning. Therefore, in order to improve overall environmental performance, LCA tools have to be implemented in these early design phases. Indeed, manual re-entry of project information into LCA tools constitutes a major problem as it is a redundant, failure-ridden and time-consuming task. As a rule, the data are already contained in the building model, so there is really no need to enter them again. If the building information has to be re-entered, the risk of mistakes and misunderstandings increases. By integrating BIM and LCA, this problem could be solved, since the LCA tools would have direct access to the BIM information (Eastman, et al., 2011).

As a matter of fact, there is a general lack of standardization concerning LCA procedures. The existing ISO standard provides a general framework, but does not indicate individual methodology (American Institute of Architects, 2010).

Environmental assessment of the entire building is a complex procedure due to the multifaceted constructions, which, in themselves, are made up of a wide variety of products. Each of these products has its own features and life span, which means that they have varying relevance with regard to environmental impacts. There is also uncertainty concerning the use phase of the building (Tritthart et al., 2010) and therefore assumptions have to be made, which, in turn, increases the inaccuracy of the assessment (Buyle et al., 2012).

The construction industry is well known for its complicated nature, which makes the implementation of LCA methodology more difficult. Each of the projects has its own characteristics, specific location, features, etc. Therefore an individual assessment for each project is required considering its different conditions. An automatic LCA calculation in the mean time is not accurate because of several reasons; one of these reasons could be the difficulty of considering transportation issues, which have a noticeable impact on the environment.

It would be possible to solve some of the main drawbacks by integrating LCA and BIM tools. The three main pillars of sustainability (i.e. environmental, economic and social aspects) could be taken into account in the early design phases and thus approached more effectively.

3. Integration of LCA and BIM

The advantages of integrating LCA and BIM in the early design phases with the purpose of achieving a wider approach to sustainable construction are clear. Nevertheless, the integration of LCA in the BIM framework could be approached from different perspectives. Two different proposals for this integration are going to be presented below.

3.1. First approach: Direct access to the BIM model information to calculate the LCA performance

The information required for performing an assessment of the complete construction project during its entire life cycle can be obtained directly from the BIM model, since this model is created during the early design phases and contains the main features characterizing the construction. By drawing on this information, manual data re-entry into the LCA software, which is one of the main drawbacks of the LCA performance, will be avoided.

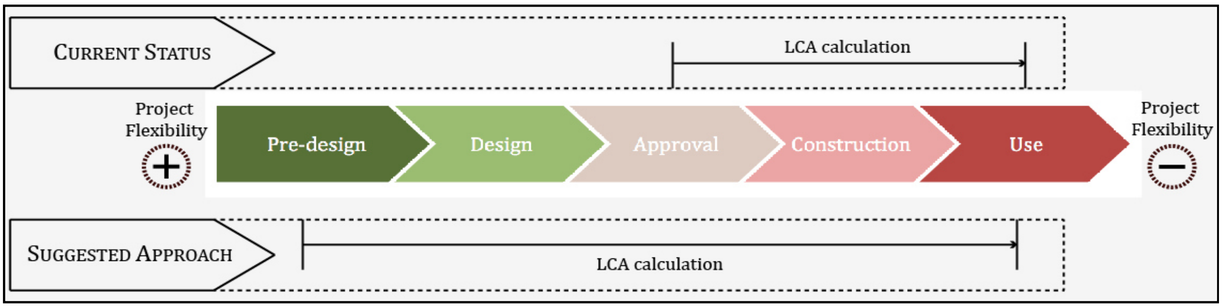

Figure 1. First suggested approach for LCA and BIM integration.

Despite the fact that some research and software are already available in relation to achieving effective integration of LCA and BIM, further development is required in this field. LCADesign can be highlighted as an example of current achievements. It is an automatic take-off tool that extracts information directly from the BIM model, using IFC as a data-sharing format. LCA is performed by combining the quantity building data obtained from the BIM model with the life-cycle inventory data in order to obtain different environmental indicators. LCADesign also makes it possible to compare different alternatives (Tucker et al., 2003). Ecquate Pty Ltd, which is the company in charge of managing the software, has temporarily withdrawn it from the market for improvements with a view to assessing bigger structures and civil projects.

Advantages of this approach:

- Avoids manual data re-entry
- Different alternatives can be compared. The results will highlight the hotspots where intervention is required and thus enhance environmental performance.
- Evaluates the entire life cycle of the building, thus achieving a more accurate approach to LCA evaluation. Makes it possible at an early stage to calculate the environmental performance of the complete building from beginning to end.
- Different environmental indicators may be used for assessment.
- Real-time assessment, which means that it can be employed as a decision-making tool.

Disadvantages of this approach:

- As the performance of the LCA is not developed in the BIM software itself, any changes in the BIM model can only be made by going back to the BIM software and then re-importing the model into the LCA platform.
- Interoperability between BIM models and LCA tools has not been fully developed yet. Up to now, this problem has been solved by transferring the model information via IFC format into a common database, where it can be combined with the LCA inventory database. Therefore one of the challenges now is how to extract the BIM model information effectively and import it into the software for LCA performance.
- There are also some difficulties involved in performing the LCA of the complete building during its entire life cycle.

3.2. Second approach: Environmental properties included in the BIM objects

This second approach seeks to find an automatic and efficient link between BIM models and environmental information included in the life cycle assessment databases.

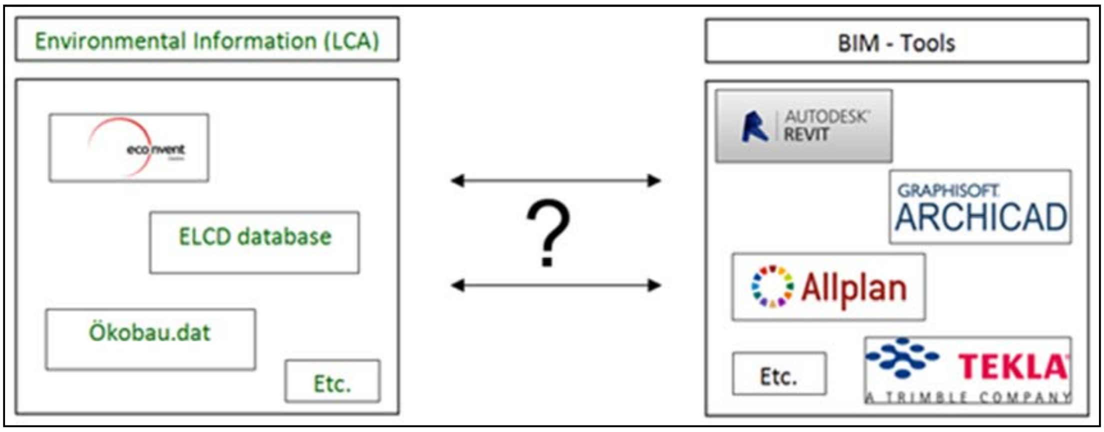

Figure 2. Seeking an automatic and efficient link between BIM models and environmental information.

With this approach, the features of the various BIM objects (information) include environmental properties based on LCA calculations. There are already a number of libraries which describe the different characteristics of BIM objects. One could thus incorporate the relevant environmental information pertaining to these objects (which were previously calculated with LCA methodology) with the other properties. In this way, it would be possible in the pre-design and design phases to include environmental criteria in the decision-making process regarding the selection of materials and building elements. Consequently, when the designer is selecting the different elements to be included in the model, the planner can also take into account the environmental performance of these elements, as shown in Figure 3.

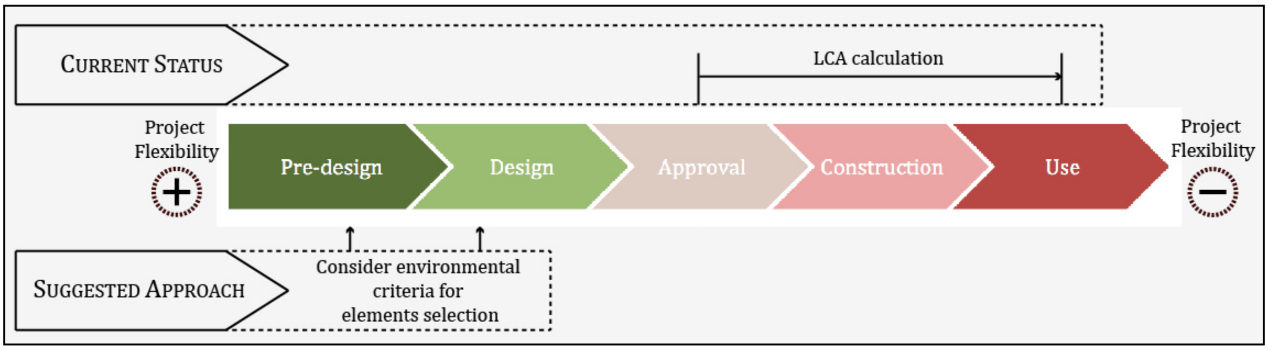

Figure 3. Second suggested approach for LCA and BIM integration.

Once the model is ready, a list can be made of the different components and their properties. It is then possible to take information from this list for the LCA of the building. For example, a spreadsheet can be used for relating building quantities to LCA database information. The resulting assessment will be mainly material-oriented, since it is based on information referring to different materials and components. Moreover, it is just an estimation for use up to the construction phase, because it is too difficult to evaluate the entire life cycle with such simple tools.

Nevertheless, this procedure might constitute an initial step in integrating and relating information from the building model and the LCA databases.

Moreover, for achieving an efficient use of the environmental information included in the smart-objects, designers have to be trained. It is important that designers are able to understand the environmental information given and its meaning in order to be able to compare between different alternatives. Therefore, this information has to be presented in a clear way.

Advantages of this approach:

- Environmental information is included in the properties of the BIM objects, which means that environmental properties are on the same level as other properties regarding the construction elements and may be used as decision-making criteria. Moreover, designers and engineers will get used to including environmental criteria in the regular decision-making procedure.

Disadvantages of this approach:

- It is less accurate in terms of calculating the LCA of the whole construction.
- Although it may be considered as an initial step in integrating the model information with the information included in the LCA databases, further developments are needed to improve the efficiency of this approach.
- It is still unresolved the issue of calculating and automatically including the information related to transportation of the different materials and elements to the construction site, considering the different characteristics, location, and features of each project.

4. Conclusion

One of the main aims of integrating LCA and BIM is to obtain a convenient decision-making method. Obviously, it must be easy for the designers to apply such tools on a day-to-day basis without being LCA experts. If greater effort is required, they will not use the tools adequately. Indeed, a lack of information must be seen as a general obstacle irrespective of which tools are used for life-cycle assessment.

With regard to the two approaches which have been presented for integrating LCA and BIM, it can be concluded that the first one, which is based on the assessment of the entire construction life cycle, is more accurate despite the fact that it is more complex, and further development is required in this field. The second approach, which is mainly material-oriented, may be seen as a way of including environmental criteria on the same level as other features in the early design phases in terms of selecting materials, products and elements. In other words, it highlights the importance of environmental criteria during the decision-making process.

Ongoing research shows that the second approach is not as suitable as the first approach with reference to the LCA of the whole construction because it is generally less accurate. Nevertheless, it could be viewed as a starting point for the inclusion of environmental criteria in the early design phases.

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"Triple R"- a quantitative model for critical infrastructures to withstand extreme events

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Abstract

Modern societies are increasingly dependent on the successful provision of critical services delivered through Critical Infrastructures (CI). A Critical Infrastructure consists of systems that, if disrupted or destroyed, have a serious impact on the health, safety, security, and wellbeing of society or the effective performance of governments. Terrorism and physical attack on CI have continued to increase and the safety of Critical Infrastructures concerns nation's stability and economic wellbeing. This research proposes a quantitative risk analysis model named "Triple R Analysis" (TRA) to determine the most effective protective Strategy (Resilience, Robustness or Redundancy) to mitigate hazards and risks to Critical Infrastructures under the scenario of man-made extreme events. TRA model consists of four main phases: *Initialization* (site characteristics), *Risk Analysis* (Probabilistic Risk Assessment and Fault-Tree-Analyses), *Cost of Protective Effectiveness* (CPE) of alternative protective strategies, and *Total Cost of Protective Effectiveness* (TCPE) that sums up the costs of risk and risk mitigation. The proposed model provides distinctive alternative protective strategies: Redundancy, Robustness and Resilience, it quantifies the risk and risk mitigation costs along the C.I. life cycle and proposes a layout for protective policy making and investment in C.I.s. A case study on electric power supply sub-station was carried out to demonstrate the model; three alternative strategies were analyzed and compared. Redundancy was found to be the least effective solution in terms of cost-effectiveness whereas resilience was found to be a preferred solution for Protective Effectiveness (the effectiveness of the protective system to prevent the event) of between 0.50 and 0.90. The costs of all strategies diverge as the Protective Effectiveness is greater than 0.95.

Keywords: Critical Infrastructures, Extreme Events; Redundency, Resilience, Robustness, Risk.

1. Introduction

The performance of Critical Infrastructures is essential for the civil society security and well being particularly in Extreme events. Critical Infrastructures Such as energy and water supply, Critical storage, gas and oil plants and others are required to perform in a diversity of conditions, beginning with routine maintenance through extreme events (Luiijf & Klaver, 2005). Each infrastructure is inherently a complex system, when grouped together these systems become highly interconnected and mutually dependent, because of that the rippling effect of extreme events to any critical infrastructure may have an amplifying impact that can be far-reaching and long lasting (Zimmerman 2004), (McDaniels, Chang, Peterson, Mikawoz, &Reed, 2007), (Utan, Hokstad, & Vtan, 2011).During the last decades terrorism and physical attack on CI have continued to increase and the safety of the Critical Infrastructures concerns nations' stability and economic wellbeing (Zimmerman 2004). Such events may consist of explosives or suicide bombers, armed attacks and CBRN (chemical, biological, radiological and nuclear) agents (Bonsen & Gaasbeek,2009).including London city (2005), (Aylwin, KÓnig, Brennan, Shirley, Davies, Walsh, & Brohi,2006), Oklahoma City (1995) (Osteraas, 2006),(Corley, Mlakar, Sozen, & Thornton 1998). Pentagon and World Trade Center (2001) (Mendonca & Wallace, 2006) Australian Embassy in Indonesia (2004) etc. Terrorists act with purpose, they observe defensive preparations, evaluate alternate plans, and choose to act at a time and place where they can apply their limited resources to a maximum effect. Any event that disrupts the performance of Critical Infrastructure may have a major impact on the society (nation's stability and economic wellbeing) (branscomb, 2004). All of the above-mentioned derives indicate the high priority to develop a systematic tool for critical infrastructures risk assessment tools under the occurrence of extreme event.

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2. Research Method

2.1 The Decision Variables and Parameter

In 1981, Kaplan and Garrick posed three fundamental questions that constitute the risk assessment theme: "what can go wrong?", "what is the likelihood?", and "what are the consequences?", to quantify this process we used the formulation for annual risk for a Critical Infrastructure exposed to terror threat as shown in expression (1):

$$R= (P_S| P_A) \cdot (P_A) \times (1-P_E) \times C \qquad [1]$$

Where:
R - Risk Expectancy associated with extreme event [$]
P_A- Probability/Likelihood of event [%]
$P_S|P_A$ - Condition event success Probability/Likelihood [%]
P_E - Effectiveness of the protective system to prevent the event [%]
(1- P_E) - Vulnerability of the CI to a given extreme event, derived by the ineffectiveness of the protective system [%]
C - Consequence of the event [$].

Each component of equation (1) may be multidimensional and interdependencies may exist between the variables, in particular: (a) The Probability/Likelihood of event (P_A) and the Attack success Probability/Likelihood ($P_S|P_A$) are functions of the time of the event (T) and the vulnerability of the CI to a given attack (1- P_E).(b) The Consequence, C, is a function of the time of the event (T) and the vulnerability of the CI to a given event (1- P_E).

The innovation we offer in this paper according to Kaplan and Garrick risk assessment process is that there is an interdependency between the questions "what is the likelihood?" and "what are the consequences?" and the state of the Critical Infrastructure (CI). Therefore we add here the following questions: "what is the planning horizon?", "what is the vulnerability of the CI to an attack within the planning horizon?" Unlike risks due to natural disasters, accidents, and CI failure, these are unique attributes of terrorism risks. The state of the Critical Infrastructure plays a crucial role in estimating its future behavior for any given threat. The parameter that indicates this attribute is PE, the Protective Effectiveness of the protective system. For example: if the Critical Infrastructure is optimally protected we assume rational assumption that the expected attack success probability ($P_S|P_A$) from a given threat scenario will be reduced and consequently the likelihood of attack (P_A) as well as the consequences (C). On the other hand if a Critical Infrastructure is not protected at all for a given event, then the expected success probability for a given event ($P_S|P_A$) from a given threat scenario will be maximized and so the likelihood of attack (P_A) and the consequences (C).

Since we understand that risk to a CI is inherently and fundamentally a function of the state of the CI, we offer the "Triple R Analysis" to find the most effective protective alternative strategy represented by Resilience, Robustness and Redundancy to reduce the overall risk to CI caused by extreme terror event. The need to add security features has placed a heavy burden on the already strained budgets of the decision makers. Likewise, there are many possible and costly protective measures that make the decision makers process harder.

In the following paragraph we define the three strategies in details:

Resilience- Haimes,2012 offers the following definition: "the ability of a system to withstand a disruption within acceptable degradation parameters and to recover within acceptable losses and time". Resilience is a vector that represents the state of a system. It’s the ability to absorb impact, and reduce loss of power within acceptable predetermined level of degradation. For example: resilience of a system may be achieved through security devices, measures for protecting people, fire alarm systems, etc.

Robustness is defined by the structure’s ability to withstand any unforeseen loading as well as initiating damage scenarios without a disproportionate response. It also represents the structure’s ability to absorb minor structural failures (perturbations) without affecting the overall structural integrity. For example: passive protection such as shelters reinforced concrete components, bullet-proof glass, steel constructions etc.

Redundancy is the slack of critical components of a system with the intention to increase reliability of the system.

For example: redundancy may be achieved by power supply backup, parallel devices to create redundant capacity of the CI, etc.

2.2 Triple R Model

The "Triple R Analysis" for Critical Infrastructure consists of the following four phases:

1. Initialization: In this phase we highlight various aspects of A Critical Infrastructure such as: (A) the critical infrastructure Architecture which includes organization layer and physical layer. The obtained result is a platform for identification of the critical assets requiring protection and prioritization of these assets by using: FMEA (Goel & Graves 2007), (Gofuku, Koide, & Shimada, 2006), FMCEA (Faber & Stewart, 2003),(Automatic Industry Action Group.2008), Event Trees, (Ezell, Bennet, Winterfeldt, Sokolowski, & Collins, 2010), (Haimes & Jiang, 2004), (Pinto & Lambert, 2002). and FTA (Andrews & Sinnamon, 1996), (Bluvband, Polak, & Grabov, 2005), (Goldberg, Vesely, & Robert, 1981))methods.

(B) Identifying of hazardous events-choosing the threat scenario. It is sought from Community Intelligence, site security manager, local law enforcement, media, etc. (C) Alternative protective strategies to the CI in the following categories: Resilience, Robustness and Redundancy base on the cumulative knowledge so far and the advice of various experts in the organization.(D) Converting of the Protective strategies to Protective Effectiveness level in percentage by using Pressure-Impulse Diagrams for assessing the expected damage (Ramsay, Gupta, & Ngo, 2007),(Krauthammera, 2008), (Dyer, Raibagkara, Kolbe, & Salzano, 2012), (LiQ & Meng, 2002)). Stochastic simulation was developed and provides a response for different charge weight and standoff distance combinations. The code assesses blast damage to the critical infrastructure structural components, and it is converted to Vulnerability of the CIs to a given event represented as ($1-P_E$) the ineffectiveness of the protective system [%].

2. Risk Analysis: development of a functional relationship between the level of Robustness, Resilience and Redundancy with respect to the Expectancy of Risk.

Risk Analysis is carried out using expression 1 above for each strategy for variable values of PE. The Risk Expectancy phase includes four sub-stages in accordance with the four components of equation 1:

(a) Threat Scenario Analysis- The likelihood of extreme event is assessed with the aid of a questionnaire for the experts in the facility that includes the following aspects: Collect information on the potential threats. It should be sought from Community Intelligence, site security manager, local low enforcement, media, etc (FEMA 452, 2005) (FEMA 427, 2003).Derive an adversary spectrum for a given threat scenario. Describe adversary capabilities. (Based on the degree to which combination of these factors: existence, motivation, capability, intent, history, targeting, security environment, weapons, transportation, etc.), asset characterization such as visibility, vulnerability to a given extreme terror event, security, etc.

(b)The Conditioned probability of successful event ($PS|PA$) is estimated from a statistic database of the chosen scenario.

(c) Consequences analysis-The purpose of consequence analysis is to estimate consequence values for each undesired event for a given Critical Infrastructure.

3. Cost of Protective Effectiveness (CPE) Function: This function calculates the expected cost required to invest in risk reduction per protective effectiveness level for the "Triple R analysis". Each strategy in the Triple R analysis (Resilience, Robustness and Redundancy) has a finite number of different alternative discrete solutions, which can be expressed in economic terms.

4. Total Cost of Protective Effectiveness (TCPE) Functions: The final phase is to derivate the optimal protective solution of a given strategy from an integrated model. A new function Total Cost of Protective Effectiveness (TCPE) was defined as the sum of the total of Risk Expectancy (R) and Cost of Protective Effectiveness (CPE) as shown in expression 2:

$$TCPE=R+CPE \qquad [2]$$

An optimal solution would be a minimum of TCPE (Fig.1) that expresses minimum of the total of risk and capital investment in protective effectiveness.

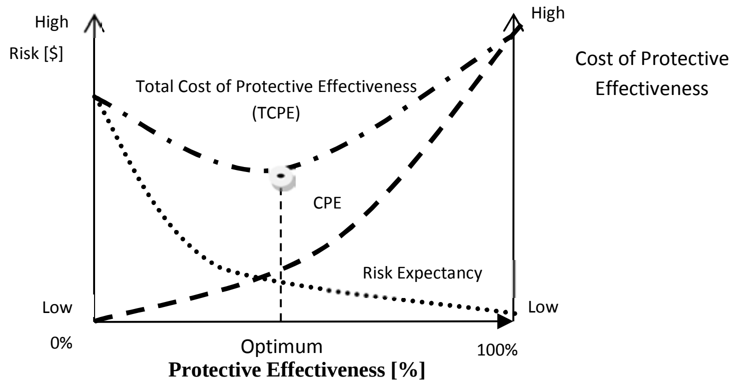

Figure 1. Total Cost of Protective Effectiveness (TCPE) as a function of the Protective Effectiveness (PE) of a C.I.

This procedure may be repeated for each alternative strategy as shown in Figure 2. The minimum curve for a required Protective Effectiveness (PE) is the optimal solution. From this step one can assess the trade off between Robustness, Resilience and Redundancy in the overall risk expectancy and the Total Cost of Protective Effectiveness in Critical Infrastructure.

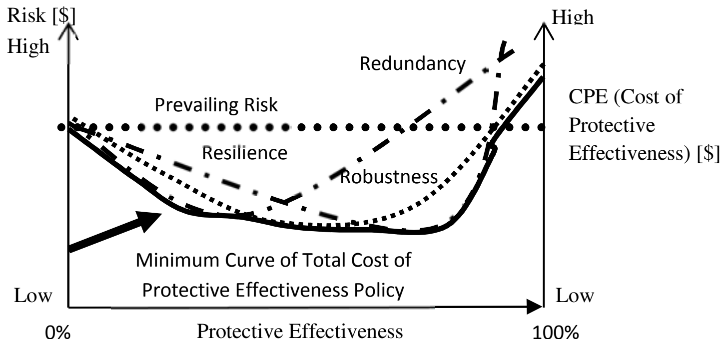

Figure 2. Minimum Envelope of total cost of Protective Effectiveness for aggregation of 3 alternative protective strategies: Redundancy, Robustness and Resilience

3. Case Study - Electric Power Sub-Station

Electric Power Systems constitute the fundamental infrastructure of society that supplies an essential and critical service for society (Nystrom & Austrin,2006).An Extreme terror event attempts to disrupt power supplies and effects on national security, the economy, and many aspects of civil life such as healthcare, industrial plants, security, etc. The implementation of the Methodology is on an Electric power Substation located in Sderot town. The area is found under a constant threat, especially steep-path shooting of Grad Rocket with explosive of 90 kg TNT, in a range of 10 km approximately from the border line with the Gaza strip. This Electric Power Systems is a First Degree Strategic Facility, being the Central Electric power Supplier of Sderot town.

A complete characterization of the facility carried out and the critical assets requiring protection were identified and prioritized by using Fault Tree Analysis and experts advices.

For each strategy in the "Triple R Analysis" (Redundancy, Resilience, and Robustness) five different alternative discrete ascending solutions were developed. The next step was to translate the suggested solutions into a Protective Effectiveness (P_E) percentage by analysis of the expected damage (consequences) to the facility and its occupants. For example, the Protective solutions for the Robustness strategy included: full protection of steel construction (P_E=0.99), protection by concrete construction (P_E=0.90), burial of critical components in the soil (P_E=0.65), protection by the concrete walls (P_E=0.50), protective secured space (P_E=0.35), and without protection (P_E=0.01). For each level of P_E a calculation of the risk expectancy analysis was measured. The outcomes of the annual attack probabilities are found to be 0.253, 0.303, 0.358, 0.408, 0.487, and 0.606 respectively. These probabilities based on weighting the expert questionnaire according to equation 2.

The condition extreme event success Probability/Likelihood ($P_S|P_A$ [%]) was estimated from a statistic database of steep-path shooting of Grad Rocket to Sderot area According to the Israeli intelligence agency (SHABAC) and found to be 0.17 per annum. The consequences analysis of each solution was measured in terms of direct consequences: physical damage, production loss, loss of life or injury and indirect loss which include user delay, environmental damage, increase security costs etc. Fig. 3 depicts the expected results obtained from equation 1 for each of the 6 protective solutions mentioned above for the Robustness strategy form the "Triple R Analysis".

It is apparent from Figure 3 that the optimal solution for Protective Effectiveness is found to be around P_E=0.58. From Protective Effectiveness of 95% and above the suggested protective solution is not cost-effective and economic, this can be shown by the point of intersection of the two graphs: Total Cost of Protective Effectiveness and the prevailing risk graph. The breakeven point between the Risk curve and Cost of Protective Effectiveness (CPE) curve is found to be at around 50% of Protective Effectiveness, this explains the relatively high feasibility margin of 95% of protective Effectiveness in the Robustness Strategy.

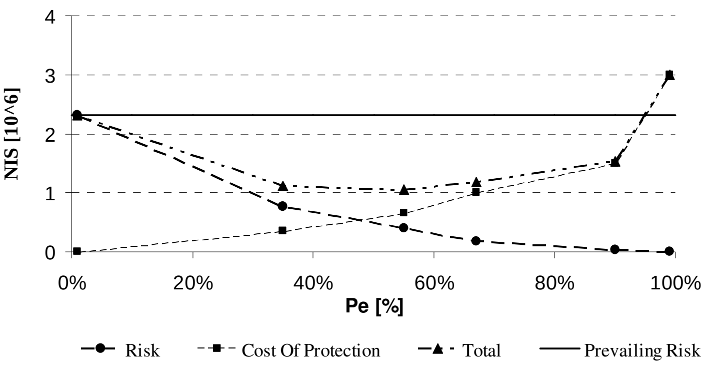

Figure 3: Total Cost of Protective Effectiveness (TCPE) Vs, level of Protective Effectiveness – Robustness

Figure 4 shows the Total Cost of Protective Effectiveness (TCPE) for each strategy and the optimal solution for the asset which consists of the minimum envelope created by the combination of three graphs. One can see that the redundancy strategy is found to be the least effective solution in terms of cost-effectiveness of the strategy; it is realized as this strategy is found above the charts of the Robustness and the Resilience strategies For the other two strategies, it is found that resilience is a preferred solution for Protective Effectiveness (PE) of between 0.50 and 0.90.

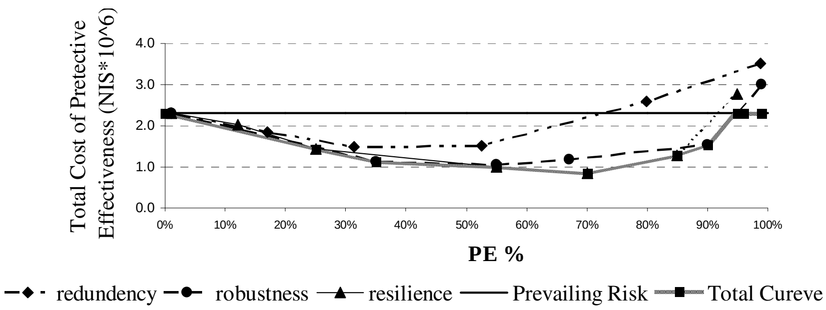

Figure 4: Minimum Envelop of Total Cost of Protective Effectiveness for aggregation of 3 alternative protective strategies: Redundancy, Resilience and Robustness.

4. Conclusion

This paper introduces a probabilistic computational risk analysis model that incorporates blast-response models and Benefit-Cost-Ratio (BCR) analysis that investigates whether the prevailing risks in C.I.s exposed to extreme terror events are acceptable and assesses if a reduction in the prevailing risk as a result of a risk mitigation strategy worth the additional investment, and to what extent, particularly in situations that require careful allocation of resources or limited budget. The TRA model provides in-depth understanding of the decision variables of Critical Infrastructures protection against extreme terror events, such as the Risk expectancy (R) function and the Cost of Protective Effectiveness (CPE), both functions are core elements for risk management decision making problems in critical infrastructures protection. Following the 10 principles for risk assessment management and communication proposed by Haimes, 2012, the research suggests implementation of a combined Pareto-optimal frontier of policies between Redundancy, Resilience and Robustness along a two dimensional space of Protective Effectiveness and Risk. This provides a communicative term of risk where the two main variables are: Protective Policy (independent) expressed by PE and Risk (dependent). From the case study one can deduce that comprehensive risk mitigation policies are not economically effective and feasible, whereas it is found that there are multiple near optimal solutions that may be combined of different strategies such as Resilience and Robustness. Furthermore, it can be seen that Redundancy is more effective for highly vulnerable (PE≈0) facilities, where Resilience and Robustness are effective for facilities at low vulnerability (PE≥0.8).

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Toward the reduction of environmental impacts of temporary event infrastructures

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Abstract

In the context of temporary events, the use of structural systems suitable for short-term use, is a key strategy in terms of organization. However, this type of infrastructure currently requires the implementation of significant resources, for which the characteristics of flexibility and economic efficiency most often prevail over considerations related to sustainability.
This lack of sustainability exists due to several attributes of a temporary building. Firstly, the distance between the place of storage and the one of use requires transportation, which can sometimes represent a significant share of consumption and environmental impacts. Furthermore, heat energy required to achieve an acceptable level of indoor comfort in a building with little or no thermal isolation is disproportionate to the short time of use. Finally, the materials used, in most cases, have a significant life cycle in terms of embodied energy required for their manufacture and respectively their disposal. However, many parameters are not as yet subject to specific studies. Contributing to remedy this lack, the present paper aims to evaluate the environmental impacts of current temporary event infrastructures and to compare them with the expected performances of an alternative proposition, the On STAGE Project, the design of which refers to architectural quality and high level of comfort with an optimal use of resources and a minimization of environmental impacts.
In this context, a detailed analysis of several existing building systems is presented, including three significant indicators calculated on the whole of their life cycle: Non Renewable Energy (NRE), GWP Global Warming Potential (GWP) and Acidification Potential (AP). A set of results will secondly demonstrate, based on the preliminary values obtained for the On STAGE Project, that it is possible to design a novel temporary infrastructure capable of preserving our resources and reducing environmental impacts. Through an integrated design process based on the principles of bioclimatic architecture and the use of renewable energy sources, it is possible to meet sustainability goals, even when devices with a short lifespan are being utilized.

Keywords: temporary infrastructure, sustainable construction, integrated design, energy, environmental impact, life-cycle assessment.

1. Introduction

The project "OnSTAGE " proposes an alternative to typical event infrastructure. Indeed the use of this kind of temporary infrastructure is booming and should be designed in a sustainable way. Not only in terms of flexibility and speed of erection but also from the point of view of thermal and acoustic performance, from architectural aesthetics, or regarding gray energy needed for manufacture, use and transport.

Firstly, this article observes some data on the development of the cultural sector to illustrate the favourable context for the project "OnSTAGE". Then through a multi criteria evaluation of sustainability parameters of a typical tent, representative of current practice, we are going to specify advantages and disadvantages of such infrastructure. An assessment that will be useful to set out the specific objectives of the project "OnSTAGE", both from an architectural and aesthetic point of view than in terms of use, or in order to minimize environmental impacts. Finally, the presentation of conceptual vision, currently under development through a process of integrated design, in order to optimize iteratively the different dimensions of the project (APPLEBY, 2011) will provide reliable base for the next realization of an operational prototype.

2. Increasing demand regarding temporary event infrastructures

In consideration of the especially significant number of cultural manifestations (festivals, shows, exhibitions), commercial (trade fairs, fairs, exchanges), sportive or political festivals, where the assembly of temporary infrastructures is necessary, a tangible need regarding the material is manifested. Nevertheless, the consultation of all regional, national or international agendas, which appear on the media, induces an impression of the real growth in the event branch. The specific analysis of this area, as measured by a country like Switzerland, shows this importance: the revenues generated by the event industry in its entirety (summing up commercial, cultural,

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festive, sportive and political forms) have increased regularly since 2003 by 6% per year (DESILVA, 2008). The Federal Statistical Office (OFS) adds a completion in the field of the frequentation linked to cultural practices. In terms of musicals, 67 % of the Swiss population attended at least one concert or another music event (OFS, 2011). In terms of the entirety of the European countries, the average of the population attending a “live” performance in 2006 (including the Swiss category “music or other musical events”) was around a little bit more than 40 % of the population (EUROSTAT, 2011). Furthermore, it is noted that the International Organization for Standardization (ISO) has published a new standard for organizers of events in order to increase integration of sustainability into their activities (ISO, 2012). This standard emphasizes in particular the need for certain temporary event constructions, thus avoiding oversized infrastructures in relation to actual needs once the event happened. The London Olympics in 2012 are a prime example of the application of these recommendations. These figures highlight the interest in the project "OnSTAGE" which is characterized by a strong development potential.

3. Limits of the common practice

In order to comprehend more precisely the advantages and the disadvantages of the usual practice of material for the temporary event infrastructure, a case study has been conducted on a representative model of this type of temporary model. A tent of classical fabrication had been specifically chosen, which harboured the main stage at the Cully Jazz Festival (Switzerland), destined for about 1000 viewers. This case study took place in april 2011. The results of these analyses are summarized below.

3.1. Thermal comfort

In order to evaluate the climate inside more precisely, four data loggers had been place inside and outside the tent during the whole festival, namely one week. The results obtained and presented in figure 1 clearly show the characteristics of the light construction of the analyzed model. In fact, the tent had neither any insulation nor any thermal sealing, which made it susceptible for the different temperatures outside, but especially for the influences of the direct solar radiation. In that way, you can note the important variation of the monitored temperatures, at the beginning of the afternoon, on a sunny day (March 30) and on a very cloudy day (March 31), which expresses the strong dependence of the inner climate on the direct solar radiation. A second peak in inner temperature had been monitored at the end of the evening of the concert. In fact, the presence of one thousand visitors represents an energy input inside which may not be neglected, and it is recommended to consider the users (viewers, musicians and technicians) in the objective for the improvement of the thermal comfort. These two factors influencing the climate inside, which are the direct solar radiation and the internal heat gains, are furthermore not controllable by the operators. In case of the analyzed construction it remains difficult to compensate the climatic variations inside and however reach satisfactory thermal comfort (LAST et al., 2011).

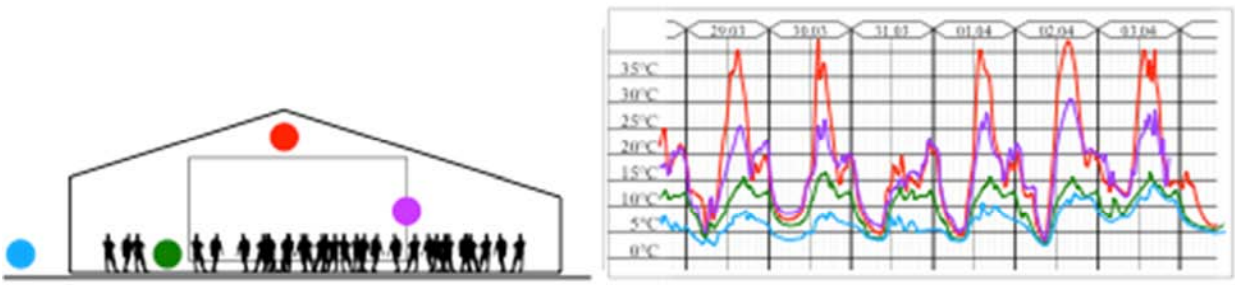
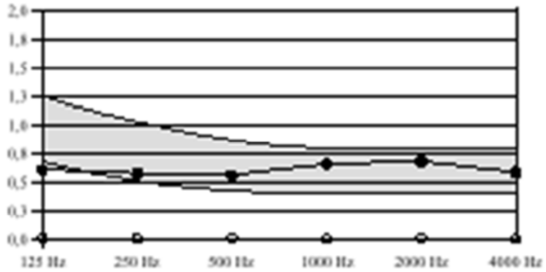


Figure 1. Position of the data loggers and measuring of the temperatures during the Cully Jazz Festival (March – April 2011).

3.2. Acoustic comfort

The acoustic comfort is also influenced by the light construction, the more acoustic quality you have inside the more emissions sound to the neighborhood. In order to evaluate the acoustic quality inside, the times of reverberation had been measured during a concert. The results, illustrated in figure 4, show that it is possible to stay within the optimum area for jazz, but with one time measuring around the limits for the bass frequencies as a consequence of the light construction of the model. A model with big awnings made of cloth tensed across the ceiling of the tent, contributes to improve the periods of reverberation in order to reach a satisfactory level for the jazz. During the analysis, a different type of noise pollution, especially annoying for the users (viewers and musicians) had been detected. It is a disturbing noise due to the constructive modalities of the infrastructure. In case of strong wind you can also note additional noise resulting from the movement of the construction and the ceilings, especially when the sound volume of the concert is low (LAST et al., 2011).



1

2

	External noise dB(A)				
Points	Leq.e	Lr max.e	Leq10.max	Lr.m	
1	64,5	68,9	75,5	75,5	Above legal limit
2	68,0	70,9	79,0	79,0	Above legal limit
3	67,2	70,1	78,2	78,2	Above legal limit
4	64,3	67,2	75,3	75,3	Above legal limit
5	62,0	64,9	73,0	73,0	Above legal limit
6	67,2	70,1	78,2	78,2	Above legal limit

Figure 2 . (1) Measurement of the time of reverberation during a concert on the occasion of the Cully Jazz Festival (2011) – it is possible to stay within the optimum area for jazz but with one time measuring around the limits for the bass frequencies, as a consequence of the light construction of the model. (2) Measures of the medium noise level at several points in the neighborhood of the tent during a concert at the Cully Jazz Festival (2011). The measurements show values far above the legal limits for permanent constructions.

3.3. Consumption of non-renewable energy (NRE) and environmental impacts (GWP)

Furthermore, another aspect is the development of current practical limits considering criteria of sustainability. In this way the necessary grey-energy is subject to special verifications, especially regarding the influences on the environment. In this case study the aluminium is the main material used for the structure, as it offers interesting characteristics of lightness and hardiness, but it although requests a lot of energy during its production. As illustrate on figure 3, it represent until 63% of non-renewable energy (NRE) and 51% of global warming potential (GWP). In this way a better planning regarding the material use could optimize this aspect. Another environmental impact revealed by this assessment is the huge energy consumption required to heating system. In fact, to reach an acceptable inner climate during cooler periods, it would be necessary to compensate the thermal losses of the casing of the tent by temporary heating oil devices, but their efficiency is very bad, the influences on the environment are not to neglect and their results are very quickly dispersed due to the light construction (FUMEAUX and REY, 2012).

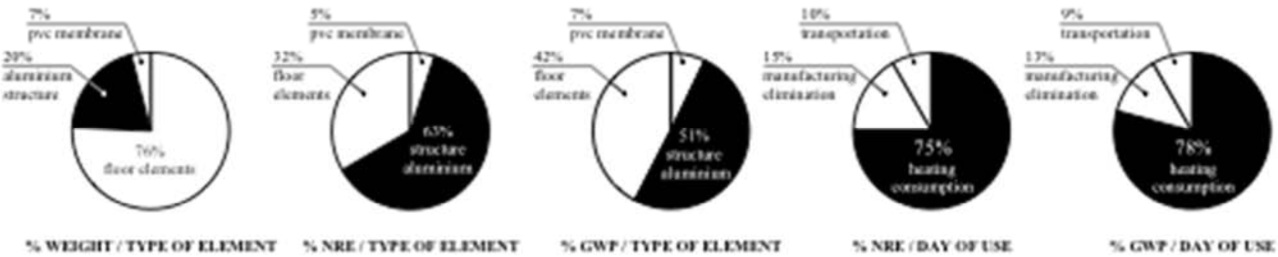


Figure 3. The aluminium is the main material used for the structure, as it offers interesting characteristics of lightness and hardiness, but it although requests a lot of energy during its production. The environmental impact revealed by this assessment is the huge energy consumption required to heating system, it represent until 63% of non-renewable energy (NRE) and 51% of global warming potential (GWP).

4. Targeted objectives for the project "OnSTAGE"

Regarding the analysis and the significant points mentioned above, the following targeted objectives are formulated for the development of the project "On STAGE", from point of view of planning an alternative infrastructure for the usual practice:

- Flexibility is the first objective. The project has to be able to offer adequate advantages for the current practice. Constructive modalities by elements, which have to offer an important level of modularity. The assembly of the whole or of parts of the systems must be possible, in order to adjust the size and comfort of the infrastructure.
- Comfort optimization of the planned infrastructure must permit the users the optimal management of the thermal and acoustic comfort. The objective is to keep the inner climate in a comfortable zone, which is the same condition as outside and the occupancy rate (ROULET, 2010).
- For an optimal use of resources the project will include architectural bioclimatic principles, especially regarding the thermal insulation, protection from the sun, natural ventilation and passive refection, which allow the reduction of its energetic demand (warmth and cold) and the prior valorisation of resources that are locally disposable (AIULFI and REY, 2010).
- Efficient exploitation: parallel to technical models the project aims at establishing a basis of a concept of efficient economic exploitation of the infrastructure. By rationalizing the process, the project has to reach an economic feasibility for the operator. The project aims at establishing bases of a financially balanced concept, regarding its lifecycle including an optimization of production costs and exploitation (REY and RYTER, 2003).

5. Architectural and technical concepts

Subsequent to the definition of the objectives of the project, a conceptual vision had been developed in order to set the basis of the constructive system and to specify the components that have to be developed in detail regarding the specific objectives mentioned. This conceptual vision is the basis of an iterative process of integrated design in the course of which the interdisciplinary competences of the different partners of the project (civil engineers, experts for thermal and acoustic, carpenters, specialists for photovoltaic and operators) have to optimize the conceptual vision in terms of the objectives stated. Turning these principles resulted in the development of solutions and complex systems based on several overlapping effects and integration with overall architectural design (APPLEBY, 2011).

As shown on figure 4, the project will include architectural bioclimatic principles, especially regarding the thermal insulation, protection from the sun, natural ventilation and passive cooling which allow the reduction of its energy demand. The project uses the given space between the two skins as a sealed space that helps to deflect the warm and provide a tempered layer, which contributes to the thermal insulation for the stability of the temperature inside. For the demand proportion, the integration of models working with renewable resources will be researched, especially with reference to solar energy (solar roofing including moveable photovoltaic cells) and the production of warmth (thermal heat pump). It is especially about evaluating the modalities of a neutral balance between consumed energy and renewable energy captured by the infrastructure (CSEM et al., 2013; SORANE SA et al., 2013).

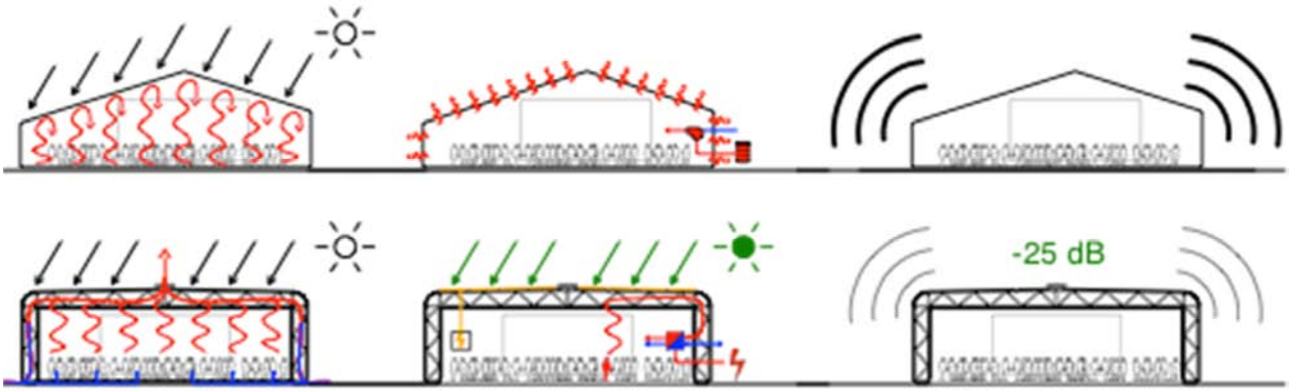


Figure 4. Principles of bioclimatic architecture applied to the project "On STAGE" in response to the limits of comfort and durability that characterizes current practice.

Regarding the acoustic, as illustrate on figure 4, the additional mass which is filled inside the acoustic panels will help to control the acoustic of the room better and to reduce the noise toward outside. According to the law of mass action it's possible, just by adding an acoustic skin of 10 kilograms per square meters to reduce by the sound emissions towards the exterior up to 25 dB. It may therefore benefit from a certain tolerance from the neighbourhood, and increase opportunities for implementation on most sites (A21 et al., 2013).

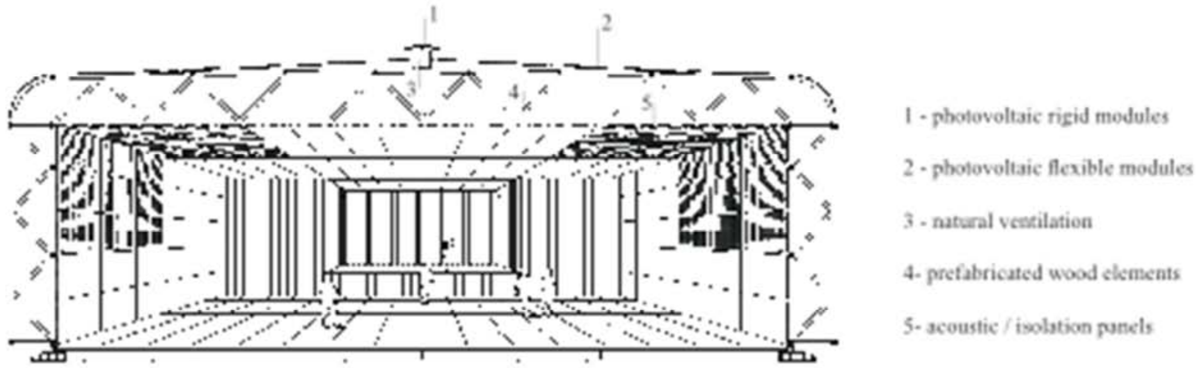


Figure 5. Cross-section of the projected casing. The project uses the space between the two layers of the casing as a sealed space assisting the bioclimatic control of comfort

As shown in figure 5, a series of triangulated frames, compounds of wooden elements, prefabricated in the workshop and assembled on site, compose the structure of the building (ERNE Holzbau AG et al., 2013). On this structure, an inner casing is fixed consisting of wooden panels by means of which the mass is reduced in order to facilitate the operation, but sufficient to comply with the acoustic requirements and to offer a certain thermal insulation. Finally, an outer casing in form of a sheer cloth including the moveable photovoltaic system on the roof completes the model. The assembly of this double casing allows the reduction of the amplitude of variations in temperature and the optimization of controlling the internal output by allowing at the same time the reduction of further energy input, determined on the occasion of the analysis of the current practice. For the energetic demand balance, the integration of models working with renewable resources will be researched especially regarding solar energy and the production of thermal heat pump.

The graph in Figure 6 shows that the significant reduction of energy needs is the result from the abandonment of oil and renewable energy output produced by the infrastructure through the integration of photovoltaic cells in its outer envelope. Along with these measures at the operating energy demonstration project "On STAGE" is also characterized by a significant reduction in embodied energy and emissions of carbon dioxide. A guidance and estimated the graph shown in Figure 7 shows a comparison of the overall balance in terms of non-renewable primary energy (NRE), and CO2 equivalent emissions (GWP). Reduction between the conventional system and the demonstration project "On STAGE" is of the order of 60% for primary non-renewable energy (NRE) and 40 % for CO2 equivalent emissions (GWP) (FUMEAUX and REY, 2012).

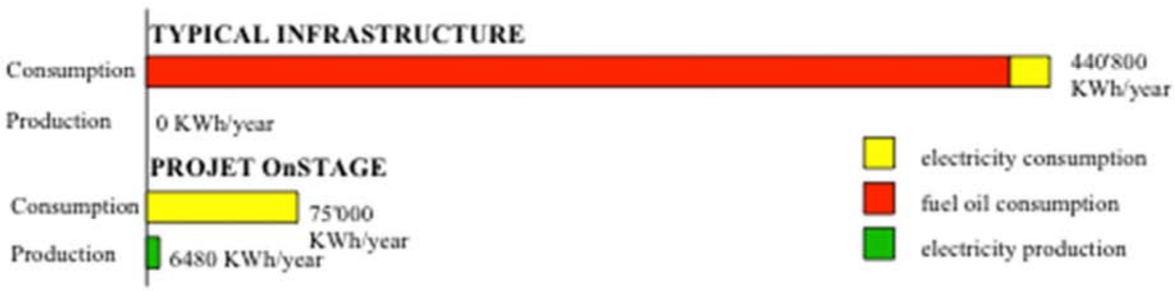


Figure 6. Comparison of energy consumed and produced (final energy) for annual use (100 days per year) for the conventional device and the project "On STAGE". The significant reduction of energy needs is the result from the abandonment of oil and renewable energy output produced by the infrastructure through the integration of photovoltaic cells in its outer envelope.

Figure 7. Comparing the estimated overall record non-renewable primary energy terms (NRE) and CO2 equivalent emissions (GWP) for the conventional device and the project "On STAGE".

6. Prospects

Following this integrated design process it was possible to have this day the main concepts of the infrastructure, verify and demonstrate feasibility. The next phase of the project is to go deep each element imagined conceptual and technical level to achieve complete constructive study, establish plans prefabrication and finally build the infrastructure for the 2015 edition of the Cully Jazz Festival, which takes value of first operational prototype.

Figure 8. Night view of the project "On STAGE" mounted on the site of the Place d'Armes in Cully (VD).

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Sustainable optimization of winter road maintenance services under real-time information

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Abstract

In the last couple of years the climate change is becoming more and more obvious. The temperature extremes are increasing, both maximum temperatures in the summer, as well as temperature minimums in the winter. This causes severe problems for the winter road maintenance service that has to deal with sudden cold spells followed by precipitation and difficulties it brings with. The research was conducted by reviewing present situation of winter road maintenance service of Kraljevica - a city with lot of everyday commuters toward two larger urban areas, Crikvenica and Rijeka. The problem arises when the cold front brings unusual weather conditions. The objective of this research is to provide a sustainable optimization of winter road maintenance service by maximizing the potential of the service to ensure steady traffic conditions. The problem was reviewed through a vehicle routing model. The model has been used to review the current situation in winter road cleaning based on the weather conditions over the last five years, and the worst case scenario was chosen for the simulations. The winter road cleaning optimization was carried out, and it led to possible solutions for adjustments of the winter road maintenance service in the city of Kraljevica. The results of the optimization have shown that there is room for improvement of the current winter road maintenance service conditions in the city, making it more sustainable in the future. Further, models presented in this paper could be used for improvement of maintenance services in other urban areas as well. Suggested possibilities could be used for service improvements, as well as cost and time optimization of the city budgets.

Keywords: cost optimization; operational research; time optimization; winter road maintenance service

1. Introduction

Winter road maintenance service involves a large number of operations, representing a notable challenge to municipal government. These operations include spreading of chemicals and abrasives, snow plowing, loading snow into trucks, and hauling snow to disposal sites. Decision-making at the supervisory level of winter maintenance operations is complex and often constrained by time and resources. For example, at the beginning of a snow storm, maintenance supervisors must decide when to start sanding, what operation routes and sequence to follow, and how much chemical agent or abrasives to apply. All these variants can be modeled and solved using operations research techniques. Many maintenance services still rely in large part on decision rules dictated by field experiences when making vehicle routing and depot location decisions. The limited progress in the use of optimization models is somewhat surprising given that even a small increase in efficiency or effectiveness through optimization could result in significant savings, improved mobility, and reduced environmental and societal impacts. The objective of this research is to provide a sustainable optimization of winter road maintenance service by maximizing the potential of the service to ensure steady traffic conditions.

This paper is divided into two sections. The first section presents a case study on Kraljevica winter road maintenance service. The road network is presented, as well as the model used for optimization, its structure and data input is explained. The second section shows the comparison of the results obtained by different inputs into the model presented in the first section and possibilities that could be used for winter road maintenance service improvements are suggested.

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2. Problem formulation and solution approach

The research was conducted by reviewing present situation of winter road maintenance service of Kraljevica - a city with lot of everyday commuters toward two larger urban areas, Crikvenica and Rijeka (Figure 1). Its area extends over 17 square kilometers, and it has approximately 30 kilometers of roadway with three main road entries to the city. Current winter maintenance service is obtained by a private company. Decisions pertaining to when and where to deploy service vehicles are typically made by a human supervisor, based on mostly static weather forecasts, the first hand reports of deployed vehicles, and personal experience. As such, it is not only difficult for knowledge to be quantified and transferred between supervisors, but also to soundly compare alternative treatment plans, or to perform 'what-if' scenarios without actually carrying them out in real life (Fu, Trudel & Kim, 2009). Its manager and working crew were interviewed about the maintenance routes, time necessary to complete the winter maintenance operations, and what operations are planned for the winter.

Decision-making at the supervisory level of winter maintenance operations are often complex and constrained by time and resources. At the onset of a snow storm, maintenance managers and supervisor must decide when to start sanding, what operation routes and sequence to follow, and how much chemical agent to apply (Fu, Trudel & Kim, 2009). Their opinion of possible improvements has been used for the beginning of the research.

Figure 9. Municipal boundaries of Kraljevica

The problem arises when the cold front brings unusual weather conditions. Based on the weather conditions given by Croatian Meteorological and Hydrological Service over the last five years (2007-2012), the worst case scenario was chosen for further research. Worst case occurred on the days between 30th of January and 4th of February of the year 2012. Temperatures were ranging from -6,1 to -2,2°C, north wind blowing up to 6 Beauforts and precipitation was measured approximately 0-45 mm/day. The main objective of this paper is to develop an operation plan for the available service vehicles, maintenance routes and review of possible fleet changes. This research is questioning could a sustainable optimization of winter road maintenance service be made by maximizing the potential of the service to ensure steady traffic conditions in long term.

In spite of the difficulty of winter road maintenance vehicle routing problems, recent models tend to take into account a larger variety of characteristics of the problems arising in real-world applications, and the proposed solution methods are often based on local search techniques (Perrier, Langevin & Campbell, 2007). There is an extensive literature of academic research on various issues related to the planning, design and management of winter road maintenance operations, summed up by Perrier et al. (2010). Since Kraljevica is located in mild Mediterranean climate area, there is no need for planning the plowing or snow disposal operations, so case study is concentrating on the spreading operations of winter road maintenance.

Spreading operations are directed at achieving three specific goals in winter road maintenance: anti-icing, deicing, and traction enhancement. The selection of the appropriate spreading operation is based on economics, environmental constraints, climate, level of service, material availability, and application equipment availability (Perrier et al., 2007). Because of its low price, ready availability, ease of application, and reliable ice-melting performance this paper will review spreading salt mixed with sand. The operations of spreading chemicals and abrasives concern the service of a set of road segments by a fleet of vehicles, which are based at one or more depots located in one or more sectors, and travel over an appropriate transportation network. Vehicle routing problems related to spreading are generally formulated as arc routing problems (Corberan & Prins, 2010; Perrier et al., 2010). The problem can be described as the problem of designing optimal delivery or collection routes from one or several depots to a number of geographically scattered cities or customers, subject to side constraints (Laporte, 1992).

In particular, vehicle routing problems for spreading operations consist of determining a set of routes, each performed by a vehicle that starts and ends at its own depot, such that all road segments are serviced, all the operational constraints are satisfied, and the global cost is minimized (Perrier et al., 2007). However, in the time-dependent variant of the vehicle routing problem for spreading operations, the timing of each service pass is of prime importance. That is, the cost to service a road segment depends on the time of beginning service. Recently, Tagmouti et al. (2007) proposed a nonlinear, mixed integer program and a column generation algorithm for a salt spreader routing problem with capacity constraints and time-dependent service costs. In this problem, the service cost on each required road segment is a piecewise linear function of the time of beginning of service.

The transportation network is presented through a graph, whose arcs and edges represent streets to be serviced, and whose nodes correspond to the road junctions and to the vehicle and materials depot locations. In Kraljevica there are total of 119 nodes, including nodes for vehicle and material depot location. Associated with the transportation network is a maximum time for completing spreading operations based on political and economic considerations. For this case study one model with two different variations was programmed. The first model variation calculates optimal routes for the current winter maintenance service, and the second model variation increases the number of vehicles and depots for given network.

2.1. Optimization of routes with current winter maintenance service

Currently there is one vehicle assigned for the whole network. Total time needed to complete the operation is two days, according to the winter maintenance service manager. Since agencies have finite resources that generally do not allow the highest level of service on all roads, they must then prioritize their response efforts. The roads of the chosen network were partitioned into four classes which induced a service hierarchy (Fu et al., 2009; Gabor, 2010).

From Operational program for winter maintenance of local and county roads (Road Administration, 2013) and Operational program for winter maintenance of unclassified roads and other public-traffic areas (Utility Service Department, 2013) main entrances to the city were defined as top priority, followed by road connecting the center of the city with both entrances. Roads that lead to ambulance, school and kindergarten were selected as third priority roads, and the rest of the network were given the minimum priority. The routes performed for spreading operations can start and end at one or more vehicle depots (Cai, Liu & Cao, 2009). Associated with every vehicle depot are a given number of vehicles of each type, in this case one vehicle for one depot at node 2 assigned to maintain Kraljevica road network (Figure 2).

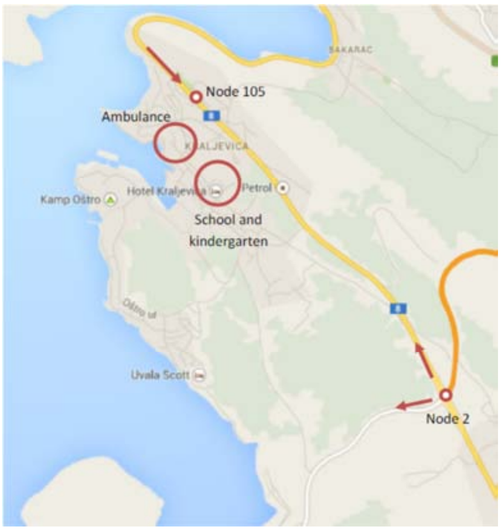

Figure 10. Main entrances into the city and depot locations

Spreading operations are performed using a fleet of vehicles, called spreaders, whose size and composition can be fixed or can be defined according to the level of service policies, the configuration of the streets and sidewalks, land use and density of development, and times for spreading completion for each class. The capacity of the spreader is expressed as the maximum quantity of chemicals or abrasives the spreader can discharge

(Feillet et al., 2004; Perrier, Langevin & Campbell, 2007). In this case the spreader type is like the one already used for the purposes of road maintenance in Kraljevica, with the capacity of 4 tons and application rate of 180 kilogram-per-lane-kilometer.

The routes must satisfy several operational constraints, which depend on the level of service policies, and on the characteristics of the transportation network, road segments, sectors and spreaders. The routes start and end at one or more depot locations and each route can end service at a depot other than the original starting depot. In anti-icing operations, routes must start at the proper time for effective spreading of chemicals. The decision must take into account such factors as type of snow, expected temperature conditions at the time of, and following, application, anticipated variations at the critical freeze-thaw point, methods of application, and types of chemicals. To balance the workload across routes, they are often approximately the same length and duration. This helps ensure that all spreading operations will be completed in a timely fashion. Service connectivity requires that sub graph induced by the set of road segments serviced by a spreader is connected. The configuration of routes may also need to conform to existing sector boundaries. Routes crossing these boundaries must be avoided from an administrative standpoint. Some operational constraints can be treated as hard constraints and others as soft requirements or as terms in an objective function. Finally, several, and often conflicting, objectives can be considered for the routing of spreaders.

2.2. Optimization of routes with depot and fleet increase

For the second model variation the number of the depots and vehicles has been increased. Another depot and same type vehicle have been added to the model at node 105, so the total number of depots and associated vehicles equals two. Locations of the depots are on the opposite sides of the city. Nodes 2 and 105 are representing the depots location in second model (Figure 2). The second model variation has been programmed to review the possible improvements for the winter maintenance service. The routes must satisfy several operational constraints, which depend on the level of service policies, and on the characteristics of the transportation network, road segments, sectors and spreaders. The routes start and end at two depot locations and each route ends service at the original starting depot.

3. Results

The two scenarios have been carried out and led to expected results. Current maintenance fleet number and depot location are sufficient for optimal road maintenance of a small town like Kraljevica. Nevertheless the route optimization shows great possibilities for improvement of maintenance service time and cost management. By following optimal routes, the amount of time needed to complete the spreading operation is decreased. According to the analysis and route optimization, Figure 3 presents a part of the generated optimal routes for both models.

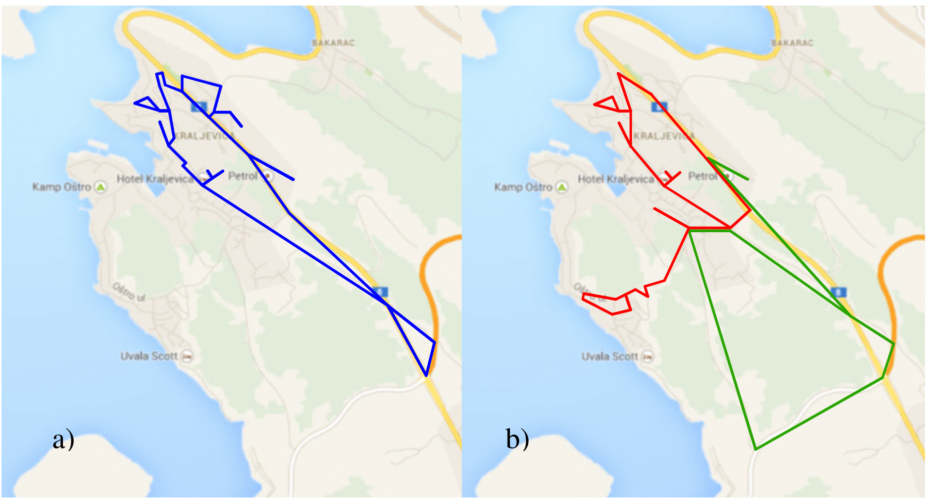

Figure 11. Part of generated routes for both model variations

The first model with current winter road maintenance service fleet is shown on Figure 3a, and the second with depot and fleet increase is shown on Figure 3b.

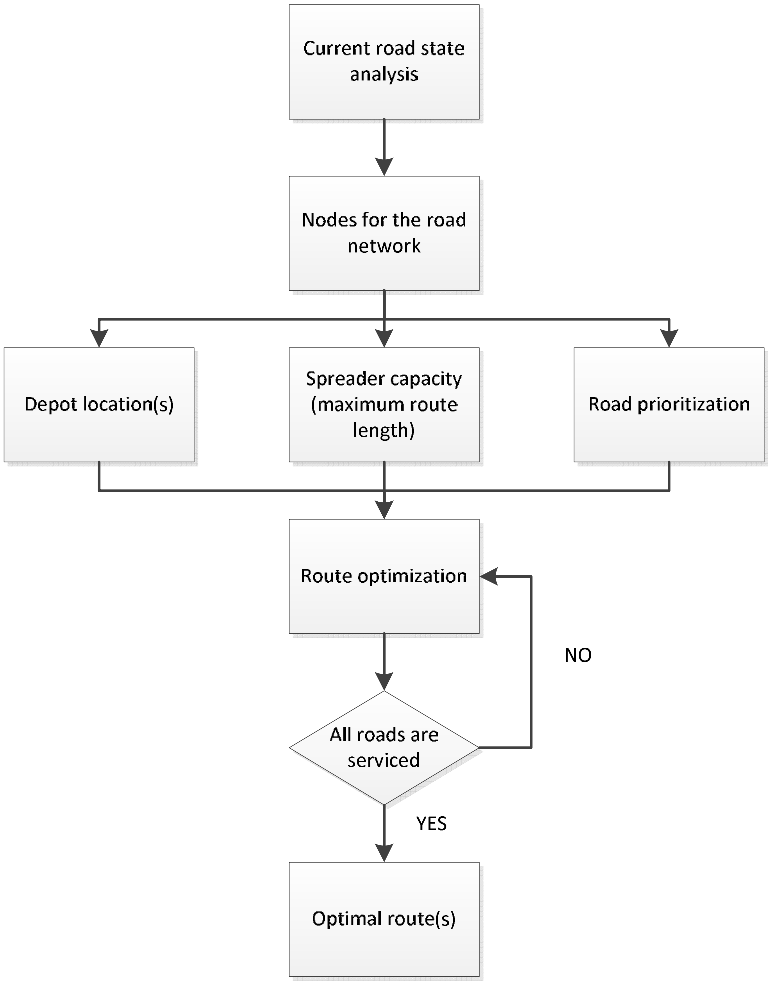

Figure 12. Suggested models flow diagram

The winter road cleaning optimization was carried out according to the model flow diagram (Figure 4). The model was formulated with Python, a programming language created by Guido van Rossum, based on earlier operations research models for routing of spreader vehicles (Perrier et al., 2007; Perrier et al., 2010). Current road maintenance service was examined. According to the road network of the city, nodes were associated with every conjunction on the roads, giving the road network a total of 119 nodes. Parameter d was defined as a matrix for distances between each node:

$$d = \begin{bmatrix} n_{1,1} & \dots & n_{j,1} \\ \dots & \dots & \dots \\ n_{1,i} & \dots & n_{i,j} \end{bmatrix}$$

Constraints were formulated by above mentioned conditions. Locations of the depots were set at node 2 for the first model variation, and at nodes 2 and 105 for the second model variation. Route distance was limited by spreader capacity - 180 kilogram-per-lane-kilometer is equal to 17 kilometers per one route for one spreader. Road network was divided into four service hierarchy classes. Road prioritization was formulated with the prioritization matrix p, for every connection between two nodes, a priority level was defined:

$$p = \begin{bmatrix} p_{1,1} & \dots & p_{j,1} \\ \dots & \dots & \dots \\ p_{1,i} & \dots & p_{i,j} \end{bmatrix}$$

The main objective of the model is to minimize total distance traveled with a guarantee that every arc is serviced at least once (Omer, 2007). Given result for the first model show that a significant time can be saved while performing spreading operations, almost 40% of time usually spent for the operation. While the new model demonstrates impressive capabilities to include more issues important to the operating agencies, there is still a large gap between state-of-the-art models and actual implementations. Some reasons for this gap include the difficulty of the problems, the unfamiliarity in the practitioner community with the advantages and benefits of OR models, and problems of technology transfer to a decentralized area such as winter maintenance (Perrier et al., 2010).

4. Conclusion

The research described in this paper was conducted by reviewing present situation of winter road maintenance service of Kraljevica. Although located in the mild Mediterranean climate, the cold front in the last couple of years brings unusual weather conditions. The objective of this research was to provide a sustainable optimization of winter road maintenance service by maximizing the potential of the service to ensure steady traffic conditions. The problem was reviewed through capacitated vehicle routing problem with the worst weather scenario chosen for the simulation. The winter road cleaning optimization was carried out, and showed room for adjustments of the winter road maintenance service in the city. The results of the optimization have shown that there are optimal maintenance routes that improve time management of the maintenance service. Model presented in this paper could be improved with more informations and constraints, and used for improvement of maintenance services in other small town areas with similar climate conditions as well. Suggested model could be used for service improvements, as well as cost and time optimization of the city budgets.

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Creative Construction Conference 2014

MILD HOME and EcoGreen Village: an ecological and economical concept for sustainability

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Abstract

"MILD HOME and EcoGreen Village" is the title of a transnational project in South East Europe region and a name of a concept, which aims to find a realistic middle way in the usage of sustainable architectural and technical tools for the residential buildings and areas helping the home builders, the building sector and the local small and middle enterprises. EcoGreen Village is a partly autonomous, sustainable settlement or a part of it. MILD HOMEs are residential buildings within this settlement having wise architectural solutions, energy efficient constructions, natural materials and economical construction methods. In the project area eight architectural competitions were held to find the suitable solutions for eight different sites in Hungary, Italy, Austria, Bulgaria, Serbia, Romania and Greece according to the concept. This paper presents the most interesting awarded entries of the international competition series, highlighted the first and exemplary Hungarian competition. In this one the Hungarian postgraduate schools were invited to participate and 28 packages arrived for our call. The site was given in the area of Tatabánya city. Beside the rich architectural content the entries show a very interesting image about the attitudes of the young architects and indirectly about the accents of our educational system. Several energy and environmental conscious solutions were included in the competition designs, which were evaluated by an expert jury and an architect jury. The awarded designs give the most complex solutions for the site from the society model to the applied materials. One aim of this paper is to present which sustainable solutions were preferred by the applicants. Discussions in this topic can help us to have a clear picture about our present possibilities in creation of a sustainable future.

Keywords: architectural competition, energetic evaluation, tools of sustainability, transnational project, urban development.

1. Knowledge levels of sustainability

In 2014 necessity of thinking about sustainability is not a question. Sustainability is a very complex notion which came from economics, but nowadays it has also a social and environmental meaning. It embodies the harmony among the different aspects of these three fields. According to the usual definition sustainability aims to meet human needs while preserving the environment so that these needs can be met not only in the present, but in the indefinite future. Notion and related issues are discussed by scientists since long time ago often with intense debates. (Stivers, 1976)

In contrast with the scientific discussion the ordinary people know about the sustainable issues just a few. Their knowledge is significantly influenced by the communication of the commerce and industry. It is important to see that these communication are parts of marketing strategies in which unfortunately there are sometimes false statements, misleading half-truths highlighted only the advantages, the peak performances, concealing the disadvantages, the side effects, the real performances, the real payback times and the prizes.

Naturally the education and information of the society could help, but in this confused situation professionals have a special responsibility. In a good case they have a confidential relationship with the users and/or owners giving advices, suggesting solutions. For example it is useful to think about the role of an architect or an engineer in the building process. This responsibility requires that all professionals have to be well informed in the issues of sustainability and have to evolve their own critical approach. It is a moral obligation that they have to help the users to make right decisions according to their best knowledge.

2. MILD HOME – A project for a clear picture of sustainability

In urban development and home buildings it's visible now, how initial is to create a realistic value judgments in connection with sustainable architectural and technical tools. MILD HOME project wants to help all participants of these development processes to have a more realistic picture. The full title of the project is "My

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Modular, Intelligent, Low cost, Do it yourself, nearly zero energy House for our EcoGreen Village". It contains several fashionable expressions which are often used by the environment and energy conscious architecture. Therefore during the project implementation the project partners had to focus on the content rather than on the project title.

The EU financed project work started in October 2012 under the auspices of South East Europe Transnational Cooperation Program. This program gave a territorial border, so the project partners are from the South East European region. 26 partners are involved from Italy, Austria, Bulgaria, Greece, Hungary, Romania and Serbia by the lead partner, the Regional Union of Veneto's Chambers of Commerce. The activities of the project were planned and defined in seven work packages. They have to be implemented until September of 2014. (S. n., 2012)

In the project ecological and economical sustainable solutions are researched for housing and urban development. The 'MILD HOME' was defined as the prototype of an affordable housing for the next few decades, discovering the appropriate architectural responses for the continuously changing environmental and social challenges. And the 'EcoGreen Village' is a complementary system to the individual MILD HOMEs, integrating those into an almost autonomous settlement. (Stein, Élő 2013)

3. Architectural competition series of ideas in South East Europe

At the beginning of the project the international partnership worked on the definition of the characteristics of MILD HOME and EcoGreen Village. In this process seven descriptions were created in seven countries, which are very similar in the environment and energy conscious issues, but they content several small differences according to the local social, geographical, financial needs and conditions. (Stein, Élő, Cseh, Horváth, 2013) The main chapters of these descriptions were the followings:

- General definition of MILD HOME and EcoGreen Village
- Types of MILD HOMEs as basis of EcoGreen Village
- Way of living in the MILD HOME and EcoGreen Village
- Financial background in the country
- Functions and services of MILD HOME and EcoGreen Village
- Scale, size and location of the EcoGreen Village
- Transport connections of the EcoGreen Village
- Applicable materials and structures
- Expectations in environmental impacts
- Expected energy performance
- Available energy resources
- Budget plan of building costs
- Budget plan of operating costs

Based on this general theoretical descriptions eight architectural competition calls were worked out. Eight sites were selected for the contests, where the applicants had to design residential estates. They had to find out real solutions for the MILD HOMEs and arranged them in an EcoGreen Village. The competition entries as several case-studies put the theory into practice.

3.1. Tatabánya, Hungary

The Hungarian competition was organized at first, because this was the example of the other competitions. The Széchenyi István University has a special role in this activity of the MILD HOME project. The university is the only institute among the partners whose professional field is the architectural and urban design. This is why the university became the responsible partner of the competitions.

For the competition an external partner, the city of Tatabánya gave the place and the half of the financial background. Tatabánya is an industrial city with 68.000 inhabitants, which has firm intention to go along the path of sustainable development. Three sites were examined here and the area called Alsógalla-Falurét was selected for this purpose with its 25.000 m^2 size.

Considering the available funds and striving for the best accessible quality the Hungarian competition was a restricted competition in which the students of Hungarian postgraduate architect schools were invited. In particular:

- Doctoral School of Architecture of the Budapest University of Technology and Economics
- Doctoral School of the Moholy-Nagy University of Art and Design Budapest
- Breuer Marcell Doctoral School of the University of Pécs
- Cziráki József Doctoral School, University of West Hungary
- Master School of Master Architects Association
- Wandering School of Kós Károly Association

The competition call was announced on 13th September 2013, when a kick-off conference was organized for the invited participants of the competition. Not only the tasks to be undertaken was discussed there but each school presented the experiences and special attitude to the environment and energy conscious architecture.

According to the call the design task was to work out a prototype of a residential building that can be constructed in an economical way (MILD HOME) whilst providing appropriate architectural responses to the continuously changing environmental and social challenges during the forthcoming decades. The building type to be designed is not only an innovative construction model but rather a new philosophy, the expression of a new way of life, indicating the relation between human beings, their home and environment. Further task was to design a settlement (EcoGreen Village) in which a collection of residential buildings with a new ethos can be created by the integration of building types, the separate housing units and community spaces. The main design aspects were:

- There were three different types defined for MILD HOME as a unit. The users of homes shall consist of young couples, young families, families and elder people. There was no restriction concerning the building design or flat types. The use of apartments was determined as a flexibly varying tenement flat system. The areas of units foreseen range from 40-100 m^2 depending on type, one housing unit shall include following functions: windbreak, living room, kitchen, bedroom, toilet and bathroom.
- Within the areas of units there are 100-200 flats to be installed as foreseen. As a community area, the following functions shall be located as a minimum: multifunctional area, laundry, bike storage, etc.
- The overall energy performance of buildings designed shall be of 50 kWh/m^2a, their energetic classification A+, heat transmission coefficient in case of walls 0.20-0.26 W/m^2K, roofs 0.16-0.20 W/m^2K, and doors and windows 0.90-1.10 W/m^2K.
- Reasoning in life cycles, searching innovative solutions and experimenting free conceptual design were equally expected as imperatives when designing housing units and the settlement integrating them. (S. n., 2014)

The submission of the competition entries happened on 13th of January 2014. 28 works arrived in time. The evaluation process started on 15th with an expert jury in which five experts examined the works. Building structures, load-bearing structures, energetic solutions, building service systems and the budget plan of building and operating costs were rated by the experts. Specialists were not in a good situation, because in several cases the conformity of the solutions could not be judged, because of the missing informations. On 17th the entries and the professional opinions were passed to the architect jury which was composed by the staff of MILD HOME project, the representatives of Tatabánya city and each postgraduate school. In the final report the Assessment Committee selected works for the first, the second and the third prizes, and gave honorable mentions to further five works. The announcement of results was held on 6th of February in Tatabánya. (Assessment Committee, 2014)

Short descriptions of the awarded works and those outstanding elements:

- Third prize, created by Antal Gabriella, Bartha András, Gyulovics István, Nagy Balázs and Klobusovszky Péter:
  In this design the site is divided into two parts by the relocated brook which ran before along the north border of the area. The south part of the site is reserved for single family houses evoking the land use of the traditional Hungarian village. The wooden structures of houses can be built by the residents with do-it-yourself technology. On the north part of the site four multi-story buildings stand. The blocks of flats are formed according to the principles of passive sun energy collection. These buildings have heavy concrete walls with a glass surface to use the greenhouse effect. Although the block houses represent a high quality architecture they got a lot of critic in the final report. The public and semi-public spaces are well designed and assigned. The facility of the existing district heating was accepted. It was used in the blocks of flats and the waste heat of the pipeline was also used, because a greenhouse was located over it. (Bartha, 2014)

- Second prize, created by Sztranyák Gergely and Schunk Tímea:
According to the final report this design is the closest to a feasible MILD HOME prototype. Designers created a very wise structural composition which resulted good covered open spaces. These spaces can have community building forces, as well. The two-story houses are made of wood-straw-clay structures under a big and cheap steel roof. Four homes are under one agricultural hall. The mating of these strange structures is a good symbiosis, the roof solve the problems caused by the rainwater, what can endanger the straw-clay structure. The roof makes shadows and between the roof and the top of the building air can move. In this way the indoor climate can be comfortable not only in winter but in summer as well. The natural materials grant a low level of built-in energy. (Sztranyák, 2014)
- First prize, created by Kovács Zsófia, Alkér Katalin, Pelle Zita, Balázs Marcell and Kozma Zoltán:
In this work not the technical solutions but the rethinking of our way of life and our social relations were appreciated by the Assessment Committee. The site is imagined as a poplar forest where as time goes by buildings appear. The buildings are designed for a big multi-generational family or for a community of ten people. The central core of the house is a massive and thick wall. On the north side of the wall the communicating spaces are, on the south side the living areas are, on the ground floor the spaces of daylight activities, upstairs the bedrooms are located. These spaces are incorporating in a bigger volume, where covered, open spaces come up. This work has symbolic meanings expressing that the environment and the community can live together in harmony as the traditional and organic cultures did it in the past. (Alkér, 2014)

The Assessment Committee declared that the competition was successful, but there was no entries which could give a complex solution for all the problems described in the competition call. They suggested the further development of the best designs and thanked for the special interest what the contest got. Hopefully the exhibitions and the publications of the entries will indicate a fruitful discussion on different forums.

3.2. *Feltre, Italy*

In Italy two competitions were organized. The site of the first one was found in Feltre which is a town with 20.000 inhabitants in Veneto region. Here the task was to continue the configuration of an existing residential area, where a 19.300 m^2 large area was still unbuilt. The competition was open for architects and architect studios. In the final evaluation three very different works were awarded with a first, a second and a third prize. (Condotta, 2014)

- Third prize, created by Anna Lovisetto:
Small houses (similar to holiday apartments) are designed in different sizes made of wooden structure with straw filling and clay plaster. Houses are in a lush green park.
- Second prize, created by Studio di Ingegneria ed Architettura de Biasio e Associati:
This work carefully deals with the environmental design. MILD HOMEs are single-story buildings which can grow as a family with a flexible sized second story.
- First prize, created by Michele Domeneghetti, Michele Romagnolli, Marco De Fazio:
Small, two-story detached houses are designed for families. The building form considers the possibility of energy harvesting on the roof and with the cross airing protects against overheat in summer.

3.3. *Castelnuovo Rangone, Italy*

In Italy another competition was organized in Castelnuovo Rangone. In this small town 13.000 inhabitants live. Here a very small site (enough for maximum 10-12 apartments) was selected for the competition because the municipality has a firm intention to realize MILD HOMEs as a social housing project. Therefore the competition call was a little bit different from the others. The applicants could be architects or architect studios. They had to make not only a building design but an economic plan as well. At writing of this paper nine designs are selected based on those architectural qualities. These nine works will be examined further according to financial aspects. Let's hope that the architectural quality and the economical solutions will meet. (Fava, 2014).

3.4. *Sofia, Bulgaria*

In Bulgaria the project partners jointly organized one competition. The assigned site is a huge area in Sofia, it is 93.440 m^2 large. The competition was open for architects or architect studios. In the final evaluation four works was awarded with a first, a second, and two third prize. It is interesting to notice that three of the prized works used straw bale structures. (Guevska, Maneva, Manolova, 2014)

- Third prize, created by Nikolay Slavov:
  In the site plan the main arrangement is central but the houses face to south with their roofs. Three different buildings are worked out, they made of wood-straw-clay structures. The façades show the original look of clay.
- Third prize, created by Team Studio H65: Nikolay Gylabov, Petyr Kasydzhikov, Stanimir Tonev:
  Here the houses are dispersed in a green park which is well equipped with additional functions. Houses seem like small containers in an enclosing shape which communicates that the users can design their own home.
- Second prize, to Nikolai Stoichev, Victoria Atanasova, Zornica Petrova, Iliana Stoyanova, Georgi Grozdanov:
  This work has an organic site plan. Three different kinds of two-story buildings are designed made of wood-straw-clay structures with wooden façades. Roofs face to south harvesting the energy of sun.
- First prize, created by Green Art: Milen Arnaudov, Daniela Anegelova, Daniele Marinangeli, Lorenzo Boteghelli:
  The plot is cut by two green axes, along one of them public buildings, another one gardens are for agriculture. The two-story houses are simple with archetypical form. Natural materials are used like wood, straw and clay.

3.5. *Caransebeş, Romania*

In Romania the project partners jointly organized one competition for undergraduate and postgraduate students of architecture. Two universities were involved: the Ion Mincu Architectural and Urbanism University Bucharest and the Polytechnic University Timisoara. The site of the design task was selected at Caransebeş, which is a town in Caraş-Severin County with 28.300 inhabitants. A huge presently forested green area was assigned close to the town. In the final evaluation three works was awarded with two first and a third prizes. (Branda 2014)

- Third prize, created by Alexandru Ioan Nichifor, Ana Mohonea, Elena Ioana Catrina:
  In the plot small sites are designated and the areas between them are reserved for the agriculture. The houses are formed simply, they have two-story archetypical forms with a glassed solar space on their short, south side.
- First prize, created by Vingan / Razvan, Nistor / Dragos, Rvdn:
  A model is found out for the MILD HOME composed of three archetypical house forms. The three units connect to each other along a corridor line. Houses are made of wood structures and façade cladding.
- First prize, created by Sonia-Iulia Raetchi, Radu Andone, Carmen Orzea, Cosmina-Iuliana Creanga:
  The work places the two-story houses along east-west lines. The simple formed houses are made of a prefabricated wood structure in which the heat insulation is cellulose. The façades are made of wood as well.

3.6. *Savski Venac, Serbia*

The Municipality of Savski Venac is the only project partner from Serbia. Savski Venac is a district of Belgrade with 38.660 inhabitants. Project staff were very enthusiastic in the organization. The assigned plot was 31.000 m^2 large in Belgrade. The competition was public and open for architects or architect studios. In the final evaluation three works was awarded with three equal prizes. (Pejković, 2014)

- Prized work created by Čedomir Ristić, Nataša Žugić:
  This work focuses with its demonstrative figures on the social and financial situation of the young people in Serbia. The designed houses are simple multi-story houses built of prefabricated wood-straw-clay structures.
- Prized work created by Pavle Stamenović, Dušan Stojanović, Žarko Uzelac, Katarina Obradović:
  The designers imagined an arched row house on the site. The cross section of the row house is of triangular shape in which two-, three- and four-story flats can be built filling the triangle down to up. Each flat has own garden.
- Prized work created by Dragana Đorđević, Dalia Dukanac, Ivana Jelić, Predrag Milanović:
  On the site there are a long four-story building going from north to south and several smaller two-story houses in east-south rows. Between them a trapeze shaped public area is created.

3.7. *Strem, Austria*

In Austria a small village gives the place to the competition. The village is Strem with 940 inhabitants. The sustainable development works already effectively here. The Austrian competition is not yet completed and it is very simple organized. Two professional groups are commissioned to work out two different development models of Strem.

3.8. *Thessaly, Greece*

In Greece one partner is working on the organization of the competition. At writing this paper the competition is not finished. The selected site is in Thessaly. The call is open for university students of architecture.

4. Conclusions

The transacted competitions collected several very interesting and valuable works which could help the assigned places to the sustainable development. Although the contests were surrounded by special interests, it is generally true in all countries, as the Hungarian Assessment Committee also declared that there was no entry which could give a complex solution for the problem statements. The awarded designs were highlighted in many cases not because they gave the most complex solutions from the society model to the applied materials, rather because they had good partial solutions for the complex problem.

Several environmental and energy conscious solutions were included in the competition designs. Studying the entries it could be revealed in which country which problems are the most important and which solutions can solve them in a most suitable way. Beside the rich architectural content the entries show a very interesting image about the attitudes of the young architects and indirectly about the accents of our educational system. Hopefully the exhibitions and the publications of the entries on national and international levels will indicate a fruitful discussion on different forums among the specialists. The MILD HOME project and its international staff is very proud, because they could indicate this discussion with the competitions. Discussions can help the professionals and also the young generation of professionals to have a clear picture about our present possibilities in creation of a sustainable future.

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Project team social capital, safety behaviors, and performance: A conceptual framework

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Abstract

Background The current Hong Kong construction industry safety state of affairs are undesirable. While a myriad of safety approaches have been adopted in the industry through normative compliance, error prevention, and climate intervention, the situations remain dismal. One of the reasons for the ineffectiveness of these approaches to ensure construction projects' safety performance is the mismatch between the approaches' rigid and static formulations of construction operations that are put to use in the operations that are emergent and dynamic. ***Objectives of study*** We propose that the deficiency can be rectified through the project team adaptive inputs and interactions that are grounded in the project team social capital. We (1) explore such possibility by establishing the theoretical underpinning through extant literature and (2) propose a conceptual framework befitting a relational approach to ensuring project safety outcomes. ***Methods*** To accomplish the objectives set forth above, we conduct literature search and review in the domains of social capital, construction safety, social psychology, and small team research. ***Results*** Through the process of convergent and refinement of the literary domains, we put forth a conceptual framework that can be put into empirical test. The framework reveals that project team social capital can be modeled as a multi-level phenomenon emanating from individual level network structure. These structural features, together with the relational and cognitive features at the group level, influence the individual safety behaviors, and in turn, their safety outcomes. ***Conclusions*** The analysis through literature review and modeling have shown that project team members' safety behaviors are influenced by the interaction of both the individual and group level relational phenomena. This study enriches current safety research agenda by highlighting the effects of team dynamics in safety performance. In this respect, we also provide methodological suggestions to empirically test the framework.

Keywords: Construction project team, social capital, network structures, safety behaviors, human factors.

1. Introduction

The construction industry in Hong Kong is often characterised by poor safety performance. Because accident statistics tend to trail the volume of construction, the increase construction activities in recent years and the continuous rolling out of new projects in the coming years are likely to lead to further exacerbation of safety performance. For example, the number of construction industry accident has increased from 2,775 in 2009; to 2,884 in 2010; 3,112 in 2011; and 3,160 in 2012. In addition, although the number of industry fatality dropped from 19 in 2009 to 9 in 2010, the fatality increased sharply from 9 in 2010 to 23 in 2011; and 24 in 2012. In the first nine months of 2013, 2,328 industry accidents have been recorded with 10 fatalities (Labour Department, 2014). The correspondent fatality rate per 1,000 workers also increased dramatically from 0.163 in 2010 to 0.367 in 2011 (although there is a slight drop in 2012 to 0.337) (Labour Department, 2013a). In addition, 82.76% (24 out of 29 in total) of all industry fatalities occurred in the construction industry in 2012 (Labour Department, 2013b). In this regard, despite a myriad of safety initiatives administered and implemented in construction projects, safety performance of the industry plateaus and in terms of fatality, deteriorates. Clearly, the state of safety affair is not sustainable and the fact remains that current safety management in Hong Kong construction industry is not effective.

In this paper, we argue that this ineffectiveness is due to the nature of the safety management regime. The current initiatives are largely based on the rigid formulation without attention to the dynamics and interactions among the production (construction) elements. Consequently, they are less effective in ensuring safety in the construction projects in the face of the dynamics, complexities, and continuous changing situations in construction operations. In this respect, because human operators and their interactions are vital in managing projects, there is a need of a social approach in the management of construction safety. Previous research has indicated that the relationships among project team members can facilitate the actions among participants in the

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management of project safety (Koh & Rowlinson, 2012; Koh et al., 2013). Specifically, the social norms that emerge from the relationships among construction team members influence a range of behaviours of the members, including their safety behaviours. As social capital is conceptualised as consisting of a focal group's network structure through the members' connecting ties among themselves and with those outside their group, and the quality of those ties (Adler & Kwon, 2002; Bartsch et al., 2013), a question of both practical and theoretical relevance is how these social features can affect the members' safety behaviours.

In this paper, we first explore the relevance of the concept of project team social capital thereby establishing the need for relational and human factors concepts in construction safety management; and encapsulate and synthesise these concepts into forming a theoretical framework. We conclude by proposing methodological approach to empirically test this framework.

2. The human factors in managing construction safety – The relevance of team social capital

The relevance of team social capital is predicated on the structural and organisational features of construction operations. Construction operations are characterised by dynamics, complexities, and emergent interactions of components in the operations. These systems are complex and dynamic because of the presence of multiple goals (speed, quality, cost, and safety), multiple interacting parties (various trades and professional disciplines some of which have different mental models, and work packages, heterogeneous client organisation), complex social structures (hierarchical sub-contracting arrangements, multiple stakeholders), and the complex technology and operating environments (market pressures, political and institutional regulations) (cf. Reiman & Oedewald, 2007). There is a high level of interdependence among these elements within the organisational environment that is continuously changing. In terms of organising for safety, the dynamics and complexity imply that operators continuously experience change in the form of adaptations in response to short-term productivity and cost objectives. In these situations, it is possible that safety defences degenerate as a result of the production pressures and changes. To keep the construction operation system within the safe limit and maintain system adaptation, human inputs are essential as it is through human that recognition, communication, socialisation, and improvisation of unexpected events, changes, and disruptions that system safety is achieved (cf. Dekker, 2005; Mitropoulos & Memarian, 2012). In this sense, human operators and their interactions are the catalysts in managing project safety.

The above conception implies that human and social factors are fundamental in the management of construction project safety. In a project team, team members can exert considerable influence among one another. This influence may also shape the attitudes and in turn behaviours of the members. For example, the team's expectations of members to adhere to safety rules create strong social control in ensuring members' safe conduct (Lingard & Rowlinson, 2005). Indeed, previous research in the social-psychology domain of safety management indicates that team interaction, socialisation, and influence are important aspects in managing safety (Fugas et al., 2012; Torner & Pousette, 2009; Torner, 2011). In this respect, the social conditions that are characterised by intensive work group interactions; cordial members' social ties and relations; mutual trust; and shared understanding are likely to encourage positive safety behaviours (Torner, 2011). These social conditions are encapsulated under the concept of (team) social capital.

From the psychological model of industrial accident, workers' safety behaviours are the result of social influence processes. The social conditions (e.g. team social capital) have direct effect on both the supervisors and workers safety responses which in turn, affect the safety outcomes of the construction operations (cf. Melia, 1998; cited in Fugas et al., 2012). This assertion is corroborated by Choudhry and Fang's (2008) findings that peer influence is one of the reasons Hong Kong construction workers engage in unsafe work behaviours. Hence, the concept of construction work team social capital offers a way of examining how safety behaviours can be achieved through relational approach within group members of single construction team and among interacting teams.

3. Team social capital, safety behaviours, and performance

3.1. *Team social capital*

Social capital is conceptualised as both the personal and impersonal linkages between individuals, the quality of these linkages, and the shared representations embedded within these linkages (Nahapiet & Ghoshal, 1998; Wei et al., 2011). The project organisational characteristics of interdependence and intensive interactions, diffused authority, temporality, and relative closure of project membership make the application of the social capital concept relevant (Nahapiet & Ghoshal, 1998; Jones & Lichtenstein, 2008). Social capital provides a means by which coordination and collaboration among project participants can be effected. As such, social capital can be appropriated and exploited to achieve project organisational objectives (Nahapiet & Ghoshal, 1998; Coleman, 1988), including safety objectives.

Nahapiet and Ghoshal (1998) propose a three dimensional model of organisational social capital – structural, cognitive, and relational dimensions. The structural dimension represents the impersonal configuration of linkages among persons or social units. Network ties and the configuration of those networks (e.g. network density, centralisation, range, etc.) are the main facets of the structural dimension (Burt, 2000; Nahapiet & Ghoshal, 1998). The cognitive dimension refers to the aspects that involve shared representations and the system of meaning among members in the group (Nahapiet & Ghoshal, 1998) and the type of shared understanding that has been established among the members (Bolino et al., 2002). Relational dimension is characterised by personal relationships developed among group members through interacting with one another (Granovetter, 1992). Trust that is developed among group members is an important facet of relational dimension (Inkpen & Tsang, 2005).

As a primordial social condition (Adler & Kwon, 2002), social capital is different from other social psychological concepts – e.g. safety culture and climate, and safety citizenship behaviours. Safety culture represents "the set of beliefs, norms, attitudes, roles, and social and technical practices" which are connected to minimising harms to both the organisational internal and external stakeholders (Pidgeon, 1991; cited in Torner & Pousette, 2009). Safety climate, a sub-set of safety culture, is the members' collective perception of policies, procedures, and practices concerning safety in an organisation (Neal & Griffin, 2002). And, safety citizenship behaviours is characterised by members' actions that extend beyond mere rules adherence (Torner, 2011) into more positive and proactive safety behaviours (Fugas et al., 2011). While the three social psychological concepts are the framework and environment (Fugas et al., 2012) that influence organisational members' safety behaviours through safety policies and practices, the primordial social condition – social capital – is the foundation on which the behavioural forms of these concepts are effected! In other words, social capital is the "technology" that supports the operationalisation of these social psychological concepts. The "technology" in question is the network structure (Burt, 2000) and the quality (trust and shared understanding) of the human connections within a social unit (Bartsch et al., 2013).

The combination of Nahapiet and Ghoshal's (1998) three-dimensional conceptualisation and Burt's (1992; 2000) structural perspective of social capital has informed on the utilitarian value of the concept. The basic utilitarian idea of social capital is that the configuration and the quality of social ties facilitate the flow of resources and influences that result in some level of performance (cf. Burt, 2000; Maurer et al., 2011). The full realisation of the benefit of social capital, however, requires the complementarity of both internal and external network configurations. Burt (2000) has conceptualised this idea as the alignment of network closure and brokerage. These are the internally and externally oriented network features of a group, respectively. Closure occurs when every member of a group is connected to one another in the way that everyone knows the affairs of everyone else. Such feature gives rise to a dense network (Burt, 2000). Because members of a closed network have direct connections among themselves, it facilitates information flow and sanctions (Coleman, 1988). The feature of brokerage, on the other hand, argues for an actor's control of information diffusion among pockets of groups beyond his/her own network which are otherwise not strongly connected or not connected at all. Brokerage facilitates broad, early access, and control over information (Burt, 2000). Besides informational benefit, the concept of brokerage signifies the external influence to the focal group. These network features, together with the cognitive and relational dimensions, can be brought to bear on the productive use of the concept. While closure enables within team communication and coordination, brokerage brought about external information and influence that add value to the focal team. Team shared understanding and trust further lubricate members' interactions. In other words, brokerage adds value but it is the network closure that realise the value for the team's work (Burt, 2000).

3.2. *Safety behaviours*

In construction setting, works are often organised around and performed by teams. Hence, teams, as opposed to individuals, have assumed increased importance. This phenomenon has called for the group and social normative factors to be investigated for work settings that involve teams. This assertion is equally applicable to construction safety management. The effects of group on individual's behaviours have long been established (Fugas et al., 2012). Compared to organisation, work groups exert greater influence in the interactions of group members and individual members normally feel closer to their group rather than their organisation (Moreland & Levine, 2001). In a typical work team in construction, the social influence or norms are emanated from the reference groups of supervisors and co-workers. Because of the proximity of the group members – i.e. the supervisor and co-workers within the group – the strength and relevance of the norms are likely to lead to the change of safety behaviours of the focal member (Fugas et al., 2011). In this social context, workers receive and act upon the cues they decipher from their interaction within the group on the overall importance of workplace safety from the reference groups in their supervisor and co-workers (Fugas et al., 2012). The focal worker typically attunes his safety behaviours to be in line with those demonstrated by the reference groups.

Two safety behaviours are relevant in construction - the compliance and proactive safety behaviours. Compliance safety behaviours are the behaviours of following formal work procedures and safety routines (e.g. adhering to safe work practices, etc.) (Fugas et al., 2011; 2012). These behaviours are the products of formal approaches envisioned within the safety management system which purportedly advocate compliance and rule adherence (Sherratt et al., 2013). However, compliance approach alone has been proved to be insufficient in some occasions (e.g. Choudhry and Fang, 2008) and there is a tendency that workers are more than ready to bend the rules rather than following them (Sherratt et al., 2013). There is a need, therefore, to explore other dimension of worker safety behaviours. In addition, in the traditions of participative safety management and safety cultural-based intervention, a more proactive approach is advocated. Hence, workers proactive safety behaviours should be included in the model. Here, proactive safety behaviours refer to workers' actions that go beyond normal roles (Clark, 2006) involving, for example, giving safety recommendations, assisting fellow workers to perform safely, etc. In this respect, while safety compliance may be the hygiene factor in achieving minimum level of performance, proactive behaviour has the potential to leap frog the performance.

3.3. *The propositions*

Drawing on the studies on small groups (e.g. Cummings, 2004; Wong, 2008) and referring to the notion of social capital, it is possible to argue that both the internal and external social network structure and configuration, and the quality of the group members' connections affect the group safety behaviours, and in turn, safety outcomes. Team social capital, conceptualised here as network structure and the qualities of members' connections, facilitate the flow of information and communication thereby giving rise to norms that are likely to affect members' behaviours. Hence, the examination of the ways the small group's (e.g. a carpentry trade small group led by a foreman in a construction project) team social capital affect the members' compliance and proactive safety behaviours is a plausible proposition. For the structural dimension, the focus is set on the task advice network instead of friendship network. This is because in work settings, task advice network is the channel by which work related information and influence are likely to be most relevant for the prediction of the focal group (safety) behaviours. We take "work group" to mean a group of individuals whose memberships are clearly defined and are responsible for a shared output (Hackman, 1987; cited in Wong, 2008).

In line with extant literature, the network measures that characterise the network cohesion (measured as network density), the central position of individual/s (measured as network centralisation), and network range represent the structural dimension of team social capital (Wei et al., 2011; Wong, 2008). Internally within the work group, network density represents the number of advice ties group members have as compared to total number of possible ties (Wong, 2008). As the number of ties increases, the density of the network increases giving rise to a tightly knitted group that exerts strong influence on individual member safety behaviours. Network centralisation measures the differences in the network ties of group members in such a way that when centralisation increases, individual/s within the group is more highly consulted thereby becoming more central and influential within the network (Sparrowe et al., 2001; Wong, 2008; cf. Burt, 2000). This measure provides the indication of the leadership impact of a leading worker or supervisor within the group on the other group members' safety behaviour. And, network range is an "external'' network measure to the focal group. Network range measures the number of advice ties the focal group members have with those other groups. Because the other groups are likely to have different norms from the focal group, this measures the diverse influence exerted by external sources to the focal group. Hence, the structural dimension of social capital, through its various measures, can be expected to positively affect a group members' safety behaviours.

The cognitive and relational dimensions of social capital can similarly be expected to affect members' safety behaviours. The shared understanding developed through the social interactions among group members contribute to the development of joint perception of safe working norms. As safe work practices are socially constructed (Fugas et al., 2012; Gherardi & Nicolini, 2002), shared understanding on safe working is likely to affect safety behaviours in a positive way. Similarly, trust has been shown to be an antecedent to safe behaviours. An environment imbued with trust promotes empowerment and the development of responsibility norms (Torner, 2011) which are likely to lead to safe behaviours. The safe behaviours – in terms of compliance and proactive behaviours – in turn, are likely to lead to positive safety outcomes. Overall, the conceptualisation of causal relationships among team social capital, safety behaviours, and outcome are shown in Figure 1.

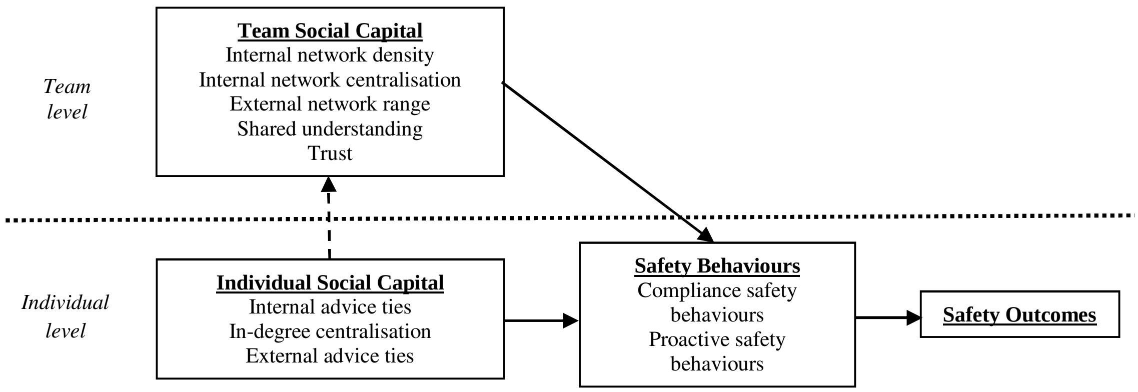

Figure 1. Framework linking team social capital, individual safety behaviours, and outcomes

4. Conclusion and methodological suggestion

In this paper, we set out to explore the proposition and the associated underlying relational conception in achieving construction project safety. The proposed framework links the structural, cognitive, and relational aspects of social life through the concept of social capital to the safety behaviours and outcomes of individuals in construction project teams. The analysis and modeling have shown that project team members' safety behaviors are influenced by the interaction of both the individual and group level relational phenomena. This exploration has enriched current safety research discourse by highlighting the effects of team dynamics and providing a more fine-grained exposition on the individual-team levels interaction mechanism.

Following Kozlowski and Klein (2000), and Payne et al.'s (2011) recommendations, configural multi-level approach can be used to present and analyse the network data. In this approach, lower level data (e.g. individual internal advice ties) is configured to tap the higher level construct (e.g. team internal network density) (the dotted arrow in Figure 1). To ensure that the lower level data can be aggregated to represent the higher level construct, within unit dispersion should be established (e.g. interrater agreement) (Kozlowski & Klein, 2000). That way, the measurement of the team level internal social capital (Reagans et al., 2004), and the influence of this team level construct to the individual level phenomenon in safety behaviours and outcomes can be ensured (see Figure 1). A longitudinal approach should be adopted. A large scale survey can first be administered targeting the frontline work groups within construction projects (e.g. a steel fixing group). This is the first wave of data collection. After 5 months (cf. Tholen et al., 2013, of 6 to 7 months), the second wave of data collection will take place with the same groups of respondents. The quantitative data can then be analysed to establish the causal relationships among the constructs. Through this approach, not only causality can be established but the opportunity to examine the temporal development of social capital in project settings is also provided.

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Creative Construction Conference 2014

The role of green roofs in sustainable construction

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Abstract

Sustainable construction, also known as green construction, aims to reduce the environmental impact of a building over its entire lifetime, with regard to its economic, ecological and social aspects, in order to leave behind an intact environment for future generations. The sustainable construction of green roofs plays an important role. Green roofs are widely used in many countries, in recent years a number of projects have been initiated to promote energy efficiency and renewable energy technology. Nowadays, many cities want to be involved in these projects in order to improve their environment. There are many ongoing research projects on the benefits of green roofs, such as improving rainwater management and water quality, the reduction of energy use and air pollution, the improvement of the climate as well as creating new natural habitats for flora and fauna. Green roof insulation can help mitigate the urban heat-island effect, heat loss from building, and also protect against wind effects and atmospheric factors such as storms, hail and UV radiation. One way of increasing the sustainability and energetic efficiency of a building is the installation of a green roof. The purpose of this study is to review the current knowledge concerning the benefits of green roofs.

Keywords: green roof; sustainable construction; ecological benefits; economical benefits; plants

1. Introduction

Sustainable construction is achieved by upholding the principles of environmental protection as well as focusing on the social and economic impact of buildings, in order to leave an intact environment for future generations. The role of green roofs in sustainable development is very important. Green roofs have many benefits that contribute to the quality of the environment on a long-term basis. Furthermore, construction and maintenance of green roofs provide business opportunities.

Before human development started disturbing natural habitats, it was the natural soil and vegetation which constituted parts of a balanced ecosystem that managed precipitation and solar energy effectively (Getter and Rowe, 2006). Nowadays, new cities, neighborhoods, business and administrative buildings are growing across the world. Greenery is disappearing from cities. Impervious surfaces of concrete and asphalt cannot absorb precipitation, the water flows off surfaces and does not infiltrate into the groundwater. In forests, ~95% of rainfall is absorbed, whereas only about 25% is absorbed in cities (Scholz-Barth, 2001). Torrential rainfall disproportionately overwhelms the municipal sewer systems, streams and rivers, causing flooding.

The air becomes less humid and the temperature rises. In cities there is almost no difference between day and night temperatures. According to the USEPA (2003), urban air temperature can be up to 5.6°C warmer than that of the surrounding countryside. In the urban heat island effect situation, even night air temperatures are higher because man-made surfaces absorb heat and radiate it back during the evening hours. In Berlin, temperatures on a clear windless night were 9°C higher than in the countryside (Von Stulpnagel et al., 1990).

These problems could potentially be solved by green roof technology, which offers many advantages. Green roofs capture dust and other pollutants. They help to keep buildings warmer in the winter and cooler in the summer. They can also filter out harmful gases such as carbon dioxide and then release oxygen back into the air. They can absorb up to 60% of rainwater throughout the year. The plants on green roofs can reduce noise inside buildings. A green roof can last up to 2 times longer than a conventional roof, because a green roof will be less expensive and will result in less material in landfill. New studies are showing that green roofs can almost eliminate electromagnetic radiation penetration. Moreover, they even look nice.

2. The history of green roofs

Greenery on green roofs from a historical perspective does not represent a new phenomenon. When people left the caves and mountain gorges, which were protecting them from the elements, they began building the first shelters with roofs from branches and wicker. When they built the first huts, they needed to keep themselves warm. Therefore, they sealed the roof with greensward and clay. Airborne seeds covered them with greenery that made for even better insulation. These dwellings can be seen today in every European open-air museum of folk architecture.

The history of green roofs in the world can be divided into two main categories – extensive and intensive. An intensive green roof is what is typically called "roof garden". It's traditionally more expensive because the soil medium depths are between 1 and 1,3m to enable the growth of small trees and a wide variety of other plants. The first known historical reference to a roof garden above grade is for the stone temples in the region of Mesopotamia (Werthmann, 2007). Civilizations in Mesopotamia built roof gardens on the landings of Ziggurats, or stepped pyramids, thousands of years ago. The plantings of trees and shrubs softened the climb, provided shade and relief from the heat (Dunnett and Kingsbury, 2008). The most famous green roofs were the Hanging Gardens of Babylon, built by the Persians around the 500 B.C (Weiler and Barth, 2009), one of the Seven Wonders of the Ancient World. In the Middle Ages and the Renaissance, the art of building roof gardens started to develop again, especially in Italy. They were established on the roof of the palace of the Medici - Villa Careggi in Florence and Palazzo Picolomini in Pienza. In Russia, they were built as sign of luxury since the end of the Renaissance period. In the USA, rooftop gardens became popular at the turn of the 20th century.

Extensive green roofs have a thinner profile which makes them lighter and more economical. They were mainly built in Scandinavia, Canada, Iceland, where these roofs are still a traditional element of modern architecture. In the cold Nordic climates, green roofs are preferred for their good thermal insulation properties. They are also used for the opposite reason, to insulate the interior from the outside heat, and they are utilized in some tropical countries, such as Tanzania (Minke, 2001). While the history of roof gardens can be connected with the cities and especially their affluent residents, extensive green roofs are more of a matter of utility (isolation from the surrounding environment) and are found more often in the countryside or in small towns. There is much less information available about the history of extensive green roofs than there is about the history of intensive green roofs. This is probably related to the fact that while intensive roof gardens were urban affairs and also a showcase of social prestige, while extensive green roofs were more of a pragmatic attempt to use nature in the fight against the elements. This may be due to the fact that while the culture of the Mediterranean society was already relatively developed in the antiquity, the northern areas experienced a similar development a while later.

Nowadays, these differences are not as pronounced. These days, the main difference is in their geographical distribution, which is significantly linked to the climate - while in warmer areas (e.g. Mediterranean), there are many houses with roof gardens, in colder regions such as Scandinavia they are logically found very rarely.

Figure 1. Hanging Gardens of Babylon

Figure 2. Sod roof in Milton, North Dakota, Norwegian Immigrant, c. 1896. Sod roofs were common in Norway because they added an additional layer of insulation and protection to the house.

2.1. *The modern history of green roofs*

The main pioneers of the modern development of green roofs were German-speaking countries – with Germany at the forefront. In these countries many scientists have been involved in research of new technologies and the possibility of planting green roofs since 1960s. These efforts were mostly successful and the number of green roofs has been growing significantly (Dunnett and Kingsbury, 2008). An interesting and well-known example is the famous Hundertwasser in Vienna. The house, which was completed in 1985, stands in the street Löwengasse. There were a total of 992 tons of soil and 250 trees and shrubs transported to the rooftop of the house. Originally it was meant to serve as an accommodation for socially disadvantaged people, but became a tourist attraction and one of the most famous buildings with a green roof in Austria.

Figure 3. Intensive green roof, Hundertwasserhaus, Vienna, Austria

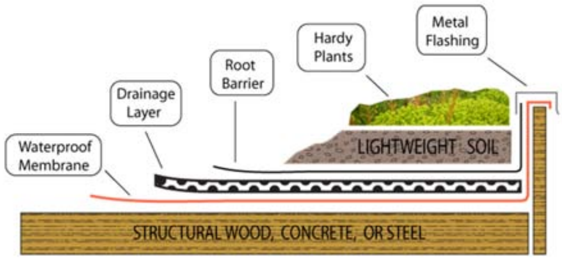


Figure 4. An example of a basic green roof system for flat roofs

The World Exhibition in Paris 1867 was one of the first demonstrations of a planted concrete roof in Western Europe, where visitors could get acquainted with extensive roofs into the mainstream where the showcase of a concrete "nature roof" was displayed (Dunnett and Kingsbury, 2008). The effort to build green roofs due to environmental considerations and to return nature to the life of city dwellers comes only in the 20th century. Perhaps the best known promoter of this idea was the architect Le Corbusier. Le Corbusier is considered one of the first systematic roof greeners. In his famous Five points of new architecture, written in 1930's, roof gardens came second. After a brief explanation of structural details, Le Corbusier concludes with the words: "*The roof garden becomes the favorite place in the house and additionally for the town it means that the built-up space lost is regained."*. (Le Corbusier, 1946).

In the first half of the 20th century, the oversized weight was still an obstacle to the greater development of green roofs, both for structural elements and soil substrates. The development of industrial chemicals and plastics partially resolved this problem after World War II.

In recent years, a lot of architects have begun to design green roofs in many European and non-European countries. In the traditionally environmentally minded countries such as Germany, Austria and Switzerland, there is a large boom of green roofs since the 1960s (Čermáková and Mužíková 2009). Especially in Germany, many specialized companies were set up, which dealt with the research of green roofs, and primarily their implementation, (an example could be ZinCo or Optigrün - Companies based in Stuttgart). In 1989 approximately 100 ha of green roofs were made (Čermáková and Mužíková 2009). The impetus for this was especially strong environmental movement and the effort to return the nature to urban life (Dunnett and Kingsbury, 2008).

Nowadays, the significance and application of green roofs consists in their contribution to the urban landscape. In addition, currently, because of the significant range of construction and the need to protect agricultural land, the use of green roofs is necessary in terms of the economical use of space. The use of a green roof is actually a logical consequence of a lack of space.

3. Why have a green roof

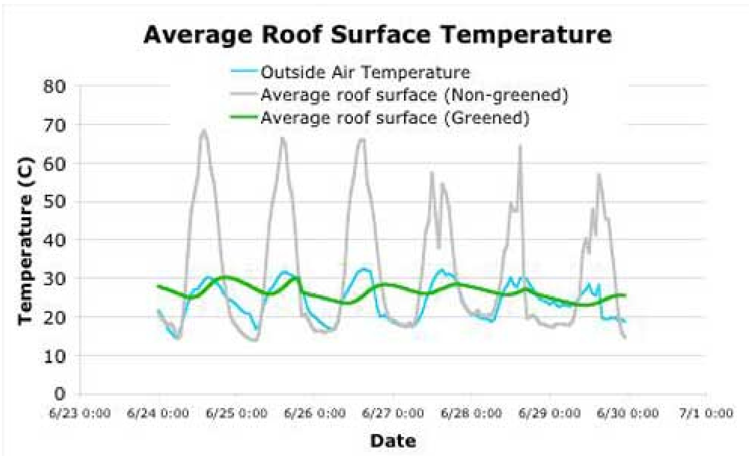
The positive effect of green roofs on air quality may seem irrelevant because of their normal sizes. However, studies have shown that this is not the case, because the improvement of air quality does not require a completely green roof city. There only needs to be a network of them, which can then greatly reduce the negative effects. Green roofs have many features, that are connected with each other, they operate on themselves in various forms, and may have different meanings according to the specific situation. Therefore, green roofs cannot be assessed without interconnection.

In terms of urban design and landscape function, the roof garden is another place where a person can rest and relax. One built-up area can be used multiple times. People do not have to live only on the individual floors of the building, but also on the roof garden and terraces where they may be in contact with plants, animals, the Sun, earth, air or water. In contrast to the tin roof that radiates very harsh light during bright sunlight and the view of it is unpleasant, sometimes painful, while a view of a green roof is a pleasant and positively affects a person's mood.

3.1. *Improving the microclimate*

From an ecological perspective, green roofs make a valuable contribution to improving the microclimate. By comparing the green roof with a classical roof with waterproofing or with layer of gravel, green roofs have been proven to be able to equalize the differences of extreme temperatures and reduce the intensity of radiation, but also to enhance the quality of the microclimate in our urban centers. We can see that there is an exchange of thermal energy between the plants and the environment. Green roofs provide shade and remove heat from the air through evapotranspiration, reducing temperatures of the roof's surface and of the surrounding air. On hot summer days, the surface temperature of a green roof can be cooler than the air temperature, whereas the surface of a conventional rooftop can be up to 50°C warmer (Liu and Baskaran, 2003).

The loss of vegetative cover and the increase in building activity in the form of pavements, roads and buildings results in higher urban temperatures than in the suburban and rural areas. As impervious surfaces tend to be heat absorbing, they increase the urban temperature. This specific urban phenomenon termed as the Urban Heat Island Effect (Solecki, et al., 2005), is identified by higher night time temperatures and humidity. Green roofs provide shade and insulation, which results in energy savings and in the mitigation of the urban heat island effect. Media depth, shade from plant material, and transpiration can reduce the solar energy gain by up to 90% compared with non-shaded buildings. Green roofs have reduced indoor temperatures from 3°C to 4°C when outdoor temperatures moved between 25°C and 30°C (Peck et al. 1999).



Graph 1. Average roof surface temperatures for both "greened" and "non-greened" roofs

3.2. *Mitigation of air pollution*

The plants on the roofs, as well as also other plants produce oxygen and consume carbon dioxide due to photosynthesis. They also filter out dust and dirt in the air. The particles are collected on the surface of leaves and then rain flushes them to the ground. Plants remove gaseous pollutants by absorbing them through the pores in the leaf surface. A German study demonstrated that green roof vegetation can significantly reduce diesel engine air pollution (Liesecke and Borgwardt, 1997). Yok Tan and Sia (2005) found a 37% reduction of sulfur dioxide and a 21% reduction in nitrous acid in the air above a green roof when compared to other air samples taken nearby. Others have estimated that 1 m^2 of green roof can absorb about 0.2 kg of dust particles and other pollutants per year (Peck, and Kuhn, 2003). Plants also bind heavy metals.

The roof surface without an insulation of gravel and greenery that significantly decreases temperature, can in the summer reach temperatures of 25 ° C to 60 ° C, in extreme cases even to 80 °C in central Europe. This creates the vertical movement of air above roofs (so-called "thermals"). The roof surface that is 100 m^2 may have a velocity of 0.5 m/s. Thus, the particles of dust and dirt on the streets and yards, which are blown again into the air over residential areas, create a blanket of dirt and haze. The green roof can significantly reduce air movement, because thermals do not appear above the grassy areas. In the sunlight, the temperature in a grass pillow is consistently lower than the air temperature.

3.3. *Rainwater Management*

Green roofs also help control rainwater runoff and retention. The increased urbanization of towns and cities has resulted in less green space and more impervious surfaces. Precipitation generally runs off the roof of a building into the gutters and flows into a sewer, but too much rainwater can cause a city's sewage system to overflow, discharging sewage into streams and rivers. Green roofs can help prevent this by retaining water in the plants and growing medium, thus slowing and reducing the amount of rainwater. The individual layers of a green roof soak stormwater either more or less according to the material and structure until they reach maximum saturation. It is necessary to pay attention to the main vegetation layers of green roofs in general and not to concentrate only on individual segments. During a during rain and immediately after it, a large part of the water evaporates and returns to the atmosphere. Green roof can delay runoff between 95 min (Liu, 2003) and 4 h (Moran et al., 2004), compared with the reference roofs for which runoff was nearly instantaneous. Liu (2003) found that the actual precipitation with intensity of 2.8 mm/h was reduced by the use of a green roof to a runoff with intensity of 0.5 mm/h. Also Fioretti (2005), analyzing the effect of a Mediterranean climate on a green roof installed on one of the buildings at the University of Genoa in Italy has observed a delay of water runoff from the roof ranging from 71 min to 306 min. In the course of the same research project carried out in the period September-December 2008, they have obtained results demonstrating a strong dependence of green roof retentiveness on the duration of the dry period preceding the occurrence of precipitation. Whenever the period was shorter than 96 h, the retention capacity was less than 20 %, while for rainfalls separated by less than 12 h, the precipitation water runoff was close to zero.

Table 1. Average water retention for a transitional roof vs. a green roof.

Water Retention for Traditional Roof vs. Green Roof		
Rainfall Retained %	Standard Roof	Green Roof
Average Retention	24%	80%
Retention at Peak Runoff	26%	74%

3.4. *New habitat*

The more and the larger urban centers are built up, the less space the animals have to live. Green roofs provide a habitat for wildlife, mainly for plants, microorganisms, insects and birds. Particularly blooming roofs are an attraction not only for butterflies, but also bees and other insects. A biodiversity study of seventeen green roofs in Basel, Switzerland found 78 spider and 254 beetle species. Eighteen percent of those spiders and 11% of the beetles were listed as rare and some were considered to be endangered (Brenneisen, 2003). In Berlin, Darius and Drepper (1984) found grasshoppers, white grubs, beetles, and a high number of mites on 50-year old green roofs, and in Switzerland, nine orchid species and other rare and endangered plant species were found on a 90-year-old green roof (Brenneisen, 2004). In the UK, green roofs have been found to provide habitat for the Black Redstarts, and an endangered bird species (Gedge, 2003). Water surfaces on the roofs also attract many animals, such as birds, for which the water area serves as a drinking fountain and space for cooling. On the roof, which is vegetated, one may purposely set up a location for the cultivation of protected types of plants that have become rare in the natural environment, because the natural environment is becoming progressively more undermined by factors of civilization.

3.5. *Extend roof live*

One of the major benefits of green roofs is their contribution in prolonging the life of both building insulation and roof surfaces (Weiler and Barth, 2009). Each roof structure, which is in contact with the external environment, is exposed to a large number of factors that damage it and shorten its life. The durability of the materials is determined by the time of exposure. The lifetime of the roof is negatively affected by heat, cold, wind, ozone, ultra-violet radiation or chemical agents. Leaving aside the features of the construction of building, the life of green roofs is basically unlimited with proper establishment. As a result, the roof structure can require less maintenance, saving the owner money in replacement costs over the long-term life of the roofing system. Well-maintained green roofs can more than double the number of years before a roof needs to be replaced compared to a standard roof.

3.6. *Noise Reduction*

Hard surfaces of urban areas reflect sound and are unable to absorb it. Green roofs absorb sound waves due to the nature of the substrate and the vegetation (Getter and Rowe, 2006). The depth of the green roof assembly acts as an acoustic barrier, the substrate blocks lower sound frequencies while the plants stop the higher frequency, thereby reducing the noise of traffic and airplanes. In a study at the Frankfurt airport, Germany a 10 cm deep green roof has shown to reduce noise levels by 5dB (Dunnett and Kingsbury, 2008). Other research shows that a 12 cm of substrate layer can reduce sound by 40dB (Peck and Kuhn, 2001).

4. Types of green roof

So far, there is no uniform definition that would be universally accepted and used. Lack of uniformity of terminology is often determined by different translations of foreign literature. The most frequently used phrases include: "green roof", "roof garden", "grassy roof", "vegetative roof" or a combination of these phrases.

Table 2. Green roofs are classified according to their depth and maintenance requirement. The following names for different green roofs have been adopted by the construction industry in the UK.

Type of green roof	Description
Lightweight extensive	Low biodiversity potential, water holding; includes pre-grown vegetation mats Sometimes irrigated; no additional substrate; open substrate
Super lightweight	Consists of thin (12mm) drainage board, a filter fleece/water retention mat and pre-grown vegetated mat about 25mm in thickness; minimum loadings Sometimes irrigated; practical for some retro-fits Limited vegetation diversity, tendency to dry out
Extensive	Less than 100mm substrate depth, and not usually irrigated; low maintenance Limited water holding, biodiversity potential Includes pre-grown vegetation mats or substrate
Semi-intensive	100mm to 200mm substrate depth, moderate maintenance, wider range of plants Sometimes irrigated, rainwater attenuation Supports vegetation; slightly higher maintenance
Intensive	Over 200mm substrate depth, intensive maintenance requirement Sometimes irrigated; lawn or roof garden, amenity Space Water attenuation and some biodiversity can be achieved
Roof gardens/podium decks	Intensive and well understood Outside the scope of this document
Biodiverse/wildlife (extensive)	Supports particular species or group of species; natural colonisation often encouraged Limit level of human interaction; focus on biodiversity value

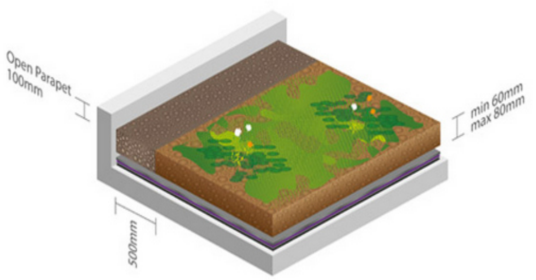


Figure 5. Extensive green roof

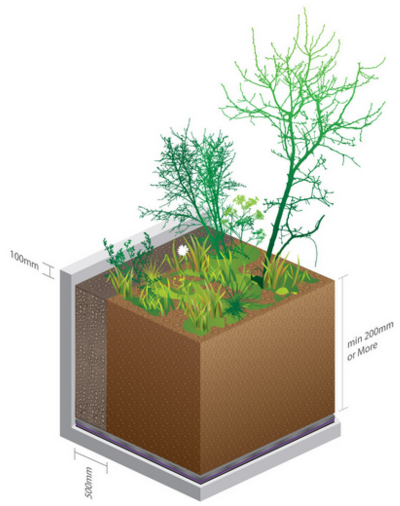


Figure 6. Intensive green roof

5. Plant selection

Plant selection is very important to the sustainability of the roof. Criteria for selection plant material depend on the growing medium as well as local conditions, available maintenance, desired appearance and plant characteristics such as rate of establishment, longevity and disease and pest resistance and substrate composition and the depth available for planting. Low maintenance, durable and drought resistant plants are used for extensive green roofs, versus a nearly limitless plant selection for intensive green roofs.

Plants for extensive green roofs have to survive intense solar radiation, wind exposure, low nutrient supply, limited root area and need to be drought and frost resistant. For this type of roofs, we can find a narrow range of species limited to grasses, herbs, mosses, and drought tolerant succulents, a succulent plant known for its tolerance to extreme conditions. The plants have to be able to store high amounts of water in the leaves to recover easily from periods of drought. Successful candidates for extensive green roofs are Sedum, Delosperma, Euphorbia and Sempervivum because they tolerate drought conditions and also have strong persistent qualities. In Germany, Liesecke (1990) tested Sedum and found that it could survive more than 100 days without water. Extensive green roofs generally require less maintenance and are generally less expensive to install than intensive green roofs.

Intensive green roofs utilize a wide variety of plant species that may include perennials, herbs, grasses, shrubs and trees. It is important to avoid plants that are too aggressive, which could then displace the other species. Intensive green roofs usually have a higher requirement for water, labor and other resources than extensive green roofs.

6. Installation

Before an initiation of a green roof, one needs to consider the slope, the structural loading capacity, and the existing roof materials, as well as the nature of any drainage systems, waterproofing, and the electrical and water supply that is in place. He should also know who will have access to it, who will do maintenance, and what kind of sun and wind exposure the roof gets.

When the issue of building the structure is resolved, it is necessary to choose a method for installing the plant material. Several methods exist for installing plant material in green roof systems. Vegetation may be planted directly on the roof as seed sowing, cuttings, root ball plants and pre-cultivated vegetation mats in the field at ground level as blankets or modular trays and then transported onto the roof. Care must be taken to avoid damaging the waterproofing membrane during installation.

The best time of year to plant a green roof is in early spring and late summer. For planting during the summer it is important to supply enough water to compensate for periods of low precipitation. One day of hot dry sun with temperatures of more than 30°C could destroy the entire planting. In late autumn cold days may lead to damage of the plants due to frost. Full coverage of extensive roofs should be completed within one year.

7. Maintenance

It is important to provide maintenance to ensure the long term aesthetic quality and the functionality of a green roof. Green roof plants require regular care and attention including irrigation, weeding, fertilizing, pruning and replanting. Some maintenance procedures should be planned immediately after damaging events such as storms or floods, while others can be planned according to seasonal events such as the germination period, season for certain unwanted and invasive species and in the fall after leaf fall. The frequency of maintenance depends on the type of vegetation and includes the inspection of the roof edges, penetration of roots, the control of irrigation and drainage facilities, mowing, the removal of undesirable vegetation or watering and fertilizing. Maintenance of extensive green roofs is usually carried out once or twice a year, unlike intensive roofs which require a more frequent maintenance.

The drainage of a green roof is the same as for a standard roof through gutter located on the roof surface or on its edge. In normal conditions, approximately 300 m2 of green roofs can be channelled into a gutter of DN 100.

In the initial phase after sowing or planting, plants should be watered immediately and then watered frequently for the first few weeks unless ample rainfall occurs. Therefore, in the project it is necessary to design enough large water supply connections on the roof or in its vicinity. After the establishment period during the first year, watering may not be necessary depending on the local environment and the plant species chosen. The amount of water required depends on the plant species. In general, extensive roofs should not require irrigation. For an intensive green roof, there is a possibility of water retention in the drainage layer, ideally with automatic irrigation. This will significantly reduce costs and optimize irrigation as it utilizes the stored rainwater first.

8. Costs

The cost of a green roof depends on the type and other factors such as the depth of growing medium, selected plants, size of installation, use of irrigation. Intensive green roofs usually require a greater investment. The estimated costs of installing a green roof with waterproof membranes begin at $10 per square foot for extensive roofing, and $25 per square foot for intensive roofs (Riggs, 2013). Most homes are not prepared for a living roof, and redoing the structure can drive up the cost even further.

Researchers and communities are beginning to perform detailed, full life-cycle analyses to determine the net benefits of green roofs. A study done at the University of Michigan compared the expected costs of conventional roofs with the cost of a 21,000-square-foot (1,950 m^2) of a green roof and all its benefits, such as stormwater management and improved public health from the absorption of nitrogen oxides. The green roof would cost $464,000 to install versus $335,000 for a conventional roof in 2006 dollars. However, over its lifetime, the green roof would save about $200,000. Nearly two-thirds of these savings would come from reduced energy needs for the building with the green roof. (Clark and Adriaens and Talbot, 2008)

9. Conclusion

A few years ago, the concept of plants on the roof was viewed with skepticism but this way of perception has been gradually changing and green roofs are widely used today. Green roofs have great potential, due to the development of urban space. Every day buildings and roads swallow hundreds of hectars of green areas. Greenery in densely populated cities is precious and prices of land reach breathtaking sums. The situation has taken a turn for the worse, especially in urban centers; the noise, heat, dust, street traffic, the view of gray building and the loss of natural habitats all significantly contribute to the feeling of stress. These ill effects associated with the rapid expansion of a built-over environment may be minimized by installation of green roofs. Green roofs are one of the few passive techniques that accomplish multiple goals simultaneously. Apart from the economic benefits as its energy cost reduction, green roofs also provide social, environmental and aesthetic values. In addition, the construction and maintenance of green roofs provide business opportunities for construction companies, nurseries, landscape contractors, irrigation specialists, and other green industry members while addressing the issues of environmental stewardship.

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Implementation of the restrictive energy efficient regulators and its impact to the operational costs of public properties

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Abstract

The impact of the construction industry on environment has been studied and regulated for years. Every state has its own politics on how to proceed with this issue. The widely discussed current question is how to keep the construction economically efficient whilst also keeping the environment protected and the buildings sustainable. Moreover, the European Union formulates new policies on this topic, for example to achieve energy savings during the life cycle of the buildings by reducing the operational costs.

This paper analyzes the economic impact of the implementation of one of the aforementioned policies (Directive 2010/31/EU) into Czech law, especially the part requiring that all new publicly owned and occupied constructions built after 31. 12. 2018 an all new buildings built after 31. 12. 2020 have nearly zero-energy consumption. Furthermore, the implementation process itself is being examined.

This article aims to have a practical importance, mainly for public authorities, in better decision-making about investment efficiency and management of their properties. The solution for ensuring that the buildings are sustainable and environmentally friendly, e.g. by constructing the buildings with zero-energy consumption, is to make them economically efficient.

Keywords: Directive 2010/31/EU; Implementation process; Nearly zero-energy building; Operational costs; Public property**.**

1. Introduction

The reduction of the operating costs of the buildings is a topic which is garnering attention for many decades. It is a trend which could be seen worldwide in the construction industry since 1980´s. This reduction brings savings for the users of the buildings. However, it usually also means increasing of the investments costs of the whole project. Therefore, it is necessary to see this issue from the perspective of the life cycle costs.

Operation of the buildings represents around 36 % of CO_2 emissions and 40 % of total energy consumption in the European Union, therefore the effort to reduce the energy consumption and significant increase in the use of the renewable sources of energy is undoubtedly necessary (Boermans et all., 2011).

In May 2010, the European Union introduced a Directive on the energy performance of buildings (Official Journal of the European Union, 2010), which defined the need for all the member states to reduce the energy consumption of the buildings. By this directive, the main goal – the reduction of the total energy consumption of the buildings in the Union by 20 % by 2020 - was determined together with the frame strategy on how to achieve it. Every member state may implement this strategy into its law system individually, but the key principles have to stay preserved, such as:

- setting of minimum energy performance requirements for buildings and buildings' elements,
- after 31 December 2018 - all new buildings and buildings undergoing major renovation occupied and owned by public authorities are to be with the nearly zero-energy consumption,
- by 31 December 2020 - all new buildings and buildings undergoing major renovation are to be with the nearly zero-energy consumption,
- establishing a system of certification of the energy performance of buildings.

The difference between the terms of adoption for the buildings with the obligatory zero-energy consumption for public properties and private properties could be explained in two layers.

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Firstly, the public authorities should serve as an example of efficient and environmental friendly constructing to the private sector. Successful well-known constructions lead to raising the public awareness about this topic. The display of the certification of the energy performance on the specific building in the public place shows the importance of the subject (Official Journal of the European Union, 2010) as well. By using the nearly zero-energy buildings (nZEB) the operational costs would be reduced too.

Secondly, the public authorities are in the long term the biggest client of the construction industry (Český statistický úřad, 2014), and this observation can be globally applied. Earlier application of the directive for the public sector means more rapid reduction of the energy consumption as well as operating cost

2. Concept of the nearly zero-energy building and the implementation

2.1. *Definitions*

According to the Directive 2010/31/EU "nearly zero-energy building means a building that has a very high energy performance, as determined in accordance with Annex I of the Directive. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby" (Official Journal of the European Union, 2010).

In view of the fact that the Directive 2010/31/EU allows member states to determine the exact definition by themselves and their needs, it is possible to find many variants. The specific research project called "*Towards nearly zero-energy buildings - Definition of common principles under the EPBD*", was prepared by the experts for the European Commission with the aim to identify the progress of the implementation of the Directive 2010/31/EU in each EU member state. This review shows different approaches to the application of this directive. For example "the Norwegian building regulation contains specific energy limits for different building types. The requirements are set in kWh/m² final energy demand per year" (Hermelink et all., 2013). On the other hand, UK measures the energy savings by the amount of the carbon emission, and the government would like to achieve using the zero carbon buildings from year 2019 (Hermelink et all., 2013).

2.2. *Implementation process*

Boermans et all., (2011) define a clear sequential possible process of implementation of the construction of the nearly zero-energy buildings.

- The method starts with collecting the existing data about the nZEB among other EU member states, related standards and regulations.
- The challenges and goals to reduce the energy demand and the quantity of CO_2 emissions and to enable the use of the alternative energy sources have to be settled in accordance with the strategy on how to achieve them.
- The feasibility and accuracy of the strategy have to be tested on different case studies and reference examples in various climate zones. The results have to show cost-optimal solution.
- The impacts of proposed strategies and goals have to be analyzed from many points of view, specially considering:
  - Technologies, materials and resources and their innovation
  - Financial investments at EU level
  - EU policies and aims
  - National policies and targets
- Prediction of the outlook of the implementation.

The whole process is visible from the Figure 1.

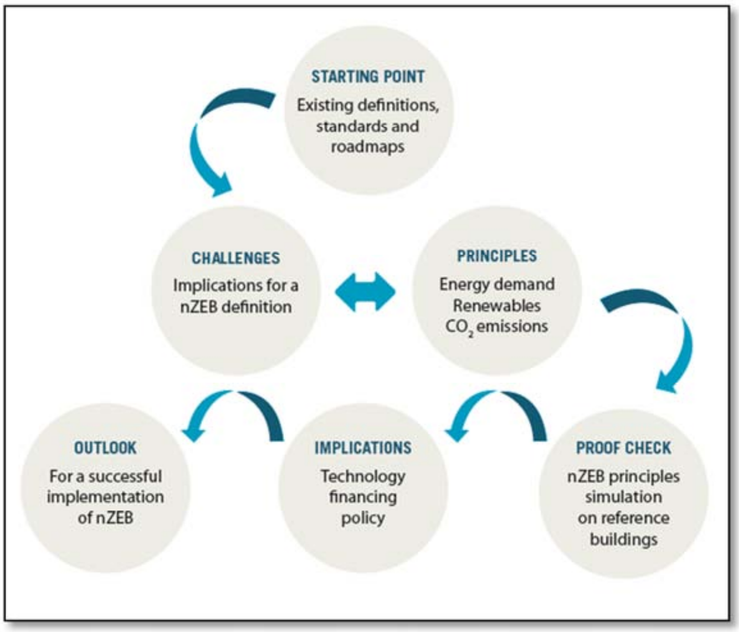

Figure 1. Steps towards a successful implementation of the nZEB. Adapted from Boermans et all. (2011).

3. Current situation in the Czech Republic

3.1. *Legal background*

Energy Management Act no. 406/2000 Coll., including all its amendments, was the first Czech law, which implemented the respective policies of the European Union (Directive 2002/91/EE of The European Parliament and of The Council of 16 December 2002, on the energy performance of buildings) into the Czech legal order. The amendment from the year 2009, for example, stipulates that when applying for the planning permission for a new building, it is necessary to provide the public authority with its Building Energy Efficiency Certificate (BEEC). BEEC can only be issued by the authorized person, and it is issued in compliance with the rules contained in the implementing regulation no. 148/2007 Coll., on elaboration of BEEC (MPO, 2008).

The last amendment of the aforementioned Act came to force on January 1, 2013, and it already implements the Directive 2010/31/EU of The European Parliament and of The Council of 19 May 2010 on the energy performance of buildings. This Act thus now stipulates that nearly zero-energy buildings are to be built in Czech Republic from year 2018 and 2020 respectively.

The implementing regulation no. 78/2013 Coll., on elaboration of BEEC, which was issued as an accompanying legislation to this last amendment of the Energy Management Act, already defines the exact method of the calculation of the Certificate. The final Certificate now includes the information if the building can be labeled as a nearly zero-energy building.

3.2. *Building Energy Efficiency Certificate (BEEC)*

The methodology for the calculation of the building energy efficiency was changed when the regulation no. 78/2013 Coll. became effective in April 2013. Former method proceeded from the reference building which would have the same size, construction materials and parts, and would be used for the same purpose as the considered building. The new methodology upgrades the model of the reference building, and now the context of the building is being considered as well, e.g. the integrated design process, the degree of using renewable energy sources etc.

Newly, the valid BEEC has to be presented by the seller to the purchaser during the sale of the building as well as to the lessee when a lease contract is being concluded. Moreover, the regulation enjoins, for every year from now, a clearly defined group of owners of the buildings to arrange a BEEC for their properties. It is expected that from 2018 every building will have a valid BEEC.

3.3. *Implementation process in Czech Republic*

The European Commission ordered an extensive international report where the progress of the implementation of the Directive 2010/31/EU in each member state was studied. According to the study (Hermelink et all., 2013) Czech Republic has achieved quite satisfied results already:

- National targets are determined till 2020,
- Regulations for new and existing buildings undergoing major renovation are adopted into Czech Republic,
- Several economic incentives and financing instruments have been put into practice,
- Energy performance certificates are in use and required,
- Provision of information to the general public is under way, but it is recommended to increase the activity in this area,
- Demonstration of the benefits is beginning with the detached houses,
- Education is provided by schools, universities and organizations.

4. Case study – Evaluation of the economic impact

4.1. *Reference building*

The headquarters of the Prague Institute of Planning and Development situated in the center of Prague was chosen as the reference construction of this case study. The building is owned and maintained by the Prague City Hall. It consists of three connected wings. The table below shows the main characteristics of the current condition of the building. Currently, the reconstruction of this building is being considered.

Table 1. The characteristics of the current condition of the reference building

Prague Institute of Planning and Development	
location	Prague 1
constructed in	2nd half of 20th century
type	office building
offices	7506 m2
structure	steel frame
facade	glass in aluminum frames
used type of energy source	electric power + natural gas

4.2. *Methodology*

The data for the case study were partly obtained from the City Hall and partly from the consultant agency. Moreover, some calculations and professional assumptions were made by the author.

The case study focuses on comparison between the operational costs of one specific office building in current condition and the same building after a major reconstruction that would transform the said building to the nearly zero-energy building standard (Investments into such reconstruction are estimated at almost 450 million CZK). At the moment, the reconstruction is being considered by the owner, therefore the future condition is modeled and calculated according to the new regulations. After the comparison of the operational costs, the investment efficiency of the reconstruction is evaluated on the basis of payback period.

The value of the operational costs was calculated as a total of value of electric power and natural gas, because the rest of operational costs stay constant.

4.3. *Results*

The case study proves that the investment into the complex reconstruction of the building will radically change the structure of used energy sources as well as the amount of consumed energy. The Figure 2 demonstrates these changes.

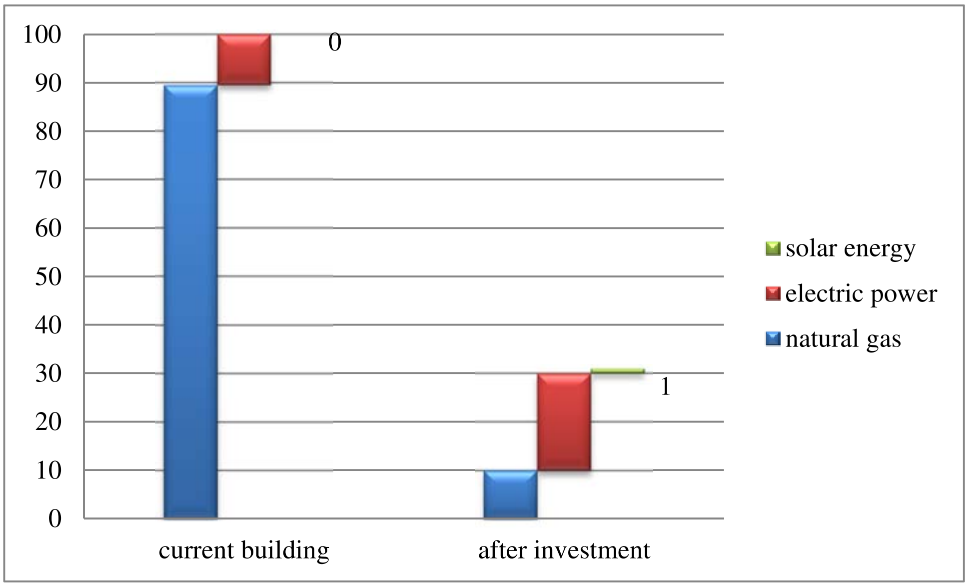

Figure 2. Comparison of the used energy sources

Figure 2 shows that the current building uses only electric power and natural gas for its operation, whereas the building after the reconstruction would use also solar energy. Because the proposed change of the entire heating, cooling and ventilation system, the consumption of all sources would be reduced, and the structure of the usage of individual sources would change. For example, the consumption of the natural gas would be significantly reduced from almost 90 % to 10 % whereas the consumption of the electric power would increase slightly from 11 % to 20 %.

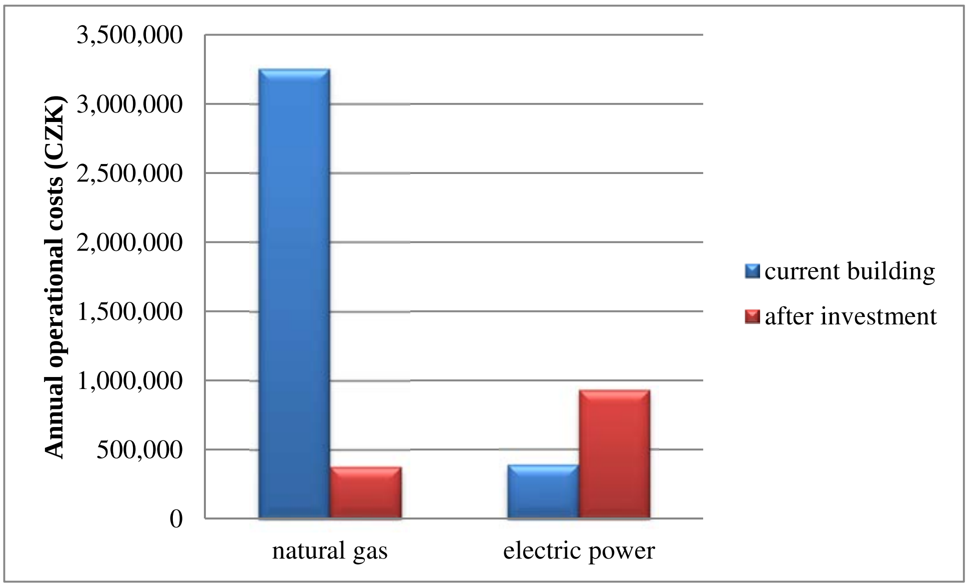

Figure 3. Comparison of the annual operational costs

Figure 3 shows the comparison of the part of the annual operational costs which would change because of the investment. The large reduction of the costs of the natural gas is apparent, and even with costs of electric power taken into consideration, the investment brings the reduction of the operational costs of about 60 % in total.

However significant the reduction of the operational costs because of this specific investment may be, the investment would still be economically inefficient from the point of view of the payback period, which is calculated at about 200 years.

5. Conclusion

Buildings are extensive consumers of the energy and emit huge amount of CO^2. For this reason, the European Union formulated a Directive on the energy performance of buildings. The implementation of this directive by all EU member states should decrease the CO_2 emission, achieve the efficient energy performance of the buildings and extend the use of the renewable energy resources.

The research was focused on the issues of implementation process of the Directive 2010/31/EU into the Czech legal order. Based on the model of an implementation process by Boermans et all. (2011), with respect to the results from the international research mentioned in part 3.3. of this paper, it is possible to say that Czech Republic is in the phase of proving the benefits and the efficiency.

Furthermore the case study about energy efficient office building was conducted which practically demonstrates the economic impact on the operational costs of buildings in Czech Republic. The significant reduction of the operational costs if the nearly zero-energy building standard is applied was proven. Nevertheless, the economic efficiency of the investment in case an existing building would be changed to the required standard could not be established.

Acknowledgements

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Vyhláška č. 78/2013 Sb., o energetické náročnosti budov (The implementing regulation no. 78/2013 Coll., on elaboration of BEEC)

Vyhláška č. 148/2007 Sb., o energetické náročnosti budov (The implementing regulation no. 148/2007 Coll., on elaboration of BEEC)

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Creative Construction Conference 2014

Life cycle energy analysis of buildings

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Abstract

Life Cycle Energy Analysis (LCEA) is an important issue of Life Cycle Assessment (LCA). LCEA accounts for all energy inputs in the life cycle of a building. Energy consumption is a widely discussed issue, especially from the point of view of measuring the environmental impact on buildings. Numerous studies attribute that over the building lifetime there are three types of energy: operational, embodied and demolition. These aim to identify phases of large energy use and develop reduction strategies.

This article presents a structured review of the theoretical issues of LCEA-related literature and then uses these studies to illustrate their use for residential and office buildings.

Keywords: Embodied energy; Life cycle assessment; Life cycle energy analysis; Operational energy.

1. Introduction

Energy consumption in buildings is an issue relevant to permanent sustainable development. The reduction of energy consumption in buildings and exhaust fumes is a priority for both the European Union and other countries. As stated by the U. S. Energy Information Administration (EIA2013) in the International Energy Outlook, the energy performance of buildings (except for buildings not designated for production) was higher than 1/5 of overall world consumption in 2010. There is an expectation of another increase by approximately 0.6% per year in OECD countries and by 2.7% per year in non-OECD countries.

The request for sustainable development and to reduce energy consumption can be met using a complex approach to the evaluation of the life cycle. The basic methodology is based on the international standard for the ISO 14040 series – Environmental management - Life cycle assessment. The methodology is divided into four basic stages - defining the goal and scope, inventory analysis, assessing the impact and interpreting the results. The second stage of the methodology contains data acquisition from each life cycle phase of the building, e.g. energy demands, CO2 emissions and other factors leading to climate change. Ortiz et al. (2009) distinguish two main approaches to LCA. The first, "Building material and component combination" comprises information about the embodied energy in building materials and the environmental impact in the course of the life cycle. The second, "The whole construction process" evaluates LCA from the point of view of the building application and divides LCA into three directions - dwellings, commercial buildings and civil engineering constructions. Even though both approaches differ in the procedure, they evaluate the same type of data.

A part of LCA forms an approach focused on energy consumption called Life Cycle Energy Analysis – LCEA. This approach focuses on the evaluation of the energy consumption of all energy entries within the life of the energy cycle of buildings. This approach enables to evaluate and state strategies designated for reducing energy consumption.

2. Life cycle energy analysis (LCEA)

Ramesh et al. (2010) and Cabeza et al. (2014) define LCEA as an "approach that accounts for all energy inputs to a building in its life cycle". Dixit et al.. (2010) divide the total energy consumption of a building within the life cycle into two groups:

- Embodied energy – energy essential for acquiring and processing construction materials, energy needed directly on-site, energy consumed during demolition of the construction and during waste disposal;

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- Operational energy – energy consumed during the phase of building usage – heating, air-conditioning, lighting, energy used for building maintenance.

Energy types and usage during the life cycle are shown in Fig. 1. Within LCEA, three phases are recognized – manufacturing, use and demolition (Cabeza et al., 2010 and Ramesh et al., 2010). Embodied energy is mainly used during the manufacturing and demolition phases. The manufacturing phase includes production costs, transport and installation of materials in a new building, and also costs connected with the renovation of the building. The usage phase includes energy costs connected with usage and operation of a building during the course of its lifetime. The demolition phase includes costs for building demolition, transport of materials to disposal sites and material recycling.

Ramesh et al. (2010) define that LCEA is the sum of the amounts used of all types of energies during the life cycle.

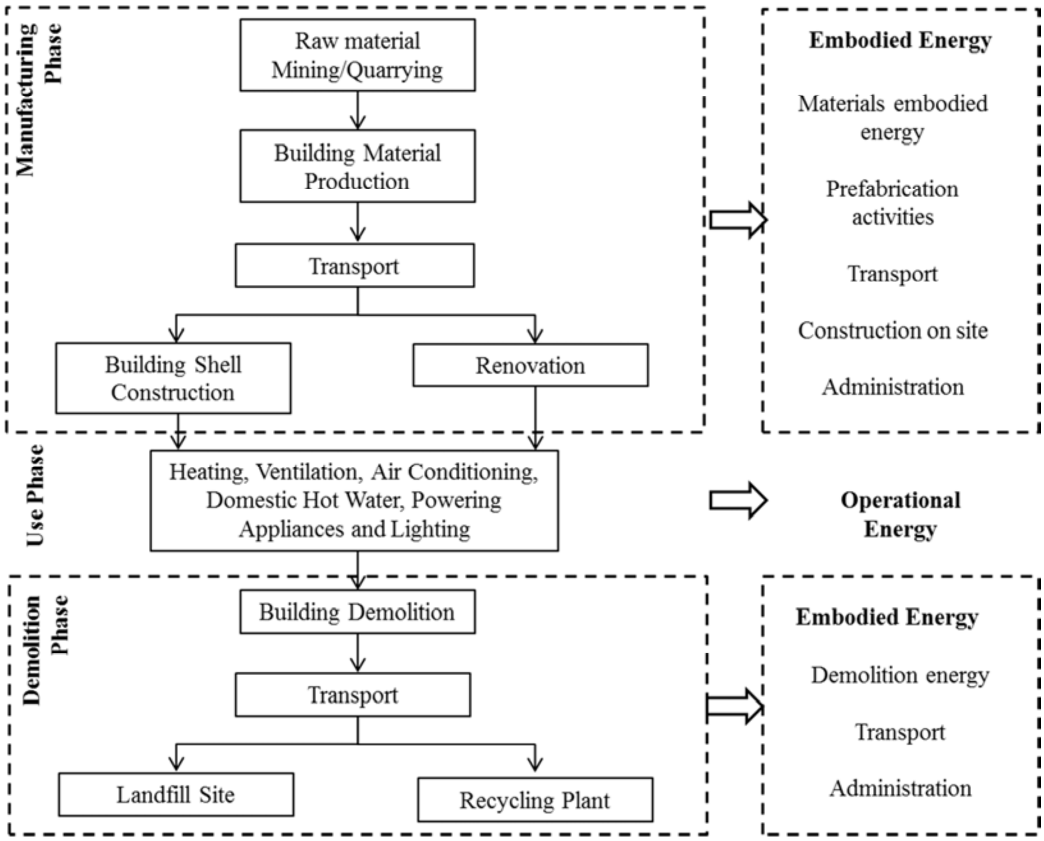

Figure 1. Life cycle energy of the building frame. Adapted from Ramesh et al. (2010) and Cabeza et al. (2014)

2.1. *Operational energy*

Operational energy includes energy consumed during the course of the usage phase. These energies include heating, air –conditioning and ventilation (HVAC), lighting, domestic hot water and other appliances. Sharma et al. (2011) state that HVAC forms approximately 40% of the total operational energy used in buildings. The share of energies consumed for heating in the winter period and cooling in the summer period is affected by the climate in the locality of the evaluated building, the materials used and the required level of comfort for the building.

2.2. *Embodied energy*

Dixit et al. (2010) point out that different authors define the term “embodied energy” differently and consider the most complex to be that which states “embodied energy comprises the energy consumed during the extraction and processing of raw materials, transportation of the original raw materials, manufacturing of building materials and components and energy use for various processes during the construction and demolition of the building". Embodied energy is divided into two parts: Direct energy and indirect energy.

Direct energy includes energy in production processes performed on site, energy in off-site prefabrication processes, transport on site and off site and administration.

Indirect energy is represented by energy consumed during the production of construction materials, during renovations and demolition. Indirect energy includes (Dixit et al., 2010):

- Initial embodied energy- energy essential for acquiring and processing construction materials and their transport to the construction site
- Recurrent embodied energy – energy consumed in maintenance and modernization processes within the usage phase
  Demolition energy – energy essential for demolition and transport of waste materials

3. Significance of embodied and operational energy

The quantification of the embodied energy requires the acquisition of data for every material used in the building, which may be relatively demanding from a time and financial point of view and, how as stated by Malquist et al.. (2011), this prerequisite is a definite obstacle when designing buildings. On the contrary, the quantification of operational energy is significantly easier.

Authors engaged in the energy consumption of buildings state that the share of operational energy in the total energy consumed amounts of 80% - 90%. Dixit et al. (2010) adds that embodied energy has a significant share in the total life energy and quotes the study by the Commonwealth Scientific and Industrial research organization, which states that the share of embodied energy in average households is approximately equal to 15 years of operational energy. On the contrary, the study mapping LCEA at the LCEA buildings concludes that the share of operational energy is within the range of 40 – 60% (Karimpour et al, 2014). The significance of embodied energy is higher in low energy houses and its significance will increase in the future. The choice of materials affects the amount of future operational energy. Thormark (2002) notes that the share of embodied energy could be significantly reduced by using recycled materials.

3.1. *Studies focused on LCEA*

Many studies uses the Literature Based Discovery (LBD) method, which is based on the literature review and forms conclusions based on a combination of knowledge from different bibliographic sources**.** In the following text three studies will be briefly introduced, which were issued in reviewed scientific magazines, using the LBD method.

Dixit et al. (2010) compares 17 different studies focused on embodied energy for typical residential and office buildings and aims to determine the standard deviation of these results. Residential buildings proved to have a lower standard deviation from the average value than the group of office buildings. As one of the reasons for this variability, he identified the disunity in processes used to determine embodied energy.

Ramesh et al. (2010) compared 73 case studies from a total of 13 countries. Both office and administrative buildings were used in the sample. The aim of the article's authors was to determine "the range of life cycle energy values for conventional office and residential buildings" and to identify the differences between low energy and conventional buildings. Individually obtained studies differed in the nature of the data presented. The smaller part of the sample only determined the embodied energy. Upon comparing the data, the author's concluded that the reliance of the operational energy on the life cycle energy of building is almost linear. Climate changes and other differences do not affect this reliance. When comparing low energy buildings and conventional buildings, it was confirmed that the share of embodied energy in low energy buildings is higher than in conventional buildings.

Karimpour et al. (2014) focused on determining the significance of embodied energy in LCEA in house buildings. The study comprises 24 residential buildings from 10 different cities from across the world. The aim of the author's was to compare projects from areas with different climatic conditions. The author's state, that where possible, they extracted energies related to heating and air conditioning. Identically as in the previous study, the author's assesses that the reliance between the operational energy and the life cycle energy is linear. The results of the study also reveal that the share of embodied energy is higher in localities with a temperate climate than in those with tougher climatic conditions.

4. Conclusion

Buildings have a significant share in overall energy consumption and with the prognosis for future development there is the expectation of further growth in consumption. Based upon attempts to achieve sustainable constructions, attention is focused on reducing overall consumption. To implement the steps focused on reducing energy consumption, approaches are used, which evaluate the consumption of different types of energy within the course of the life cycles of buildings.

Such approaches have been used since around the 1990s. Attention was first focused on reducing operational energy. With the growing level of success of the steps and measurements focused on operational energy, the second basic part of LCEA-embodied energy also results in a higher value. The share of embodied energy is primarily higher in low energy buildings than in conventional buildings.

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The study of sustainable development of state-owned enterprises' restructuring in the construction industry in China

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Abstract

The construction industry is the pillar industry in China, accounting for about 6% of China's gross domestic product (GDP) since 2008. The state-owned construction enterprises are the backbone of our country's construction sector. Large-scale restructuring has been implemented in our state-owned enterprises, and privatization has taken place in different industries in China. However, the extent of privatization is different. Many researchers have studied the performance of state-owned enterprises' restructuring, but they have mainly focused on the manufacturing and industrial sectors; they rarely considered the construction industry as the research objects. Moreover, such research usually focuses on the financial aspect, completely ignoring the assessment of an enterprise's social responsibility. Under the sustainable development perspective and upon review of literature, we establish the relationship between the state-owned enterprises' restructuring and their corporate sustainability. Then we develop the hypotheses and establish the fixed effects regression models. Based on the financial statement data of listed companies of the construction industry in China from 2007 to 2011 and using Eviews and SPSS for regression analysis we empirically verify the relationship between the state-owned enterprises' restructuring and their corporate sustainability. The results are as follows: 1）The state-owned enterprises display stronger financial capability than the privately held enterprises, especially at return on assets (ROA) and total assets turnover ratio (TATR); 2）The state-owned enterprises demonstrate a stronger social responsibility than the privately held enterprises, especially in the number of employees and the annual tax payment; 3）The relationship between the size of an enterprise and its corporate sustainability is positive whereas the relationship between an enterprise's asset-liability ratio and its corporate sustainability is negative., The macro-environment has a huge impact on the enterprise. Our research intends to help Chinese companies in the construction industry make strategic restructuring through empirical evidence.

Keywords: China; Privatization; Restructuring; State-owned Enterprises (SOEs), Sustainable Development

1. Introduction

The construction industry is the pillar industry in China, accounting for about 6% of China's gross domestic product (GDP) since 2008. The state-owned construction enterprises are the backbone of our country's construction sector. Large-scale restructuring has been implemented in our state-owned enterprises, and privatization has taken place in different industries in China. However, the extent of privatization is different.

According to statistics provided by the State Statistical Bureau of People's Republic of China (2012), the output value of domestic construction enterprises has increased year by year, as did the State-owned construction enterprises' output value. The statistics demonstrates that the ratio of State-owned construction enterprises' output to Construction enterprises' output fell from 77% to 18%, stabilizing at 20% from 2006, as shown in Table 1. Apparently we can see that the restructuring of our state-owned construction enterprises is progressive, as we took great reformative efforts. An enterprise's sustainable development is an enterprise business strategy in the pursuit of self-survival and lasting development. It is necessary to consider the achievement of the business goals and improve the market position, maintain its leading position and sustained earnings growth, as well as improve the ability to ensure the company for a long time. Whether they are state-owned or private, companies exist as an economic entity. The essence of corporate restructuring to the company is to pursue a sustainable development.

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Table 1. Overview of China's State-owned Construction Enterprise Restructuring

Year	TOTAL/GDP（%）	TOTAL（Billion）	SOE（Billion）	SOE/ TOTAL（%）
1980	4.30	28.693	22.090	77
1985	4.64	67.51	47.451	70
1989	4.67	128.298	87.857	68
1990	4.60	134.501	93.519	70
1995	6.13	579.375	367.025	63
1996	6.16	828.225	416.021	50
1997	5.85	912.648	452.652	50
1998	5.91	1006.199	457.144	45
1999	5.77	1115.286	486.138	44
2000	5.57	1249.76	505.379	40
2001	5.41	1536.156	536.281	35
2002	5.37	1852.718	558.286	30
2003	5.52	2283.077	606.023	27
2005	5.60	3455.21	843.203	24
2006	5.70	4155.716	921.856	22
2007	5.80	5104.371	1063.090	21
2008	6.00	6203.681	1223.166	20
2009	6.60	7680.774	1519.005	20
2010	6.70	9603.113	1814.859	19
2011	6.42	11705.965	2078.001	18

Note: TOTAL stands for output value of all construction enterprises in China; SOE stands for Output value of state-owned construction enterprises in China

This study aims to achieve the following two goals: 1) to investigate the relationship between an enterprise's form of ownership and its sustainability; 2) to establish a model of the relationships between a listed construction enterprise's form of ownership and its sustainability, which is verified through regression analysis. The development of the sustainability of a construction firm plays a significant role in the course of the country. Through this study, we can determine whether being state-owned or private is good model fit for our construction enterprises in the end. Furthermore, the introduction of quantitative indicators of sustainable development promotes the development of the theory of enterprises' sustainable development, as well as the theory of restructuring.

2. Literature Review

2.1 State-owned Enterprises and Private Enterprises

Bai et al.(2006) and Zhu and Liu (2012) use the same sample to conduct empirical studies, in which they define a state-owned enterprise as an entity whose paid-up capital is 100% state capital. Song and Yao (2005) define a state-owned enterprise as state-owned enterprises (100% state-owned shares) and state holding enterprises (state-owned shares is not less than 50%), which is the same as the definitions in Zhu and Liu's (2012) empirical study. The definition of private enterprises also has no uniform standard. Zhang (2001) considers private enterprises as all non-state-owned enterprises, whereas Song and Yao (2005) define private enterprises as private holding companies (private equity is not less than 50%). Another definition from Hu et al. (2006) refers to the state-owned enterprises which introduce other types of equity: the restructuring with over 50% private equity is called "complete privatization", otherwise referred to as "partial privatization". Above all, the definitions of these key points focused on the criteria for the classification of state-owned shares in proportion. Based on the definition of previous studies, as well as research samples used herein, we define state-owned enterprises as state-owned and state holding enterprises, wholly state-funded enterprises whose majority shares belong to the government whereas private enterprises are defined as private holding companies in which the enterprises have more than 50% of private shares.

2.2 Restructuring of State-owned Enterprises

State-owned enterprises are traceable to the capitalist West. State-owned enterprises contributed around 10% to GDP on average in 1980s', with 14% in Germany, 16% in UK, 20% in Italy, and 23% in France (Gu, 2000). But the situation did not last long; with the development of market economy and the continued loss of state-owned enterprises, a spate of Western countries launched a wave of restructuring. The Western countries began the restructuring process as a result of the poor performance of state-owned enterprises and the public enterprises, which had a serious impediment to the country's economic development. What's more, they adopted a radical restructuring across the board, which is restructured into another ownership structure at a certain point of time. Additionally, Western state-owned enterprises transferred directly from public to private ownership. However, the restructuring of state-owned enterprises in China is gradual; the reform of the economic system is under the premise of maintaining a stable political system, which is a unique restructuring way for a socialist country. There are a large number of studies about the restructuring of state-owned enterprises, but they do not reach the same conclusion. Most of the empirical research and theoretical studies of the effect of restructuring of state-owned enterprises are positive (Song & Yao, 2005), yet there is also considerable empirical research that suggests that the impact is neutral (Kole & Mulherin, 1997).

2.3 The Relationship between Restructuring of State-owned Enterprises and Organization Performance

The empirical study of restructuring of state-owned enterprises and organization performance has long been a hot issue. Most of the privatization has a positive effect on the enterprise's performance. Megginson et al. (1994) studied the mechanism of privatization affecting corporate performance and found that net income, profitability, operational efficiency, asset size and other aspects improved significantly after privatization, but financial leverage decreased significantly even though employment did not decline. Megginson et al. (1994) summarized the representative empirical studies of restructuring of state-owned enterprises from 1989 to 2000 and found that the enterprises were more efficient and they got higher profits after privatization, Chinese scholars found similar results. Using a Fixed Effects model and Logit Model, Liu and Li (2005) employed 451 sample enterprises from the competitive industry in China from 1994 to 1999, and found that state-owned enterprises had a negative impact on organizational performance, whereas non-state capital has a positive performance effect. Song and Yao (2005) used panel data of 683 sample enterprises from 1995 to 2001 and discovered that restructuring had a significant positive impact on corporate profitability, but the impact was not significant on labor productivity and costs for enterprises.

While most countries have benefitted from privatization, a number of studies show that the privatization of state-owned enterprises has a non-sustainable positive effect. In the research about Canadian railways, Caves and Christiansen (1980) found that in the absence of competition, there was no difference in efficiency between private companies and state-owned enterprises. Yarrow (1986) made theoretical analysis and empirical research about Hong Kong and found that the market structure had a greater impact on the company's performance than ownership structure. When analyzing the organizational performance of state-owned enterprises in China, since the restructuring is gradual, researchers need to consider indicators other than the financial performance.

2.4 Sustainable Development

Hubbard (2009) points out that sustainable development is development that tries to meet the needs of contemporary people without prejudice to the interests of future generations. Sustainable development contains three principles: environmental integrity, social equity, and economic prosperity. In the context of national development, the status of the enterprise is increasingly important. Enterprises not only create great wealth for the country but also affect the use and allocation of resources. Broadly speaking, they play a very important role in the long-term development of the country. Pratap (2011) examines the impact of privatization on firm level performance in India and argues that privatization leads to significant improvement in profitability, efficiency, real output of firms and the government gets some fiscal boost through privatization receipts. Boardman and Vining (2012) maintain that most of the privatized firms continue to operate efficiently, making them positive contributors to social welfare through the provision of increased economic opportunities, higher profits and taxes in Canada.

Based on the three principles proposed by Hubbard (2009), this research evaluates the sustainable development of construction enterprises in terms of the following three aspects: ① increase in financial capability, ② business growth in harmony with social development, ③ reasonable accommodation of stakeholders. From the review above and the current condition of the construction industry, two hypotheses are proposed.

Hypothesis 1: The state-owned enterprises display stronger financial capability than the privately held enterprises.

Hypothesis 2: The state-owned enterprises demonstrate a stronger social responsibility than the privately held enterprises.

3. Research Method and Design

To test the proposed hypotheses, an econometric analysis is conducted. In this section, the statistical method for hypothesis test is discussed first and the econometric model appropriate for the hypotheses is presented. Next, the data and how they were collected are explained. Last, detailed discussions on the measurement of model variables are presented.

3.1. Econometric Model

Ordinary least-squares (OLS) multiple linear regression analysis is used to test the hypotheses. OLS estimators are the best linear unbiased estimators (BLUEs) (Wooldridge, 2013). Two research models are applied in studies on the restructuring of state-owned enterprises: one model uses non-parametric test methods such as Wilcoxon rank sum test (Liu & Li, 2005); the other model uses a more mainstream research model: fixed effects regression model (Liu & Li, 2005; Bai et al, 2006; Hu et al, 2006). Non-parametric test is mainly applied to enterprises that undergo restructuring with a point mutation, which occurs when the domestic facts of the gradual restructuring do not match or are not reflected in the restructuring effects of the state-owned enterprises. This fixed effects regression model is the proper solution to the problem of selection bias in the study sample. A regression model is designed to test both Hypotheses One and Two. The dependent variable of the model is Yit, which represents firm I's capacity for sustainable development in year t, including financial capacity ROA and TATR, social responsibility EMPLOY and TAX. The regression model is given in the following equation

$$\mathrm{Y_{it}} = \alpha_i + \alpha_t \mathrm{YEARt} + \beta \mathrm{GOV} + \gamma_1 \mathrm{SIZE} + \gamma_2 \mathrm{LEVE} + \gamma_3 \mathrm{STS} + \varepsilon_{it} \quad (1)$$

The variables in Equation (1) are explained in Section 3.3. Note that we use ε_{it} to account for factors that are not included, such as culture and social impact. The data are evaluated against the null hypothesis to test each hypothesis and determine whether the studied variables have significant impacts, positive or negative, on the firm sustainability. The study uses the two-tailed significance level to ensure the more stringent criterion for significance.

3.2 Data

We selected the listed companies under the category of "construction, building materials and steel" in the Shanghai and Shenzhen stock markets. There are 181 companies in total, with 110 eliminated because of incomplete data. We selected the corporate annual reports of sample companies from 2007 to 2011 in Wind database, GTA database, Juchao Information Database, CFi.CN and transfer the unit into Enterprise - Year. 355 Enterprise Years are obtained from a total of 575 due to vague definitions and incomplete data.

3.3 Measures of variables

- Measurement of the Independent Variables

Although many scholars concentrate on restructurings, the measurement of variables is not unified for various purposes. As defined earlier under literature review, the independent variable in this article is a dummy variable of state-owned enterprises GOV: GOV=1 in which more than 50% of the shares state-owned shares, otherwise GOV = 0.

- Measurement of the Dependent Variables

In this paper we employ sustainability of the enterprise as the dependent variable, represented by Yit, on behalf of the capacity for sustainable development of firm i in year t. In this study, the main indicators of corporate sustainability are reflected in two aspects: financial capabilities and social responsibility. Return on assets (ROA) and total assets turnover ratio (TATR) are used to indicate financial capabilities, whereas Employment and TAX are used to indicate social responsibility.

- Measurement of the Control Variables

The firm size is represented by SIZE; enterprise asset-liability ratio is represented by LEVE; stock-to-sales ratio is represented by STS. A controlling variable is also used to indicate annual changes in the macroeconomic environment, denoted by $\mathrm{YEAR}_{t.}$ Because the study interval is 2007-2011, we set 2007 as the basis of comparison groups. When the time was in 2008, set YEAR1=1, otherwise YEAR1=0 the value of this controlling variable is assigned in the same manner for all studied years.

4. Results

We first used ROA and GOV for the base to establish Model 1 and, Model 2. Then we used TATR for the base to establish Model 3 and Model 4. In all, we get 8 models, shown in Table 2. The results show that for Model 2, the coefficient for GOV is 0.02, and the P-value is less than 5%, indicating a state-owned enterprise's return on assets is 0.02 higher than that of the private's, which is significant at the 5% level against the two-tailed alternative. The R2 and Adj. R2 of Model 2 are 0.66 and 0.56. Therefore, statistically, according to the Adj. R2 in the study, the conclusion can be obtained: The independent variables together explain 56% of the dependent variable. For Model 4 the coefficient for GOV is 0.11, and the P-value is less than1%, indicating that a state-owned enterprise's total assets turnover ratio is 0.11 higher than that of the private's, which is significant at the 1% level. In brief, for profitability, the GOV's coefficient is positive and significant. That is to say the state-owned listed construction firms in China have a higher level of profitability than private enterprises have. The R2 and Adj. R2 of Model 4 are 0.89 and 0.85. Therefore, statistically, according to the Adj. R2 in the study, the conclusion can be obtained: The independent variables together explain 85% of the dependent variable.

Similarly, the results show that for Model 6, the coefficient for GOV is 3090.58, and the P-value is less than 5%, indicating a state-owned enterprise's employment is 3090.58 higher than that of the private's, which is significant at the 5% level against the two-tailed alternative. For Model 8 the coefficient for GOV is 26147.25, and the P-value is less than1%, indicating that a state-owned enterprise's tax is 26147.25 higher than that of the private's, which is significant at the 1% level. In brief, for profitability, the GOV's coefficient is positive and significant. That is to say the state-owned listed construction firms in China have a higher level of social responsibility than private enterprises have. The R2 and Adj. R2 of Model 6 are 0.82 and 0.77, respectively, and for the Model 8 they are 0.62 and 0.52, respectively. Therefore, statistically, according to the Adj. R2 in the study, the independent variables together explain at least 52% of the dependent variable. At the same time, we can see that in Model 2、Model 6、Model 8 the coefficient of SIZE is significantly positive, indicating that there is a significant positive relationship between firm size and ROA，EMPLOY，and TAX. For LEVE, the coefficients are significantly negative in Model 2、Model 4, indicating that the higher the asset-liability ratio, the lower ROA、TATR the company gets. And STS are negative significant. But for the dummy variables YEARt, in Model 2 the coefficient of YEAR1、YEAR2 is significantly negative; in Model 4 the coefficient of YEAR4 is significantly positive; in Model 8 the coefficient of YEAR1、YEAR2、YEAR3 is significantly negative.

Table 2. Statistic for model test

	Coefficient							
Variables	Model 1 ROA	Model 2 ROA	Model 3 TATR	Model 4 TATR	Model 5 EMPLOY	Model 6 EMPLOY	Model 7 TAX	Model 8 TAX
GOV[a]		0.02**		0.11***		3090.58**		26147.25***
SIZE[b]	0.02**	0.02**	-0.04	-0.04	7112.18***	7027.20***	24731.17***	24012.22***
LEVE	-0.18***	-0.18***	-0.25*	-0.27**	3892.25	3341.67	-3833.11	-8491.17
STS	-0.01	-0.01	-0.57***	-0.57***	-1887.93	-2151.12	-3603.87	-5830.49
$YEAR_1$[a]	-0.02***	-0.02***	0.04	0.04	-698.38	-582.20	-20607.00***	-19624.12***
$YEAR_2$[a]	-0.02***	-0.02**	-0.07*	-0.05	-431.46	135.92	-25487.75***	-20687.53***
$YEAR_3$[a]	-0.02**	-0.01	0.03	0.05	-1675.55	-952.57	-20692.97***	-14576.41*
$YEAR_4$[a]	-0.02*	-0.01	0.04	0.08*	-2751.72*	-1694.88	-23263.96***	-14322.82
C	-0.15	-0.15	1.74***	1.75***	-86639.90***	-86133.66***	-295993.1**	-291710.2**
R^2	0.65	0.66	0.88	0.89	0.82	0.82	0.61	0.62
Adj R^2	0.56	0.56	0.85	0.85	0.77	0.77	0.50	0.52
Prob(F)	6.76***	6.80***	27.00***	27.34***	16.18***	16.24***	5.59***	5.83***
N	355	355	355	355	355	355	355	355

[a] Dummy Variable [b] Long-transformed, in ten thousands. *p<0.10，**p<0.05，***p<0.01 (Two tailed)

5. Discussion

With the deepening of the market economy system, the construction enterprises' growth environment has become increasingly diverse, facing increasingly fierce competition. In order to maintain long-term development, it is particularly important to choose a suitable strategy to develop. According to the results of this study, China's state-owned construction enterprises should not consider restructuring temporarily.

First, from the point of view of financial capability, the barriers to entry of construction industry are too low and there is a significant imbalance between market concentration and economies of scale. After the reform and opening up in China, an excessive number of construction enterprises entered the industry, which caused excess production capacity and low profit margins. These small and medium private construction enterprises created excessive competition among themselves because of the lack of appropriate experience and executive support. Meanwhile, the restructuring of the state-owned enterprises in China is entering in the late stage (2006-now). From the initial stage of invigorating large enterprises while relaxing control over small ones, to the later stage of filtering out the enterprises of relatively poor performance to maintain social stability (Zhu & Liu, 2012), the focus of restructuring is now shifted to the remaining large state-owned enterprises in the competitive industry or state-owned enterprises in the monopoly industries. Yet, large state-owned construction enterprises have inherent advantages and ordinarily engage in monopolistic nature of public projects like aircraft, railway, highways and hydro telecom. There is insufficient competition in these projects because of high technical barriers; therefore they produced a relatively high profit margin.

Second, state-owned construction enterprises in China have a good awareness of social responsibility. Since China is a socialist system, no matter what kind of policy is implemented on state-owned enterprises, its fundamental purpose is to achieve common prosperity and promote social development. The construction industry is labor-intensive, and the barriers to entry are not high. Construction enterprises can effectively digest a lot of social idle labor and thus help maintain social stability. Although a private enterprise has to increase the number of managerial staff and migrant workers to meet market expansion, reducing the number of employees is an automatic response when the private enterprise wants to cut cost. What's more, state-owned enterprises are less likely to be associated with tax evasion.

6. Conclusions

Through research we reach the following conclusions. First, Hypothesis 1 is rejected. State-owned enterprises are better than restructured private enterprises in terms of financial capacity. Therefore, at this stage, China's state-owned construction enterprises should maintain their growth momentum. Efforts should be made to strengthen their business advantages, such as expanding the field, developing the technology, and forming a unique competitive advantage in the international construction market. Second, Hypothesis 2 is verified. State-owned enterprises are better than restructured private enterprises in terms of social responsibility. State-owned enterprises should take the initiative to take corporate social responsibility, make a good example for other types of businesses, and contribute more to China's economic development and social progress. Third, the relationship between firm size and corporate sustainability is positive, whereas the relationship between asset-liability ratio and corporate sustainability is negative; macroeconomic environment has large impact on sustainable development of enterprises. There are some limitations. The basic situation of China's construction enterprises cannot be illustrated by listed companies only. However, since we surveyed three fields (construction, building materials and steel), the conclusions of this study are reliable.

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Buildings renovation and maintenance in the public sector

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Abstract

The paper presents a model for maintenance and renovation of public sector buildings. The model creates the basis of the Buildpass application that allows users to use these methods through a web interface. The author researched innovative approaches in detail, in order to deal with the problems of maintenance and construction refurbishments indicated by companies dealing with software applications used for Facility Management.
Maintenance and renovation costs spent on buildings are a significant part of costs within the lifecycle of structures. Rational owners and facility managers try to minimize the outlays on maintenance and renovation. However, it is at the same time necessary to respect a certain standard condition of a building that must be maintained above the fixed limit given by the type and demands on usage of an existing building.
The model must be on such a level that the user, who is not a civil engineering specialist, would be able to use it without getting biased or misguided results. On the other hand, the aim is to create such an environment where the civil engineering expert can intervene in the primary inputs of a model and thus to use his/her own experience and knowledge.
Attributes of the information-technological solution do exist – the possibility to work on various levels of the model's detail and the time exigency for gaining information outputs on tasks being solved. It is many times necessary to get data within a short time or more alternative solutions are analyzed and it is necessary to focus only on the potentially best solutions and not needlessly waste time on poor variants. The application must enable getting a result within a short time and at the same time not seriously bias the outputs. For a more in-depth analysis, the user then selects how much time wants to dedicate to the task.

Keywords: Maintenance; Renovation; Life Cycle Cost; Buildpass; Model.

1. Introduction

The public sector manages an extensive amount of assets, mostly buildings, which are seated by public sector administration or are rented. It is necessary to invest enormous amount of public expenditures which should be spent effectively. In order to establish procedures and estimate preliminary operational expenditures generated by effective facility management it is vital to use modern models and approaches which are part of software tools designated to manage construction assets.

Asset management requires ongoing use of financial and engineering resources. Furthermore, ad-hoc asset management which is managed without any conception or economical limits, without calculations and assessment of different possible solutions during the buildings life cycle, is not economical. Moreover, it offers only average degree of building user satisfaction. The amount of expenditures, designated for building operation, maintenance and modernization, should be within the range from 0.2% to 4 – 6% of the building capital cost annually (Bull, 1993). The subject of the asset management covers topics such as the rate of maintenance negligence in previous years or changing the type of the main function of existing buildings. It initiates the topic of progressive constructions, new technologies, new materials and overall conflicts of the technical progress. Pragmatic solutions are indeed feasible but they do not respect possible risks, uncertainty, incomplete information, expected progress trends in the uncertain informational future.

Terms such as building renovation and maintenance are inseparable from the term Facility Management which covers both. Facility Management is possible to define in a simplified way as a service which ensures the investment recoverability through economic operation thanks to the Life Cycle Costs or through the revenues from rents in case of leasing the building to particular tenants in a rationally used building. (Khojandi & Maillart & Prokopyev, 2007) defines operational expenditures optimization as a Facility Management tool.

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For each building there is a wide variety of known or easily accessible technical information about its technical and economic condition. Those information are procured from different sources, have different weights, different accuracy, risks and they change over a period of time, as (Frangopol, 2001) shows. It is difficult to make a proper and responsible decision about building operational investments (especially about periodic maintenance and repairs) according dispersed information over a specific period of time because we do not know the inaccuracy which influence our decision making. Rational operation and Facility Management of several buildings based on dispersed information is not even possible and that is caused because the degree of information uncertainty is even enhanced by different methodologies of information acquisition for each building, as stated by (Seeley, 1987).

On the market there exist various instruments from the field of facility management, which deal with the problems of maintenance plan setting and structural objects renewal. Software processing and connection to graphic systems is usually very beneficial. The weak aspect of these systems is of course an insufficiently worked-out model of maintenance and renewal, which would realistically describe the ageing of a structural object at the level of individual construction components (Liu & Wu, 2013). From these there follow inaccurate outputs on the level of the technical and economic formations which serve as a basis for user decision-making as to how to further dispose of the structural object.

The aim of the inaugural dissertation is to offer an instrument which will generate a quality techno-economic solution to problems of planning and optimization in the renewal and maintenance of structural objects. The theoretical principles of the model come from the newest techno-economic knowledge and personal innovative reflections through practical acquaintance with the problems.

2. Input requirements

The application instrument must be on such a level that the user, who is not a civil engineering specialist, would be able to use it, without getting biased or bad results. On the other hand, the aim is to create such an environment where the civil engineering expert can intervene in the primary inputs of a model, and thus to use his/her own experience and knowledge.

With the possibility of working to a different degree of detail in a model there is also a connected time exigency for gaining information outputs on tasks being solved. Many times it is necessary to get data within a short time period or through analysis there emerges more variant solutions and it is necessary to focus only on the potentially best solutions and not to needlessly waste time on poor variants. Applications must enable getting a result in a short time horizon and at the same time not to bias outputs. For a more in-depth analysis the user then selects how much time wants to give to the task.

The application is elaborated by use of a modular system, which means that it is possible to add further instruments which will address and process further areas connected to the existing set of problems.

The requirements can be divided into the following main areas:

From a practical point of view it:

- passportization - capture the current state,
- determination of optimized maintenance cycles and restoration of objects,
- quantification of the costs in each year,
- determining the economic balance of the building.

From a user perspective, focusing on the following areas:

- work with data in different details of specification,
- user access to a wide range of users,
- the possibility of taking into account the time needed for processing the outputs from the model.

The mentioned points above define how the preliminary structure and content will look like. Building passportization is very important and essential for planning the future building renovations. Error in the building passportization can degrade the following technically-economic estimations. It is necessary to offer such a solution which enables the user to easily and quickly assemble a model of his building of interest. It means that even an average user must be able to generate a highly professional model in order not to create major deviation from the project basis. The supporting databases, which create the model basis, must be precisely processed and the data must have a high professional accuracy in order to provide correct values for the model processes.

3. Reference database of the construction production

One of the crucial requirements for practical and effective usage of the T-E analysis (Motawa & Almarshad, 2013) is an unambiguously defined form and input data quantity which become a subject of summarization. There will be automatically added missing data among the data required by the analysis and inserted by the user before the summarization begins.

The source of the supplement data will be two internal databases:

- the characteristic representatives of construction output,
- the database of typical components.

The appropriate database assembly has created a system, which allows the user without construction knowledge background acquires very accurate practical outputs. The more components the database will include the less the output data will be misrepresented. The output data result from allocation the objects to the chosen construction components representatives. On the other hand, if the number of the chosen representatives (reference examples) will be too extensive; it will cause chaotic and difficult data insertion (Voicu et al).

4. Software processing of the building reference database

The software application is physically using a single database of characteristic representatives of the present construction production. The database allows inserting different simultaneously maintained types of building object classification. The database was adjusted as such that allows inserting more modeling techniques during the rendering of the example scheme of construction parts of a particular building. Presently, the database includes an expanding system which generating examples based on building capital expenditures (Lim et al, 2005).

4.1. *Model based on the basis of specific elements*

When the reference building has been chosen and all its main construction size attributes have been inserted, individual construction components are assigned and create the complete reference building. This mapping is carried out through the use of matrix of conversion formulas assembled for all buildings and all construction components. Each conversion formula includes characteristic size parameters of the analyzed building and an empirically determined conversion coefficient which defines the amount of construction components in the building. A fictive building is created by summarizing all the components and differentiates from the real investigated building in tolerable deviation.

For purposes of the T-E analysis, the existing construction production is divided into 7 systems. Each system includes a more specifically determined group of objects. There are defined 102 representatives of construction production in total in the database. Each object is labeled by a four digit code (first two digits represent the system; second two digits represent the building) and by a description.

The main requirement for this database is definition of all construction components, which are present in the construction production and whose lifespan does not reach to the lifespan limit of the whole building. The criteria for dividing the construction components are a component functions, its lifespan and expenses for component recover per unit. Each construction components is labeled by a code and description. In order to maintain better transparency and possibility to insert more components into the database, the construction components are included into groups labeled by letters and a binary number expressing the construction component class.

4.2. *Model based on the overall building cost*

This approach allows generating a file of construction components and its amount for the given object type based only on entering the overall building cost. The application of this approach is possible especially for processing the newly built buildings or buildings built in recent decades. The reason is that the building capital cost must be expressed in the present prices which could be a problem for historical buildings. If the user has available building budget for real construction costs or he is able to discount the cost of the present buildings, the approach based on the overall building cost could be the easiest method how to determine the proposal of schedule of construction components volumes based on typical object.

The model does not need to know the specific units at all because the principle is based on a percentage allocation the overall capital expenditure to particular construction components according the percentage scheme given beforehand, which is assembled according the specific building type.

The system JKSO (Standard Classification of Construction Structures) (Veselý et al, 2013) has been chosen as the most suitable catalogue of the typical buildings, which represents a system of classification of the overall construction industry production assembled in the Czechoslovakia in the 70s of the 20th century. Part of the JKSO is a technical register and the main classification consist 7 numbers. The JKSO was created for statistical purposes and its codes are used for monitoring the price trends and for creating typical characteristics of a similar building.

5. Construction components Life Cycle Costs

The building life cycle analysis (Life Cycle Costs, LCC), which is described by (Schneiderová, 2007) is focusing on the empirical operational expenditures improvements over the total building life cycle. Building lifespan is limited not only by its technical durability but also by the economic life. Technical lifespan is determined by the importance of material characteristics and building lifespan, which especially depends on designing construction components of long life cycle. Those construction components are of vital importance because when they are damaged (the components cannot serve to their main purpose) the whole building is not functional, the total collapse is imminent and potential repairs are extremely technically and economically demanding.

Considering the total cost for repairs it would be more effective to completely demolish the building and build a new one. Economical lifespan defines the period of time over which is economic to operate the building. Usually, the economic lifespan is shorter than the technical lifespan. It is very probable that the building will lose its economical serviceability, which could be associated with permanent losing the net revenues due to high expenses and it appears that it would be more useful to remove the building, build a new building which will return the site its profitability. The methods of decision making are described by (Macek & Měšťanová, 2007).

The total LLC calculation includes relevant input data, which are defined by technical parameters of the construction components and by the time when the particular expenses have been generated. The LCC calculation should serve as an important basis for decision making of the investor, designer and the future building end user for choosing the most optimal technical solution with regards to the ecological aspects and long-term economic impacts. It is possible to divide (Liu & Li, 2011) the expenses linked with the construction, operation and building disposal into three main classes:

- expenses linked with the building technical parameters – capital costs, repair costs, reconstruction costs, modernization costs and removal costs,
- operational costs – utilities, cleaning, amortizations and the like,
- administration expenses linked with the facility management – taxes, insurance, building management and the like.

Therefore, based on the mentioned overview, it is possible to determine the basic relation of the building life cycle costs (Kiviluoma & Korhonen, 2012) as follows:

$$LCC = \sum_{n=0}^{t_D} \frac{C_n}{(1+i)^n} \tag{1}$$

where C_n is the cost in year *n*,
i is the discount rate (time value of money) and
t_D is the length of the evaluation period (the life of the building).

The issue focuses on the costs associated with the technical parameters of the building. Life cycle costs can simply be written as the sum of the groups listed above costs:

$$LCC = C_T + C_P + C_A \tag{2}$$

where LCC Life Cycle Costs,
C_T costs associated with the technical characteristics of the building,

C_P operating costs and
C_A administrative costs.

Costs associated with the technical characteristics of the building (C_T) can be written by the following formula:

$$C_T = \sum_{n=0}^{t} \frac{\sum_{j=0}^{p} C_{T_j}}{(1+i)^n} \tag{3}$$

where T_j above j-th category of costs associated with the technical characteristics of the building,
n the year of assessment,
t life cycle of buildings (lifetime),
p the number of categories of costs associated with the technical characteristics of the building,
i the discount rate.

In terms of time sorting LCC cost object can be classified as follows:

- investment in phase (implementation) is an investment cost (purchase price),
- in the operating phase, it is the cost of the repair and maintenance of the building, modernization and reconstruction,
- in Phase liquidation is a cost for disposal of buildings.

6. Buildpass application

Previously mentioned models and techniques were processed by the software tools and the resulting application is called Buildpass. The application is using a web interface for its operation. Users can input their data on the webpage http://www.buildpass.eu with their login and password. The advantages are easy access of individual users and easy access of the reference databases stored on a server. Further advantages are actualization of individual user interfaces and adding more tools and exporting formats.

The project solution is based on the basis of software modules, which are linked with the main database system. The database creates the main foundation which interlinks the separate software tools. The user chooses which areas will be used and what the level of detail will be. The system is solved in such a manner that during the processing of the fundamental operations it is possible to generate the software exports without unnecessary pressure on the user to insert details about his building.

The application has been upgraded not only in terms of the calculation and optimization procedures but also in terms of visual interface. Furthermore, the user interface has been added allowing easy outpu processing with the table interface . In order to be able to examine the application preview it is possible to use login demo and password demo. The preview login allows examining created examples, look at all options and settings, which are included in the application.

7. Conclusions

The application Design builder offers a tool which is useful not only to industry professionals but also to users who are oriented on the economic aspects. The module structure of the software model (Macek, 2011) allows the individual adjustments and specification of the algorithmically generated schemes. The user is allowed to utilize his specialization within the industry or add specification based on consultation with other professionals. The overall calculating time intensity of the analysis depends on individual user requirements and the type of export data. Nevertheless, it is possible to process the majority of the building components within a few minutes.

The application has been developed on the modular system basis. It is possible to add other tools, which will be able to process additional areas linked with the particular building construction problems. The software export provides the application users with practical instructions for managing building repairs and refurbishments. Linkage with the technical standards is a partial application outcome. However, the technical database contribution and elaboration of the facility management expenses is crucial.

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A study on major sustainable refurbishment methods for high-rise residential buildings in Hong Kong

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Abstract

Improving the energy performance of existing building refurbishment has been identified as one of the key measures to reduce greenhouse gases (GHGs) emissions and combat climate change. However, little has been done to uncover how human behaviours would affect the selection of refurbishment solutions selection. The problem is particularly obvious for high-rise residential buildings as they are owned and/or occupied by different peoples with idiosyncratic behaviour and preference. In the research, 46 potential methods commonly used for major sustainable building refurbishment in high-rise residential buildings located in cities with sub-topic climate like Hong Kong were identified through literature review. These sustainable building refurbishment methods are classified under five criteria namely energy user pattern, domestic, high-rise building, climate feature and other building characteristics. A questionnaire survey was conducted to examine the feasibility of the identified refurbishment methods based on the perception of owners and occupants. The results show that those methods classified under building services category such as lighting, appliance, ventilation and lift receives greater support from owners and occupants. It is interesting to note that owners and occupants did not favour those sustainable refurbishment options which are related to the building envelop when it comes to major refurbishment. As for the renewable energy refurbishment methods, their acceptability are improving indicated there is huge potential for being incorporated into the major building refurbishment. This paper should help improve our understanding on what factors contribute to the satisfaction of owners and occupants of high-rise residential building in a major sustainable refurbishment scheme.

Keywords: Sustainable refurbishment, human behaviour, residential building, high-rise building

1. Introduction

As the effect of climate change is exacerbating, reducing the greenhouse gases (GHGs) emissions is an imminent task for the years to come. To achieve a significant GHG reduction necessitates the joint effort of various sectors with no exception to the construction industry. According to EMSD (2011), buildings in Hong Kong take up almost 90% of electricity consumption in the city. Building facilities, therefore, provides an immense opportunity for GHG reduction, and a practical approach is by improving the energy performance of existing buildings through sustainable refurbishment schemes.

Sustainable building refurbishment has attracted serious attention in the research community and industry in recent years. A thorough review of literatures has revealed that there are numerous sustainable refurbishment solutions which can be applied to improving the energy efficiency. However, as the climatic condition, building design, ownership pattern and energy consumption behaviour vary between different countries (Thorpe, 2010), not all the sustainable building refurbishment methods are applicable or relevant to the Hong Kong context. Applying the sustainable refurbishment concepts to high-rise residential buildings in Hong Kong, therefore, remains extremely challenging.

To successfully introduce sustainable refurbishment in high-rise residential buildings necessitates not only a better understanding of the technical merits and feasibility of sustainable refurbishment options but also the perception of owners and/or occupants towards those measures. By revealing the social and human issues, policy and decision makers can decide how to promote the application of various sustainable refurbishment solutions to maximum the GHG reduction potential. Until now, there are research gaps between (i) which sustainable refurbishment solutions are more suitable for HK high-rise residential buildings; and (ii) the relationship between the human behaviours and sustainable refurbishment. This paper, therefore, aims to establish a list of sustainable refurbishment solutions that would suit a major overhaul initiative in Hong Kong by understanding occupants' perception.

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2. Literature review

According to the theory of reasoned action, the performing behaviour is determined by the intention which can be predicted by one's attitude and subjective norm (Ajzen and Fishbein, 1980). It is not uncommon for owners and occupants of the sustainable residential refurbishment projects to stay in their property while work is carried out. Therefore, it is sensible to get the owners and occupants involved in the decision making process (Burton, 2012). Occupants' norm, attitude and intention towards residential energy consumption would inevitably affect the success of any sustainable refurbishment scheme. A small change in occupant behaviours, e.g. by lowering the indoor temperatures, using energy efficient light bulbs, turning off the lights when leaving a room, changing the hours of occupation, adjusting the ventilation rates, use various Energy Usage Systems (EUS) for cooking, switching off unused electrical appliances, etc. could lead to a sizeable reduction in energy consumption (Annika and Anna, 2007). On the other hand, the use of innovative technologies and/or materials as well as advance building services systems may also help cut down on energy consumption (Aleh et al., 2012; Shan, 2012).

Sustainable refurbishment methods can be classified according to different building components (Baker, 2009), building functions (Gelfand and Duncan, 2011), technical or non-technical aspects (Burton, 2012), etc. As discussed in the preceding section, not all sustainable refurbishment methods are applicable to Hong Kong. To determine which sustainable refurbishment methods are relevant to the local context, it is necessary to identify suitable criteria to assess the suitability of those methods. Amongst other aspects, the climatic condition (Tso & Yau, 2003) and seasonal variations (Yan, 1998) were considered influential. Besides, the building usage as well as owners and occupants' behaviour could also lead to a variation in energy demand. Therefore, five factors were used to determine the suitability of sustainable refurbishment methods and they include: climatic condition, user pattern in energy consumption, relevancy to residential building, suitability for being applied in high-rise construction, and other building characteristics.

While high-rise buildings in Hong Kong are owned and occupied by different people, it is never easy to have a consensus in sustainable refurbishment decisions except for retrofitting, i.e. one of a comprehensive nature and large scale (Living Cities, 2010). However, individual owner and occupant could also initiate sustainable refurbishment initiatives at different times. According to Shan (2012), refurbishment can be divided into light touch or refresh, medium intervention, extensive intervention, comprehensive refurbishment and demolition. Thorpe (2010), on the other hand, opined that sustainable refurbishment can be in form of a whole dwelling approach or an element by element regime to minimise the disturbance brought by refurbishment. In this research, sustainable refurbishment is divided into three types, namely: minor upgrading, medium scale improvement and major refurbishment.

In order to examine as many possible sustainable refurbishment methods as possible, major refurbishment was chosen as the subject of study. In Hong Kong, major refurbishment is mandated for those buildings which are over 30 years old, and the purpose is to uplift the building condition and maintain a safe living environment. It would be the best opportunity to integrate the sustainability measures in the major refurbishment scheme. As a result, a total of 46 potential sustainable refurbishment methods were selected for further analysis. These sustainable refurbishment methods were grouped under: (i) building services; (ii) building envelop; (iii) building layout; and (iv) renewable energy.

3. Methodology

In order to uncover the feasibility of various sustainable refurbishment methods in Hong Kong, questionnaire survey was carried out to collect the data. Meanwhile, according to the age of building, refurbishment scale and refurbishment difficulty, building refurbishment were divided into three levels: minor upgrading, medium scale improvement and major refurbishment. This questionnaire focused on major refurbishment for buildings of 30 years or more. For this type of refurbishment, the scale is supposed to be much larger and the difficulty should be higher too. The samples are the residents in Hong Kong who aged 18 or above at the time the survey was conducted.

The questionnaire consisted of two parts. The first part is to collect personal background of respondents including the personal background of respondents was collected, age, type of building living in and educational background. The second part of the questionnaire, however, aims to capture respondents' perception on the feasibility of sustainable building refurbishment methods by indicating the degree of acceptability of each building refurbishment methods assuming the degree of acceptability is a close proxy to the feasibility of those sustainable refurbishment methods. A 6-point Likert scale is used to represent the respondents' '5' being extremely acceptable while '0' denoting not unacceptable at all.

The reliability of the data collected from this questionnaire survey was tested through the Cronbach's coefficient alpha. Cronbach's alpha (Cronbach, 1951) is one of the most popular reliability statistics in common use nowadays, which determines the internal consistency or average correlation of items in a survey to measure its reliability (Santos, 1999). A mean score ranking technique is used to rank the relative importance of each variable. In this study, the rankings of various sustainable refurbishment methods were achieved by calculating the means for the whole sample. If there were two or more variables with the same mean value, the one with a lower standard deviation would be given a higher ranking (Xu, 2012). Distinguishing the differences between different groups of respondents was highlighted. Levene's Test (Levene, 1960) was adopted to decide whether equal variances between the two groups should be assumed. If Sig.>0.1, then an equal variance can be assumed. Otherwise, an equal variance should not be assumed. An independent sample t-test was then adopted to test the significance of the mean difference between the two groups. The Statistical Package for the Social Sciences (SPSS) 19.0 software was used to analyse the data and measure the indicators as mentioned above.

4. Results and discussion

The questionnaire survey was carried out in most of different districts in Hong Kong, including Kennedy Town on Hong Kong Island West, Quarry Bay, North Point on Hong Kong Island East, Hung Hom, Kwun Tong on Kowloon Island, Sha Tin of New Territories, to ensure a wider coverage and hence a better reliability. The questionnaire survey was carried out from June to July 2013. A total of 154 questionnaires were distributed. While it is a street survey, a response rate of 100% was achieved. Table 1 shows the classification of the responds. By referring to the personal background of the respondents, 3 questionnaires from those living in Public House and 3 completed by students living in the dormitory were eliminated. As a result, a total of 148 questionnaires were collected for the data analyses. With the Cronbach's Alpha of 0.934, which was higher than 0.7 and closer to 0.9, the 6-points scale measurement used in the questionnaire survey was considered reliable.

Table 1. The classification of the responds.

Age	Frequency	Type of housing	Frequency	Educational Degree	Frequency
<20	5	Private housing (Tenant)	64	High school or below	75
20-40	65	Private housing (Owner)	74	Undergraduate	50
40-60	48	Others	10	Postgraduate	23
>60	30				

4.1. Ranking of refurbishment methods

Table 2 indicates the mean score ranking results of 46 sustainable refurbishment methods analysed. The top ten sustainable refurbishment methods as perceived by the respondents included: energy efficiency appliance selection (S13), low energy lamps (T5 fluorescent) (S1), time switches (S12), motion sensors (S4), LED lighting (S2), enhance metering to audit energy performance (S14), photovoltaic (PV) panels (R3), solar water heating (R2), window frames with thermal break (E6), and mechanical extract ventilation (S8). All these 10 sustainable refurbishment methods had the mean scores of more than 4 or closer to 4.5. As for the least feasible sustainable refurbishment methods, they were inter-pane glazing (E3), tinted glazing (E2), light shelves (E12), locating room air-conditioner at floor level (L3), and reflective glazing (E4). The degree of acceptance as perceived by the respondents was low with the mean scores less than 3. The mean scores of all the identified sustainable refurbishment methods are highlighted in Table 2.

Table 2. Mean Score Ranking of Refurbishment Methods.

Code	Refurbishment methods	Mean	Rank	Code	Refurbishment methods	Mean	Rank
S13	Energy efficiency appliance selection	4.52	1	S19	Roof insulation	3.97	24
S1	Low energy lamps (T5 fluorescent)	4.49	2	S9	Ductwork and pipework insulation	3.85	25
S12	Time switches	4.48	3	E15	Revising air conditioning set-points	3.83	26
S4	Motion sensors	4.44	4	S10	Evaporative cooling	3.72	27
S2	LED lighting	4.38	5	E14	Draught-proofing	3.72	28
S14	Enhance metering to audit energy performance	4.34	6	E18	Check and repair duck work leakage	3.69	29
R3	Photovoltaic (PV) panels	4.33	7	E13	Floor or ceiling insulation	3.67	30
R2	Solar water heating	4.32	8	R4	Install showers with low-flow aerated showerheads	3.65	31
E6	Window frames with thermal break	4.24	9	S7	Wind turbine	3.62	32
S17	Mechanical extract ventilation	4.17	10	L2	Remote source solar lighting (light pipes)	3.58	33
R1	Modernise lifts with advanced VVV-F control system	4.17	11	S11	Chilled beams or under floors supply	3.48	34
S8	Phase change materials	4.16	12	S18	Building management system	3.46	35
E9	Automatic blinds	4.15	13	S5	Induction cooking	3.34	36
S3	Reflective surface (cool roofs or walls)	4.13	14	S6	Reduce hot-water storage temperature	3.33	37
E7	Green roof	4.13	15	E11	Overhangs	3.12	38
L1	Daylight sensors	4.12	16	E19	Door insulation	3.12	39
E8	Optimise lighting circuits to fully utilise daylight corridors	4.11	17	E10	Simple coating	3.04	40
E5	Lift power regeneration system	4.09	18	E1	Vertical fins	3.04	41
S16	Lifts with permanent magnet motor	4.08	19	E4	Reflective glazing	2.78	42
E17	Double/multiple glazing	4.07	20	L3	Locating room air-conditioner at floor level	2.69	43
S15	External wall insulation	4.06	21	E12	Light shelves	2.64	44
E16	Internal wall insulation	4.06	22	E2	Tinted glazing	2.55	45
E20	Replace motors and pumps with higher energy efficiency	3.97	23	E3	Inter-pane glazing	2.03	46

4.2. Most acceptable sustainable refurbishment methods

Energy efficiency appliance selection (S13) was ranked as the utmost acceptable method. Burton (2012) indicated the use of electricity by appliances involves huge amount of energy and selecting energy efficiency electrical appliances will help reduce energy consumption. Consumers can easily select energy efficiency appliances by making reference to various energy efficiency labelling schemes, e.g. Green Seal, Scientific Certification Systems, Energy Guide, Energy Star, Green-e, etc. (Banerjee and Solomon, 2003). Respondents found this very acceptable when making decisions on purchasing the electrical appliances as it would lead to energy and cost savings in their daily life. Although this is more essential to minor upgrading and medium scale improvement, respondents strongly believe that it is equally applicable in major refurbishment.

The use of Low energy lamps (T5 fluorescent) (S1) is the second most acceptable method. Upgrading existing fluorescent light fixtures become a backbone of commercial lighting upgrades according to Gelfand and Duncan (2012), and this is also relevant to domestic lighting upgrades from the perceptions of the respondents. Low energy lamps (T5 fluorescent) can help reduce the energy bill, save energy, cut down on the frequency of bulb changes, and lower the carbon emissions. Most literatures pointed out that low energy lamps (T5 fluorescent) is a very important method for sustainable refurbishment (PRUPIM, 2009; Xing et al., 2011; William, 1997; Gelfand and Duncan, 2012; CPA, 2010; GBA, 2010; GBA, 2012; Energy Saving Trust, 2007; Thorpe, 2010; Shah, 2012; Burton, 2012; Nick, 2009). With the government's supporting on low energy lamps such as the activities of buying at half price in many provinces of China, low energy lamp has gain widespread usage by the residents. Compared with LED lighting, low energy lamp is a little more acceptable due to the lower initial cost.

The third most acceptable refurbishment method is time switch (S12). 'Every morning when the sun rises, automatic curtain is slowly opened wake your sleeping; nightfall, curtains are automatically pulled together, an intelligent warm and wonderful home embrace you all the day (Baidu Wikipedia)'. This introduction indicates that timer switch plays an important role in people's lives which brings greater convenience to residents. That is why occupants tend to support this smart method.

Motion sensors (S4) come out to be the fourth most feasible sustainable refurbishment method. To fit a motion sensor light switch to automatically switch off lights when a room is empty is with high potentiality in existing building refurbishment. 'Do-it-yourselfers' has been trying to automate the lights and other applications in home (Bilger, 2005). Installing occupancy sensors in areas with intermittent usage should be strongly recommended despite the minimum standard is to put an easy to understood label reminding the users to turn off the lights when not in use (Shah, 2012).

LED lighting (S2) is the other most acceptable refurbishment method of the same category with low energy lamps (T5 fluorescent). Majority of the literatures considered LED lighting as the preferred lighting sources for residential purpose (PRUPIM, 2009; Xing et al., 2011; Gelfand and Duncan, 2012; GBA, 2010; GBA, 2012; Energy Saving Trust, 2007; Thorpe, 2010; Shah, 2012; Burton, 2012; Nick, 2009). LED lighting has a variety of colours and this could help create a stylish atmosphere (Thorpe, 2010) without generating excessive heat as secondary product when they are switched on (Robertson and Currie, 2005). However, comparing between LED lighting and low energy lamps (T5 fluorescent) should be based on their performance, cost and electrical efficiency etc., and this could affect the ultimate decision.

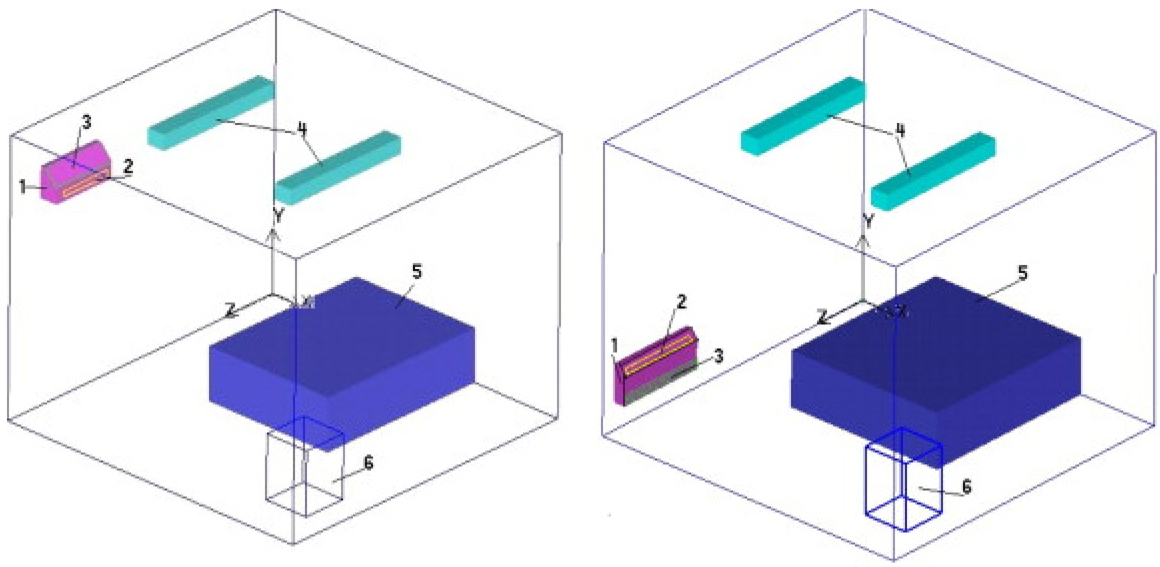
4.3. Unfavourable sustainable refurbishment methods

From Table 6, inter-pane glazing (S22) was considered the most unacceptable retrofitting method due to the high initial cost. Besides, the inter-pane glazing system reduces the indoor temperature by automatically controlling the amount of sunlight penetration. For residential buildings, occupants like taking advantage of natural ventilation by opening the windows, and this may defect the function of inter-pane glazing. The disruption caused by replacing the window should also be taken into account especially when the property is occupied. Therefore, inter-pane glazing system is seldom specified in residential building refurbishment (Baker, 2009).

Interestingly, tinted glazing (S21) was considered an unfavourable sustainable refurbishment method by the respondents. Tinted glazing is used to reduce the thermal transmittance and solar heat gain (Pfrommer et al., 1995). However, the China Glass Network reported in 2013 that tinted glazing in urban residential buildings can block off half of the solar radiation which plays the important roles of steriliser, disinfectant and deodorant. The low visible light transmittance of heavily tinted glazing would lead to a greater reliance on artificial lighting which would increase the demand for electricity in the day time (CGV, 2011).

Light shelve (S31) is an integrated approach to address the daylight distribution function and selective shading (Baker, 2009). According to Shah (2012), there are three common approaches to shade off the daylight, i.e.: external, internal and inter-pane (Shah, 2012). While the suitability of the external approach depends on the structural soundness of the façade and safety considerations, the internal approach would affect the interior space which is particular precious for residential occupants as average apartments in Hong Kong are very small. Therefore, light shelve was considered as a less popular method for sustainable refurbishment.

Usually, air-conditioners for domestic units in Hong Kong are located at high level. While research findings showed that there would be a 6.9% energy saving by installing the air-conditioner at the floor level (S42) (Gao et al., 2009) (Figure (a, b)), this would require a very substantial change to the façade. In Hong Kong, the façade is usually constructed by concrete, any such change would inevitably result in the forming of a new opening in the external wall to house the air-conditioner. Even if the statutory body approve such alteration to the structure, the nuisance brought by the work could be very high. As a result, the respondents did not support the use of floor-level air-conditioner to improve the sustainability.



(a) CAC Model (b) FAC Model

Figure 1 (a, b). CAC and FAC models. Remarks: (1) air-conditioner; (2) outlet; (3) return; (4) lamps; (5) bed; and (6) heat generator. (Gao et al., 2009)An example of a table.

Reflective glazing (S23) was also ranked very low. Gratia and De Herde (2007) stated that the reflective glazing returns most of the solar radiation to the atmosphere. However, reflective glazing is causing more and more concern in an urban environment especially from the perspective of light pollution. Some countries have already limited the daylight reflectance of glazing to minimise the social and environmental impacts. When applied to residential buildings, the effective of reflective glazing may not be as optimal as being used in office premises as occupants would still prefer opening the windows to enjoy the natural ventilation.

4.4. Comparison between different residents type groups

T-test was used to test the significance of the mean difference between different residents type groups: the tenant group and owner group. Methods with significant difference between Tenant & Owner were identified under t-test which met the condition 2-tailed Sig. Should be less than 0.05. Reduce hot-water storage temperature (S6), Simple coating (E1), Tinted glazing (E2), Reflective glazing (E4), Door insulation (E19) were found to be more acceptable by tenants in private housing, while Automatic blinds (E9) was the only method with more preference by the private housing owners.

5. Conclusions

In this paper, various energy-efficiency measures which may be adopted during the sustainable refurbishment exercise have been examined. However, the selection of sustainable refurbishment strategy will depend more on the acceptability of owners and occupants. The results of the questionnaire survey should help decision-makers realise the most favourable and unfavourable sustainable refurbishment solutions for high-rise residential buildings in Hong Kong.

All in all, replacing the building services components and systems, especially for lighting, electrical appliance, ventilation, lifts, etc. have received a much greater support from the owners and occupants surveyed. Improving the building envelops such as windows and shading are not so acceptable. As for the solutions related to renewable energy refurbishment methods, their acceptability are improving indicated there is huge potential for being incorporated into major sustainable residential refurbishment schemes. Factors affecting occupants' satisfaction to sustainable refurbishment include initial cost, operational cost, comfort, and service life. It is necessary to address the concerns of owners and occupants in order to maximise the chance of success of sustainable refurbishment schemes.

The research described in this paper is not without limitations. First, the sustainable refurbishment methods identified were mostly from foreign literature targeting different climatic condition, and there some relevant methods could have been ignored in this study. Second, this paper only focuses on the major refurbishment, and comparing with minor upgrading and medium scale improvement is inevitable to unveil the differences. Finally, the responses of the questionnaire survey are dominated by the private owners and occupants and this may affect the reliability of the findings. It is recommended further survey and comparative study shall be carried on to identify the factors influencing the success of a sustainable refurbishment project before, during and after renovation.

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Creative Construction Conference 2014

A building energy inventory and sustainable energy saving plan for municipal buildings and equipment

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Abstract

Municipalities should become leading participants in the implementation of sustainable energy consumption. Municipalities are responsible for the management of all public property on their territory, of which buildings represent an essential part and existing buildings have a particularly high potential for energy savings. According to the Joint Research Centre the building stock represents 40 % of the European Union's total energy consumption.
The goal of the paper is to present a methodology which was developed at the Czech Technical University in Prague (CTU), which enables municipalities to set energy consumption and CO_2 emissions on their respective territories. The extent of the paper is concerned with presenting only that part of the methodology which is focused on buildings (municipal, tertiary, residential) energy consumption and CO_2 emissions.
Using this methodology there were carried out by CTU a Baseline Energy and Emissions Inventories (BEEI) for several Czech towns which are members of the European initiative called the Covenant of Mayors. A further part of the paper then puts forward particular findings from the BEEI undertaken for Hlinsko municipality. The last part of the paper informs briefly about the working out of an energy concept for the capital city Prague in which the CTU participated.

Keywords: energy consumption, energy savings, CO_2 emissions, municipality buildings, energy action plan, cost

1. Introduction

The European Union (EU) leads a worldwide struggle against climate change and considers it as one of its highest priorities. Its ambitious aims are expressed in the Climate-Energy package, called Europe 20-20-20, by which the member states are obliged to limit energy consumption, decreasing CO2 emissions by 20 % while increasing energy output from renewable sources to 20 % of the total and reducing energy consumption by 20 % by 2020 (against the default year 1990). According to the Joint Research Centre (JRC, 2013) (further only JRC) the building stock represents 40% of the European Union's final energy consumption. Directing requests for savings to the buildings category is thus justified (Directive 2002/91/EC).

The saving energy policy is gradually being transferred to local administrations (Directive 2010/31/EU). In order that towns can proceed to processing Sustainable Energy Action Plans it is necessary that they carry out an inventory check of energy consumption and CO2 emissions on their territory. JRC has worked out a recommended structure for such an inventory, but the methodology for calculation of individual values has been left to each individual town. The inventory check according to JRC involves the following sectors - Municipal buildings, Tertiary buildings, Residential building, Municipal public lighting, Industry and Transport (European Commission, 2010).

Towns thus need a clear methodology by which to work out such an inventory. So far there has not been any concerted approach to evaluating the energy consumption of a whole town and neither has it been thus possible to compare directly individual towns with each other. The Czech Technical University, Faculty of Civil Engineering has elaborated methods of energy consumption calculation for individual sectors, which will give to Czech towns a primary basis for working through the Sustainable Energy Action Plan (SEAP).

The methodology reflects the division of energy consumption into separate sectors according to JRC and presents methods as to how to set, and discover the potential sources of, the necessary data on consumption. Energy consumption is monitored in very great detail at national level by the Czech Statistical Office (CSO) and the Czech Hydro-meteorological Institute. A town can gain any data which it does not possess directly from

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these sources. This data is freely accessible but it is problematic to carry out any necessary selectivity and to determine the consumption on any town territory without a clear methodology.

Once that is achieved on the basis of the elaborated inventory check of energy consumption and CO2 emissions a town can then approach planning and implementing savings measures in individual sectors. Towns have to approach differently the implementation of savings measures on the municipality`s own property and on private property. The town can implement measures on its own buildings according to its possibilities and a set plan. The town, however, does not have direct influence on private buildings, but has to act as a motivator and set its own good example. The good example of the municipality, as well as clearly targeted education (in the Czech Republic there exists an advantageous subsidy for programs which private building owners can use successfully), can properly motivate inhabitants towards the implementation of savings measures on their own buildings. The campaigns should be so presented as to influence as many inhabitants as possible.

Using the methodology there was carried out the Baseline Energy and Emissions Inventory (BEEI) for several Czech towns which are members of the European initiative called the Covenant of Mayors.

2. Methodology for an energy saving calculation on municipality territory and arriving at an emissions balance

The methodology of calculation identifies the basic data sources necessary for determining consumption of energy carriers (e. g. electricity, gas, oil, etc.) in individual sectors and provides a given reference year from which there can be planned savings measures.

2.1. Municipal buildings

Municipal building represents property under the proprietorship of the town and which it directly owns and which serves the administration in the performance of its tasks. It concerns especially administrative centres, schools and other institutions established by the town. The municipality possesses data on energy consumption of its own property and can process it. Invoices for energy from suppliers contain not only data on the price of these services but also on the amounts of consumption. Alternatively it is possible to use own readings from the installed meters at the annual interval (European Commission, 2010).

Firstly, it is necessary to carry out an inventory check of own property (if it has not been done already) and gather all data on the annual energy consumption in buildings for the reference year. In this way there is gained the data to classify them according to individual buildings and according to the energy carriers. In the CTU, for putting together such a wide range of data there was developed a practical SW tool for handling the evidence and conceptual management of energy consumption of buildings. SW enables continuous monitoring of energy, emissions and consumption costs. This supporting tool can produce and evaluate data on energy consumption and assess any saving energy action and its economic contribution.

2.2. Tertiary buildings

We will start from the statistical monitoring of the CSO which sets the final annual energy consumption for individual sectors, and which includes also the service sector at the national level. Dividing by the current number of the Czech Republic inhabitants we can set out the energy consumption of the tertiary sector per inhabitant. By subsequent multiplying of the number of inhabitants in the district catchment area of the town we can determine the annual energy consumption of the tertiary sector for the municipal territory which is of interest, regarding the quantity of provided services.

Table 1. Consumption of Tertiary buildings (data source: Czech Statistical Office)

Tertiary buildings													
Year	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Consumption [PJ]	105,8	108,4	120,4	115,8	120	132,3	127,6	116,9	122,7	115,2	113,5	132,7	115,2
Consumption [MWh]	29 391 240	30 113 520	33 447 120	32 169 240	33 336 000	36 752 940	35 447 280	32 474 820	34 086 060	32 002 560	31 530 300	36 864 060	32 002 560
Consumption per capita [MWh]	2,805	2,874	3,192	3,070	3,181	3,585	3,389	3,099	3,227	3,006	2,940	3,430	2,974

2.3. Residential buildings

Household energy consumption we will separate under the headings of total household energy consumption and energy for heating, which has to be further identified according to the source of heating (e. g. coal, gas…).

Household energy consumption is monitored by the Czech Statistical Office in great detail. By simple recalculation per unit household and multiplying by the number of municipality households we can arrive at the necessary data.

The on-line database Census of people, houses, and flats from 2001 or 2011 will provide us with energy consumption for heating in a classification according to source. From this we can generate for the investigated municipality a number for inhabited households with data on the type of heating. Presuming that heating makes up around 70 % of household energy consumption, by adjusting the total consumption from the previous paragraph we can set the energy volume for heating in a classification according to source.

Table 2. Energy Consumption of Residential buildings (data source: Czech Statistical Office)

Residential buildings													
Year	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Consumption [PJ]	245,4	234,9	261,7	248,2	262,6	259,5	253,5	273,8	247,2	244	260,9	285,9	259
Consumptioní [MWh]	68 172 120	65 255 220	72 700 260	68 949 960	72 950 280	72 089 100	70 422 300	76 061 640	68 672 160	67 783 200	72 478 020	79 423 020	71 950 200
Consumption per capita [MWh]	6,506	6,228	6,938	6,580	6,962	7,032	6,733	7,259	6,502	6,366	6,759	7,390	6,686

2.4. Municipality public lighting

For determining electrical energy of public lighting it is necessary to carry out a technical inventory of this provision. On the basis of invoicing from the energy contractor or on the basis of own readings of installed meters it is possible then to determine the real electrical energy consumption. The above mentioned SW can again serve well the registering of this data.

2.5. Industry

For the determination of energy consumption in an industrial sector on municipal territory it is possible to gather the necessary data from Register of Emissions and Air Pollution Sources (REZZO) administered by the Czech Hydro-meteorological Institute. According to the JRC, the inclusion of any industrial sector for purposes of processing an energy inventory is not obligatory because a town has little influence on industry. (European Commission, 2010)

2.6. Undertaking a CO_2 emissions balance

For undertaking a CO_2 emissions balance we start from calculated energy consumption values. The emissions balance has an identical structure, in which we have prepared energy consumption figures both by sectors and by classification of energy resources. We can then approach a recalculation into produced CO_2 emissions. This we can carry out on the basis of emission factors issued by the scientific panel IPCC (Intergovernmental Panel on Climate Change). We will multiply the calculated energy consumption in the classification according to the individual resources and sectors by emission factors mentioned below (see Table 3). We will thus discover the production volume of emissions for a given municipality per year.

Table 3. The emission factors for each fuel according to IPCC

Electricity	Fossil fuels								Renewable energies				
	Natural gas	Liquid gas	Heating Oil	Diesel	Gasoline	Lignite	Coal	Other fossil fuels	Biofuel	Plant oil	Other biomass	Solar thermal	Geothermal
0,950	0,202	0,231	0,279	0,267	0,249	0,364	0,354	0,341	0,000	0,000	0,000	0,000	0,000

3. Case studies

In this chapter there will be presented more elaborated studies and approaches on towns working to introduce energy management on their territory. As part of the cooperation of the CTU and the town of Hlinsko (10, 000 inhabitants) there was undertaken the study of BEEI and Sustainable Energy Action Plan. On the basis of the inventory of energy consumption, the town plans savings measures on its own buildings and on private ones. By implementing savings measures on its own property the town tries not only to achieve savings in energy consumption but also to reduce costs and especially by appropriate measures to influence the behaviour of inhabitants and motivate them to make savings on their own private property. In this chapter there will also be given the example of the capital city Prague (1 million inhabitants), which is currently preparing a new energy concept a part of which is a pilot project for reconstruction of schools, pensioner homes and administrative buildings putting them on a low energy standard using modern technologies.

By the implementation of savings measures both towns are trying to reduce energy consumption and thus to improve the living environment. With SW and the applied methodology developed at the CTU we can exactly determine levels of consumption in town property and private buildings.

Since each town suffers from other problems in dealing with the living environment and because they also have different financial and technological possibilities for the implementation of savings measures, there will be thus presented rather different approaches to implementation of savings measures in the town of Hlinsko and in the capital city Prague. Smaller towns such as Hlinsko do not have sufficient financial capacities or opportunities for implementing ambitious projects, and at the same time the impact on the actual inhabitants is smaller. Also, it is simply the case that only a capital city such as Prague can implement a project which is ambitious in terms of a European –wide perspective.

3.1. Inventory of the nature of energy demand in the town of Hlinsko

In this chapter we will specifically deal with the elaboration of an energy inventory for the town of Hlinsko, and the example of Prague we will attend to separately. The town Hlinsko voluntarily joined the initiative of the European Commission – Covenant of Mayors and undertook thus to reduce CO2 emissions by of minimum 20 %.

In cooperation with the CTU there was worked out for the town a Basic Inventory of the Nature of Energy Demand according to individual sectors. Highest attention was given to town property – to the buildings where it was possible to extract data derived directly from meters and invoiced by the energy supplier. The data were processed with the help of SW and due to this there was the possibility to evaluate the economic return on the planned measures. This was not, of course, the only viewpoint when deciding on the implementation of particular projects. Transposing the experience of inhabitants was also equally significant. Hlinsko has high priority requirements for the development of the tourist industry and tourism. In 2010 the traditional Shrovetide carnival was put on the World Heritage UNESCO list (UNESCO, 2010).

On the basis of the inventory of town energy consumption there were discovered the following consumption levels in the individual sectors. The total energy consumption reached in the given reference year the value of 171 thousand MWh and it represents almost 58 thousand tons of CO2.

Table 4. Total energy consumption for year 2009 (Rohlena, 2012)

Category	FINAL ENERGY CONSUMPTION [MWh]															
			Fossil fuels								Renewable energies					Total
	Electricity	Heat/cold	Natural gas	Liquid gas	Heating Oil	Diesel	Gasoline	Lignite	Coal	Other fossil fuels	Plant oil	Biofuel	Other biomass	Solar thermal	Geothermal	
BUILDINGS, EQUIPMENT/FACILITIES AND INDUSTRIES:																
Municipal buildings, equipment/facilities	1 557,1	930,0	4 615,2						208,9							7 311,2
Tertiary (non municipal) buildings, equipment/facilities		12 646,6														12 646,6
Residential buildings	30 032,5		107 423,5					11 519,9					955,0	477,5		150 408,5
Municipal public lighting	440,0															440,0
Industries (excluding industries involved in the EU Emission trading scheme - ETS)																0,0
Subtotal buildings, equipments/facilities and industries	32 029,6	13 576,6	112 038,7	0,0	0,0	0,0	0,0	11 519,9	208,9	0,0	0,0	0,0	955,0	477,5	0,0	170 806,3
TRANSPORT:																
Municipal fleet							116,1									116,1
Public transport																0,0
Private and commercial transport																0,0
Subtotal transport	0,0	0,0	0,0	0,0	0,0	0,0	116,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	116,1
Total	**32 029,6**	**13 576,6**	**112 038,7**	**0,0**	**0,0**	**0,0**	**116,1**	**11 519,9**	**208,9**	**0,0**	**0,0**	**0,0**	**955,0**	**477,5**	**0,0**	**170 922,5**

Due to this inventory the town of Hlinsko approached the implementation of savings measures and set up a goal of reaching a CO2 emissions reduction by 2020 to the level of 47 thousand tons. The town wants to reach this target not only by savings on its property but predominantly by involving inhabitants living in the town. The inhabitants regard this plan as theirs and they use all the available subsidy facilities aimed at reducing the nature of energy demand of buildings, very actively. This concerns above all the state subsidy programme The Green Saving Programme, from which the inhabitants have already drawn means amounting to EUR 3.9 mil. At the same time the operator of the heating plant company invested in a change of energy source when he started using cloven timber. Due to these significant measures the aim of reducing CO2 emissions will be surely accomplished.

The town itself approached introducing energy management on its own property. The town plans to invest more than EUR 3 million in weather proofing and using sustainable resources. The town weather proofs initially all the buildings which have the highest impact on energy consumption reduction and act most typically on the citizens. This concerns mainly schools and offices. The town presents its experience in the form of educational campaigns. The town selected the construction of a new multifunction building in passive standard as a typical construction.

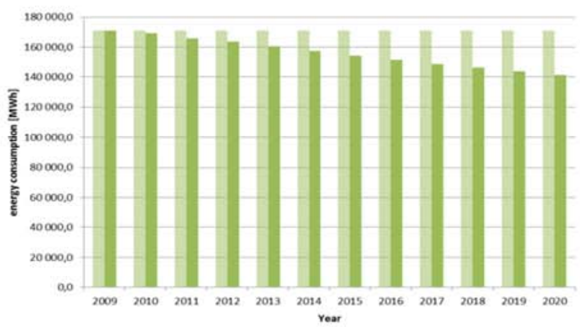

Figure 1. Planned reduction of energy consumption (Rohlena, 2012)

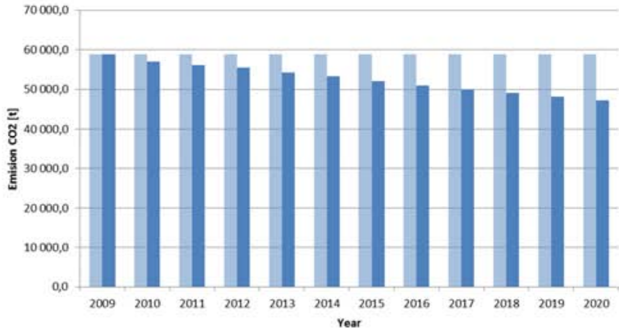

Figure 2. Planned reduction of CO_2 emissions (Rohlena, 2012)

Figure 1 and 2 shows the plan of a gradual reduction of energy consumption and CO2 emissions city of Hlinsko.

3.2. Intelligent buildings in the concept Smart Prague

The capital city Prague chose a very interesting approach to energy concept implementation. We present here an example of a pilot project which is a constituent part of the prepared energy concept. For the preparatory requirements of the Prague energy concept there was carried out a study of the reconstruction of selected buildings, where there can be achieved high energy savings while ensuring a quality living environment in the buildings. Schools, homes for seniors, and administrative buildings were selected for this ambitious project on the basis of a multi-criteria evaluation of impact on the nature of energy demand, the condition of buildings and any potential for gathering experience (Tencar, Zadina, 2013).

It is possible to approach the concept vision of SMART Prague and its associated SMART Infrastructure by the implementation of buildings revitalization through funding by the capital city Prague, and this is primarily justified by the high impact effectiveness of its measures, which can be replicated in the form of general principles. Revitalization includes not only building cover and technical systems treatment, or even minimising environmental impacts but also:

- management of consumption and use of water, soil, greenery functionally connected with the building,
- use of ecologically certified materials influencing, among other things, internal environment quality,
- improving users comfort and safety,
- positive stimulation of the internal environment,
- management of life cycle costs, above all operational costs and waste,
- solutions for, and management of links to, immediate surrounds (Chvalkovská, 2013).

20 buildings were selected for the pilot project. There was analysed current energy consumption and energy sources for these buildings. On the basis of requests from users and building caretakers there were proposed measures leading not only to reducing the nature of energy demand but also to improving the quality of the internal environment. Owner requests were for introducing intelligent buildings principles, i.e. on automatic heating management, hot water heating, lighting, and ventilation (Tencar, Rohlena, 2014).

High demands are put on the preparatory process itself as well as the actual implementation of projects. The project documentation according to the standards Building Information Modelling (BIM) will be carried out for all projects and all the buildings will be subsequently validated for the evaluation of the comprehensive quality of buildings by the national certification tool SBToolCZ.

If we summarize planned measures, there will thus be carried out such measures on the revitalized buildings as weather proofing of building cover, exchange of windows, exchange of heating source, installing forced ventilation with heat regeneration, exchange of light sources with automatic regulation, shielding, using sound healthy materials and above all integration of the Building Management System (BMS). This project will be implemented gradually in the years 2014 – 2020.

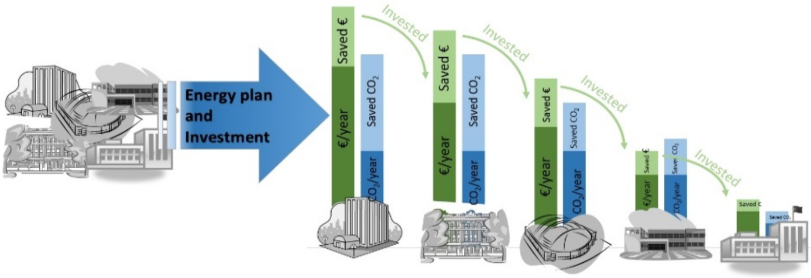

Figure 3. Diagram of energy management establishment (Rohlena, 2014)

Due to savings measures on the sample of buildings there will be achieved primary energy savings from the original 31,6 thousand MWh of 17 thousand MWh thus reducing this figure to 14,6 MWh annually i.e. a reduction by 54 %. Expressed in CO2 emissions, there will be achieved savings of 4, 600 tons annually (Figure 4).

This project can be considered as an ambitious one also because of presumed investment costs amounting to EUR 51 million.

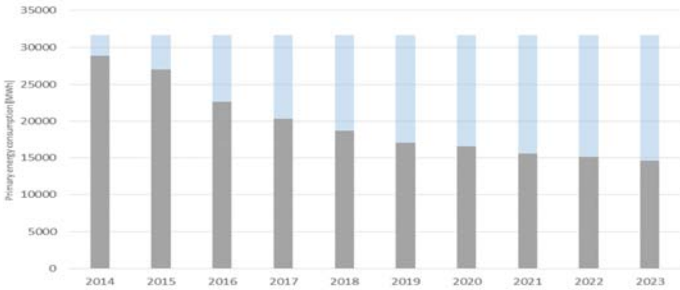

Figure 4. Diagram of the primary energy consumption reduction on the gradual implementation of the pilot project (Tencar, Rohlena, 2014)

The project will have to be implemented gradually because of its obviously demanding nature. According to the above shown diagram (Figure 3) by this gradual transformation of buildings there will be reached the highest of cumulative primary energy savings. This project will be implemented involving the cooperation of BIM specialists, including agents of buildings certification, university representatives and others. Comprehensive details of knowledge will be handed over to all persons interested.

This pilot project brings to bear an innovative viewpoint on using energy in buildings. Energy savings must not in reality act to negatively impact on the internal environment. By using modern technologies we can to the contrary arrive at significant energy savings while also improving comfort of use.

4. Conclusion

The article presented a methodology elaborated by the CTU in Prague, which serves the determination of energy consumption on the territory of towns and presented a SW tool which supplements this methodology. In this way there was analysed the nature of energy demands including the determination of energy carriers as a basis for planning savings measures for towns. The Directive of the European Union 2010/31/EU puts towns in obligation to elaborate an energy plan. This inventory of energy consumption is very challenging in its elaboration and the presented methodology identifies data resources and methods for determining the energy consumption of any town according to individual sectors.

On the basis of the thus elaborated energy inventory, the town can approach planning and implementing savings measures which lead to reduction of energy consumption, increases the renewable energy resources proportion, and decreases CO2 emissions. Every town has a separate energy mix and therefore has to approach any measures individually. Without this over-all conceptual solution it is not likely to be possible to reach the required savings in energy consumption but also there can even be an inordinate waste of financial means on not very effective measures.

The paper then puts forward particular findings from the BEEI undertaken for Hlinsko municipality. On the basis of the BEEI there was elaborated a complex Sustainable Energy Action Plan. In the context of its scale of capacity it cannot implement projects that are extremely financially demanding. Nevertheless, the energy savings given by the SEAP on the territory of the town studied is succeeding operationally.

The paper also presented the example of the pilot project Smart Prague in which the CTU participated. Given its size and significance Prague can afford to conduct much more ambitious projects. This pilot project calculates a gradual transformation of 20 buildings in the city property holdings to become very economically intelligent buildings. With the integration of these intelligent buildings elements there will be reached the lowest possible energy consumption and an ensured quality to the internal environment of such buildings.

Acknowledgement

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Creative Construction Conference 2014

Disaster management based on information monitoring technology

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Abstract

Disaster management became an important task for every country. Data from United Nations for Disaster Risk Reduction, between 2000 and 2012, reported that disaster costs about US$1.7 trillion in economic losses, 2.9 billion people affected, and 1.2 million killed. Experts believe that natural disasters, particularly floods and storms, will become more frequent and severe because of climate change.
Information and communications technologies (ICT) can play an important role in helping disaster managers quickly access, contextualize, and apply near real-time information, thus, improving the speed and effectiveness of critical actions like warning populations at risk. Information monitoring systems (IMS) is an ICT technique related to a class of hierarchical fuzzy discrete dynamic systems. IMS can handle uniformly diverse, multi-level, fragmentary, unreliable, and varying in time information about some process. Based on this type of information, IMS allows ones to perform monitoring of the process' evolution and work out strategic plans of process development.
In this paper, we will describe main ideas of disaster management based on information monitoring technology along with main features of disaster management systems and characterization of available information. We will also provide description of information monitoring technology which allow us handle with uncertain, fragmentary, varying in time information. In conclusion we collect pro and contra arguments for applicability of the technology for disaster management.

Keywords: disaster management, information monitoring system.

1. Introduction

Disaster management became an important task for every country. Data from United Nations for Disaster Risk Reduction (UNISDR), between 2000 and 2012, reported about US$1.7 trillion in economic losses, 2.9 billion people affected, and 1.2 million killed.(UNSDR, 2013) In 2013, overall economic losses from catastrophic events reached $130 billion and the total loss of life climbed to around 25,000 from 14,000 last year.(Swiss Re, 2013) Experts believe that natural disasters, particularly floods and storms, will become more frequent and severe because of climate change.(Leaning and Guha-Sapir, 2013)

In 2011, Thailand witnessed its worst flooding in half a century, leaving severe impairments to the country's economy, industrial sector, and society. The World Bank has estimated 1,425 billion baht (US$ 45.7 Bn) in economic damages and losses due to flooding.(Word Bank, 2011) Most of this was to the manufacturing industry, as seven major industrial estates were inundated by as much 3 meters (10 feet) during the floods. Disruptions to manufacturing supply chains affected regional automobile production and caused a global shortage of hard disk drives which lasted throughout 2012.

Trying to cope with this problem in the future, many countries have upgraded its infrastructure in handling with disaster. As for the case, Thai government proposed the budget of 350 billion baht (US$ 11,000) billion to upgrade water management infrastructure as a result of severe flood in 2011. Thai government's also spent millions of dollar built an information system that integrates real-time information from various sources in gathering and collecting all available information concerning to disasters to support decision making process when disaster takes place.

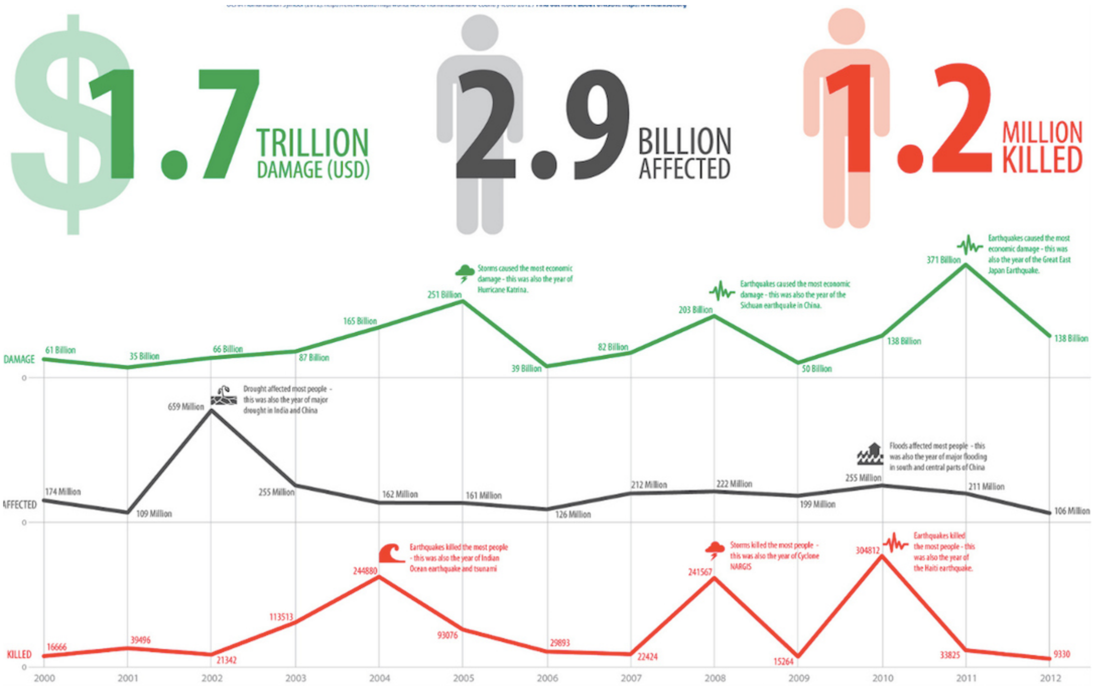

Figure 1. Economic and Human Impact of Disasters in the last 12 year [UNISDR]

In order to build an information system that integrates real-time information to predict and to support the decision making process of decision makers is still a challenging problem. In 1995, Clement identified four factors which determine the difficulty degree of the decision-making process (Clemen, 1995, Cioca 2010). The first, and altogether the most important factor is *the complexity of the problem*. The human factor has a limited capacity of perceiving and solving complex problems and, therefore, builds simplified mental models of real situations. Even if these models are applied in the best way possible, any simplification may lead to defective decisions. The second factor is given by the *uncertainty degree of the problem*, and the third is the fact that, in most cases, *several different objectives* are set. A certain decision may be right in the short run, but may prove wrong in the long run and vice versa. The last factor presented by Clement and which we should also consider refers to the *different conclusions that may be derived from different perspectives*, especially when several people are involved in the decision-making process.

In order to alleviate some of those challenges aforementioned, one possible way is to provide decision makers with information available in an appropriate format and with the right tools for them in making decision. Information Monitoring Technology can give decision makers an overview of the situation, provide information processing based on fragmentary and uncertain information; impact of possible action on the status of the situation and possibly can reveal those elements of the problem that may qualitatively change the status of the process as a whole.

In this article, we will first discuss an overview of information management technology, its basic elements and characteristic, and its principles. Then, the prototype system developed for the Thailand's Department of Highway (DOH) for monitoring risk of a bridge from the effect of flood will be discussed. Summary and conclusion will be drawn in the final section.

2. Information monitoring technology

Information monitoring systems (IMS) relate to a class of hierarchical fuzzy discrete dynamic systems. The theoretical base of such class of systems is made by the fuzzy sets theory, discrete mathematics, methods of the analysis of hierarchies which was developed independently in works of (Zadeh 1965 Messarovich, 1970) and others. IMS address to process uniformly diverse, multi-level, fragmentary, unreliable, and varying in time information about some process. Based on this type of information, IMS allow perform monitoring of the process' evolution and work out strategic plans of process development. These capabilities open a broad area of applications in business (marketing, management, strategic planning), socio-political problems (elections, control of bilateral and multilateral agreements, terrorism), etc. One of such applications is a system for monitoring and evaluation of Thailand's DOH's bridge vulnerability assessment system – which is shortly described in this article.

2.1. Basic Elements of IMS and Characteristics

We shall name a task of evaluation of a current state of the process and elaboration of the forecasts of its development as an information monitoring problem and human-computer systems ensuring support of a similar sort of information problems - information monitoring systems.

Basic elements of monitoring system at the top level are the information space, in which information about the state of the process circulates, and expert (experts), working with this information and making conclusions about the state of the process and forecasts of its development.

The information space represents a set of various information elements, which can be characterized as follows:

- d*iversity of the information carriers,* i.e. newspapers, social media, audio- and video- information etc.;
- *fragmentariness.* The information more often concerns to any fragment of the problem, and it may be incomplete or isolated*;*
- *multi-levels of the information.* The information may concern the whole problem, some of its parts, or a particular element of the process*;*
- v*arious degree of reliability.* The information may contain the particular data which has a various degree of reliability, resulting from conclusions on the basis of the reliable information or indirect conclusions;
- p*ossible discrepancy.* The information from various sources can coincide, differ ,or contradict one another;
- *varying in time*. The problem develops in time, therefore the information at different time of the same element of the problem may be differ;
- *possible bias.* The information reflects certain interests of the source of the information; therefore it can have tendentious character.

The experts are an active element of the monitoring system and, observing and studying elements of the information space, they make conclusions about the state of the problem and prospects of its development taking into account listed above properties of the information space.

2.2. Basic Information Monitoring System Functionalities

Information monitoring systems allow:

- processing uniformly diverse, multi-level, fragmentary, unreliable, information varying in time;
- receiving evaluations of status of the whole process and/or its particular aspects;
- simulating various situations in the subject area;
- revealing "critical point" of the development of the process. It means to reveal those elements of the problem, the small change of which status may qualitatively change the status of the process as a whole.

Taking into account the given features of the information and specific methods of its processing, it is possible to declare the main features of the information monitoring technology as follows: (Ryjov et al. 1998)

- The system provides the facility for taking into account data conveyed by different information vehicles (journals, video clips, newspapers, documents in electronic form etc.). Such a facility is provided by means of storage in a database of a system of references to an evaluated piece of information, if such information is not in electronic form. If the information is a document in electronic form, then both the evaluated information (or part thereof) and a reference thereto are stored in the system. Thus, the system makes it possible to take all pieces of information which have a relationship to the subject area into account and use for an analysis irrespective of the vehicles concerned.
- The system should be able to process fragmentary information. For this purpose a considerable part of the model is represented in the form of a tree. Representing the model in this form could be over simplified for a complex process. However, in this way good presentation and simplicity of operation with the model is attained.
- Information with different degrees of reliability, some of it possibly tendentious, can be processed in the system. This can be achieved by reflecting the influence of a particular piece of information on the status of the elements of the model of the problem with the aid of fuzzy linguistic values.
- The information with a various degree of reliability, probably, biased shall be able to be processed in the system. For this purpose, the description of the influence of the information received on a status of the model

of a problem was done with use of fuzzy linguistic variable. It is necessary to take into account, that the evaluation of the element of model may both vary under influence of the information received and those that remain unchanged.

- Time shall be one of the parameters of the system. This makes it possible to have a complete picture of the variation of the status of the model with time.

Thus, the systems constructed on the basis of this technology allow having the model of the problem developing in time. It is supported by the references to all information materials, chosen by the analysts, with general and separate evaluations of the status of the process. Use of the time as one of parameters of the system allows us to conduct the retrospective analysis and to build the forecasting model of the process. There is also an opportunity of locating "critical point", i.e. an element(s) of the model in which a small change causing by this element can cause significant changes to the whole process. The knowledge of such elements has large practical significance that allows us to reveal "critical points" of the process and to work out the measures on preventing undesirable situations.

3. Case Study: Risk-based evaluation Bridge under Flooding

In this section, we focus on a problem of disaster management during flooding. We applied information monitoring systems based on information management technology described in this article and we discuss our experiences from working on the project sponsored by Thailand Department of Highway. During the project, we divide our effort into here stages: model development; development of a prototype of the system and its operational testing; and development of the final system.

During the model development, we model a problem of risk identification, we explore numbers of the model that calculate a risk of a bridge during flooding but most of them requires an extensive numbers of parameters that couldn't be easily obtained during the crisis. Thus, we ended up employing the bridge risk assessment tool from New York State Department of Transportation (NYSDOT 2013). This assessment tool is a condition rating by the bridge inspectors based on the assessment of hydrological conditions, substructures and foundations of both piers in the middle of the river and on the river bank of important route in the transportation networks, traffic densities, and tendency of the bridge to collapse. We then combine risk calculated by NYDOT model with the risk that resulting from the water level and precipitation level from different gauging stations within the region. Thus, risk will be constantly updated from the input that the system gets from gauging stations in the area considered.

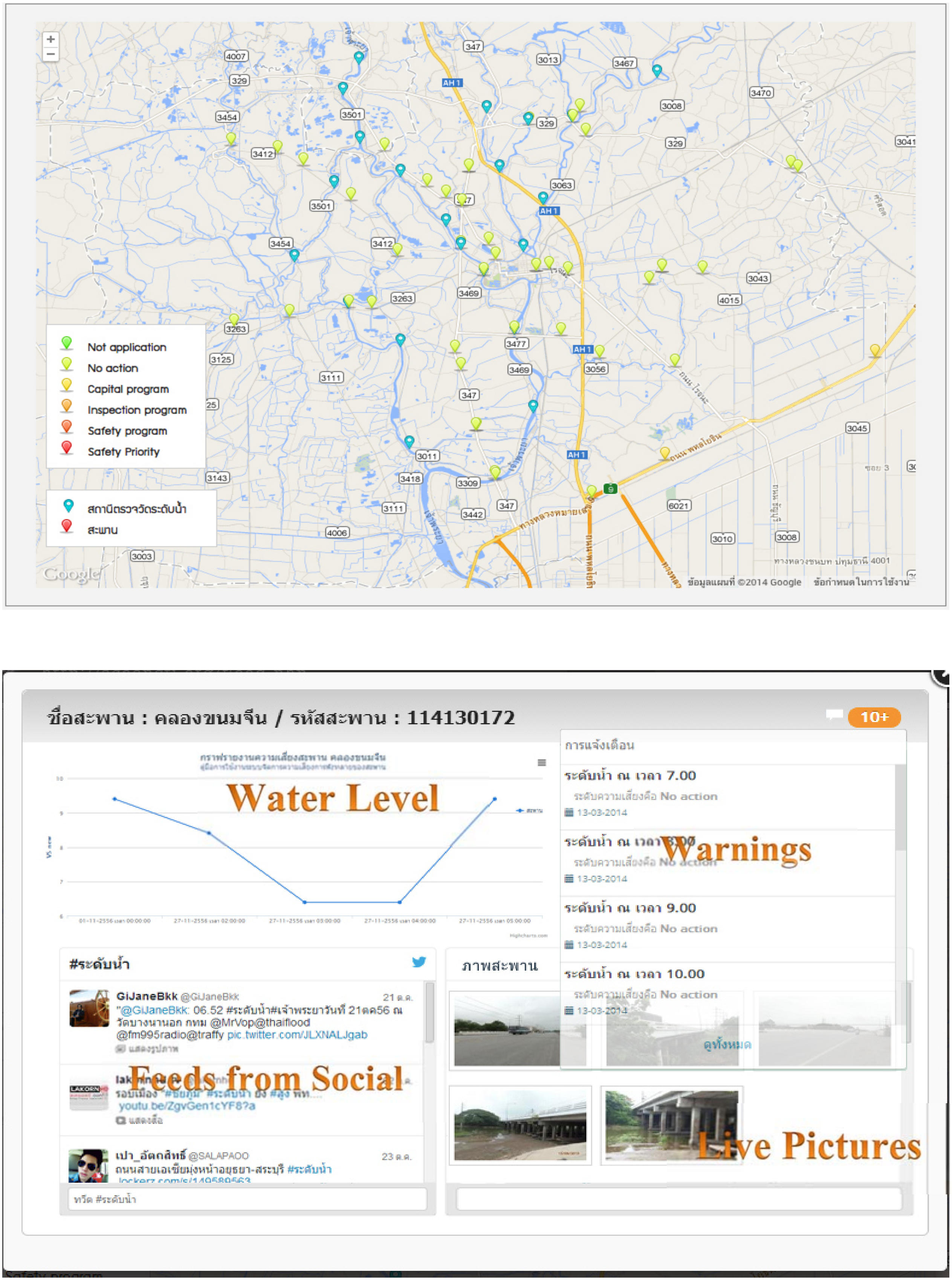

Figure 2. Screens illustrating an information about a particular bridge from multiple sources

Once the model was developed and approved by DOH, a risk mapping system due to the flood in the area was developed by using the abovementioned criteria. It is a web-based application integrated with GIS technology to display reports on Google maps. This system consists of various modules linked together to process and display risk assessment results calculated from real-time water level data from the Hydrology and Water Management Center for Central Region (www.hydro-5.com), geographical condition, and other available data about a particular bridge. Once the risk of a particular bridge is determined, the system informs users whether the closure of that particular bridge will cripple the traffic in the area. Decision makers also receives news alert, twitter messages, live photos and video from the area where the instruments to captures those data were in place. Figure 2 illustrates a screen of the prototype system.

4. Summary and Conclusion

Disaster management systems are a special class of decision making systems which handle uncertain information in hard time limits. Information monitoring systems works with diverse, multi-level, fragmentary, unreliable, and varying in time information about some process and allows performing monitoring of the process evolution and working out strategic plans of the process development. The most difficult point in development process is the elaboration of structure of the process model.

Our first experiments shown that map-based information monitoring system can be a good tool for this task especially if we have a lot of data to present to the decision makers. However, in order to obtain the utmost benefits from this kind of tools, works need to be done on how information can be organized, processed, and provide visualization to decision makers in a more meaningful and intuitive way. We believe that with today's technology e.g. cloud, social media and big data. We can further enhance the information monitoring technology for disaster management problems thus allow us guarantee optimum work of IMS.

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Sustainable building development in China – A system thinking study

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Abstract

The demand for sustainable building is increasing rapidly throughout the global construction marketplace. However, the real success of sustainable building development depends on the concerted effort of different stakeholders. Without knowing the drivers and barriers, it is difficult to introduce pragmatic policies and strategies to promote such development. While sustainable building development in China is still at an infancy stage, its experience should help other developing countries to develop a road map for developing sustainable buildings. In this paper, twelve semi-structured interviews with senior managers of listed real estate developers in China were conducted. The results indicated that government regulation, incentives and CEO's vision are the key drivers of sustainable building development. The most significant barriers identified by the interviewees are the additional costs due to sustainable initiatives, lack of customers demand and lack of mature green supply chain. To better understand the system structures causing these management problems, a causal loop diagram was developed to identify the relationships and the causal influences between the elements of the sustainable building development sector. Finally, a suite of effective sustainable strategies is proposed based on the findings.

Keywords: Sustainable building; system thinking; causal loop diagram; drivers; barriers

1. Introduction

Sustainable buildings are regarded as one of the most effective solutions to address various global issues such as climate change, human health, social impact, renewable energy, etc. In China, the strain on energy and natural resource along with environmental degradation during recent years alerts Chinese government and business enterprises to promote a sustainable building practice which seeks to strike a balance between economic, social and environmental performance (Diamond, Ye, Feng, Yan, Mao, et al., 2013; Zhang, Shen, & Wu, 2011). The Chinese government first released the Three-Star Green Building Evaluation Standard in 2006. Then in 2012, the Ministry of Finance and the Ministry of Housing Urban and Rural Development published "The Implementation Opinion Regarding Accelerating Promotion of National Green Building Development" which sets an aggressive target to have 30% of all new construction meeting the green building standard by 2020. In view of such an ambitious goal, it is imperative to have the real estate developers actively participated in the sustainability practices to lead the best practice. However, most developers especially those listed companies would put their profit and shareholders' interest at the first place. Therefore, what key barriers they are confronting and how to motivate them to develop more sustainable buildings become the key questions for this paper.

2. Literature Review

2.1. *Drivers and Barriers*

Various studies have addressed barriers and drivers during the process of delivering sustainable buildings. Häkkinen and Belloni (2011) concluded that the major barriers for promoting sustainable buildings in Finland were the steering mechanisms, economics, a lack of client understanding, process, and underpinning knowledge. On the other hand, the major drivers were clients' awareness about the benefits of sustainable building, development and adoption of methods for sustainable building requirement management, sustainable building tools mobilisation, designers' competence and team working, and development of new concepts and services. Bond (2011) investigated the barriers and drivers of sustainable building in Australia and New Zealand and suggested that the initial costs of sustainable features, a lack of consumer information, and people's reluctance to change are the main barriers for improving building energy efficiency. Instead, an appropriate mixture of government regulation, greater use of energy saving technologies and behavioural change are the major drivers to reduce CO_2 emissions. Zhang, Platten, & Shen (2011) examined the costs and barriers in the process of developing Chinese sustainable property projects. They recognised that 'active' design strategies are more expensive than the passive design strategy, and the major barrier is the higher costs and this has hindered the widely application of sustainable technologies in the construction industry in China. Another research in China by Shi, Zuo, Huang, Huang & Pullen (2013) identified that additional cost, incremental time and limited availability of green suppliers and information are critical barriers to foster a sustainable construction practice. These factors are similar to previous researches in Hong Kong by Gou, Lau & Prasad (2013) and in China by Zhang, Shen, & Wu (2011). Ahn, Pearce, Wang, Y., & Wang, G. (2013) also investigated the main drivers and barriers of sustainable design and construction in the US construction industry. Energy conservation, improving indoor environmental quality, environmental/resource conservation, and waste reduction were the most important drivers while the most noteworthy barriers were first cost premium of the project, long pay back periods from sustainable practices, tendency to maintain current practices, and limited knowledge and skills of subcontractors.

Although these researches identified the barriers and drivers encountered during the sustainable building development, most of them failed to capture the underline relationships of these factors as well as the causes and effects among them in a systematic way. Thus, this paper seeks to apply a causal loop diagram to capture the system structure and highlight the causal relationships between the factors which may impact sustainable building development and performance from a systematic perspective.

2.2. *System Thinking and Casual loop*

Richmond (1993) defines systems thinking as: "the art and science of linking structure to performance, and performance to structure-often for purposes of changing structure (relationships) so as to improve performance." System thinking can be applied in numerous scientific fields including planning and evaluation, education, business and management, public health, sociology and psychology sustainability, and so on (Cabrera, Colosi & Lobdell, 2008). System dynamics is one of the important approaches of system thinking and is best suited to assist businesses and government organisations in developing strategies; analysing dynamic processes and selecting policies by capturing the information flow and feedback (Khaji, Shafaei, Mohebbi & Aghaie, 2009). Causal loop diagram can be applied to describe a complex system in terms of its cause-and-effect relationships, to restrain the complexity by seeing things as a whole, and to highlight the connectivity of various component parts (Sherwood, 2002). It can be used to build system dynamics simulation model to show the impacts of inputs on outputs and vice versa (Sterman, 2000).

3. Research Method

According to the Annual Report on Climate Change Actions (Wang & Zheng, 2013), real estate developers especially those listed and well-known developers became the pioneer in the development of sustainable buildings in China. Since the local listed real estate developers have larger market share and more social and market influences than those small ones. Therefore, a total 20 invitation letters were sent by email to invite them to participate in an interview. After the telephone follow up, eight developers consist of both state-owned and private-owned ones responded and accepted the invitation. A total of twelve semi-structured interviews were carried out during October 2013 to December 2013. Among them, ten interviewees were from the eight developers who had diverse backgrounds ranging from top managers who are responsible for setting the sustainability strategies for their business, to design consultants, procurement managers who are carrying out the day-to-day works. The other two interviewees were from the China Academy of Building Research – Shanghai Institute which is the branch of the largest research institution in the Chinese construction industry and have devoted much effort to drive sustainable building innovation and research during recent years.

4. Interview Results Summary

The interviewees were invited to express their opinions related to the key drivers, and barriers of sustainable building development and they were also encouraged to talk about any other experience and perception on sustainable building development. Each interview lasted for around an hour.

4.1. *Key drivers for sustainable building development*

The interviewees were asked to identify the key drivers for sustainable building development. As show in Table 1, the top three key drivers identified by the interviewees are government regulation, government incentives and CEO's vision.

Although some developers opined that a good reputation in sustainability, lower operation cost and higher rental value are their motivation, ten interviewees admitted that it is the series of government regulations at all levels in recent years that have effectively stimulated their sustainable building development plan. For example, several interviewees mentioned that the Shenzhen Government stipulated that all new residential projects should meet or surpass the one star green building standard in China from 20 August 2013, and the carbon emissions of all sustainable buildings should be calculated and evaluated. Furthermore, the city government as also grants subsidies, expedited permit, waiver of application fee, etc., to sustainable buildings and these has resulted in a higher application of sustainable technologies and energy performance contracting. Most interviewees agreed that the regulations and incentives of the government would influence CEO's vision by and large and this would in turn change the company's sustainable strategy.

Table 1. Drivers for sustainable building development.

Drivers	Frequency
Current government regulation	10
Government incentives	9
CEO vision	8
Anticipated sustainable marketing expansion and government regulation	7
Social Responsibility	7
Company's sustainable development strategy	6
To lead the best practice	5
Increasing profits	3
Market Reputation	3
Customer demand	2

4.2. *Key barriers for sustainable building development*

The key barriers as identified by developers are additional cost due to the sustainable initiatives, lack of customers demand and lack of mature sustainable supply chain as showed in Table 2. 11 of 12 interviewees believed that sustainable buildings would cost more than conventional buildings, but yet the profits brought by sustainable buildings are still unclear. This is partly because sustainable building is just at an infancy stage in China. Many sustainable buildings are still yet to recover their initial costs partly because the high material and equipment prices originated from the immature sustainable supply chain, and also due to the fact that developers have little benefits accrued from the saving in operation costs. According to majority of the interviewees, most local customers choose a building to buy or rent according to its location, house type, floor area, price, reputation of developer instead of sustainability, which shows they still lack the demand and understanding of sustainable buildings. Besides, a number of developers indicated that they did not practice sustainable supply chain management in their projects. Although they have been trying to establish long-term strategic relationships with green suppliers, there are not sufficient qualified green suppliers in the market. Sometimes there may only have a single supplier available for a specific green product and the delivery of such product could take time. Only two developers interviewed had developed their own green supplier database in order to keep track on their performance.

Table 2. Barriers for sustainable building development.

Barriers	Frequency
Additional cost due to sustainable initiatives	11
Lack of customer understanding and demand	9
Lack of mature sustainable supply chain	9
Low level of facility management and operational management	8
Insufficient Regulatory demand and incentives	6
Difficult to meet profit goal	6
Lack of integrated process management for the life cycle of sustainable building	6
Sustainable design elements may be wasteful and cannot be fully implemented during operation stage	5
Costly and time-consuming to apply for the green building certification	4
Incomplete and insufficient sustainable building standards and green material label	4
Immature new sustainable products and technologies	3

4.3. *Casual loop diagram analysis and discussion*

By referring to the interview findings, a causal loop diagram was developed (Fig. 1). The causal loop diagram demonstrates the influences of key barriers and drivers for sustainable building development from the developer's perspective and the inter-relationships between these factors can also be identified through the diagram. In a causal loop diagram, loops consist of links where the cause is the tail of the linking arrow and the effect at the head. A positive link (arrow with "+" or "s") represents that there is an increase in the cause giving rise to an increase in the effect while a negative link (arrow with "-"or "o") represents there is an increase in the cause leading to a decrease in the effect (Sherwood, 2002).

As shown in Fig. 1, "government regulation" and "government incentive" affect "CEO vision" which in turn influences "sustainable strategy". "Customer understanding and demand" and "profit" as well as "sustainable strategy" lead to "willingness for developing sustainable building and related products" which determines "sustainable building market size". The links between these variables are all positively linked (arrow with "+") representing that the stronger these variables are the more willing the developers are in developing sustainable buildings and hence a bigger sustainable building market size. Government regulation has always been found to be the most important determinant of sustainable practices (Akadiri & Fadiya, 2013; Pitt, Tucker, Riley & Longden, 2009). Walton, Handfield & Melnyk (1998) argued that the tightening of government regulations for environmental practice could influence executive's perception and strategic planning, which echoed with the perception of the interviewees. Furthermore, government incentives such as density bonuses, tax incentives, zoning requirements for private buildings (Retzlaff, 2009) can stimulate sustainable innovation and lead to cost-effective sustainable technologies (Pitt, Tucker, Riley & Longden, 2009). Therefore, it is recommended that the Chinese government should devote greater effort to regulate and to provide more incentive to stimulate the sustainable building market and to influence the vision of developers and their sustainable strategies. Meanwhile, it is also very important for government, news media, and developers to promulgate sustainable building concept and to increase customer understanding and demand for sustainable practices promotion (Pitt, Tucker, Riley & Longden, 2009).

The "willingness for developing sustainable building and related products" would not only lead to an increase in "sustainable building market size", it could also increase developers' "investment on sustainable building and related sustainable products". This together with the "government incentive" can stimulate "sustainable technology and innovation". Eventually, this would help improve the "maturity of sustainable supply chain" and the "capability of life cycle process management" in China. As mentioned before, lack of mature sustainable supply chain is a key barrier for sustainable building development, in order to implement a sustainable supply chain, more investment and incentive on sustainable technology and innovation should be considered. Moreover, some interviewees mentioned the lack of integrated process management from the life cycle perspective of sustainable building plan, design, construction, and operation hampered to achieve high performance sustainable buildings, the capability of life cycle process management should be fostered by more mature sustainable technology and qualified managers.

"Government regulation" and "sustainable building technology and innovation" can help to enhance the "maturity of sustainable building standards and label". Although Chinese government at all levels declared central governmental and a diversity of local sustainable buildings standards, these standards all use qualitative analysis method which are considered by the interviewees as incomplete and insufficient, and the sustainable material label systems are not complete as well. It is recommended that by adding more quantitative measurements, integrating assessment during the building life cycle, the "maturity of sustainable supply chain" can be increased (HM Government, 2008). Moreover, the sustainable building standards and labelling scheme should take into account economic and social concerns along with the environmental aspects so as to practice the true spirit of sustainability (Haapio & Viitaniemi, 2008; Prum, 2010).

The greater the "maturity of sustainable supply chain" and "capability of life cycle process management", the lower the cost and the better the "performance of sustainable building" will be leading to a lower sale or rent "price", a higher "marketing reputation", "customer understanding and demand", and capability of "leading the best practice". All these would result in a higher "profit". In China, among over five hundred projects which achieved the green building certification in 2013, only 50 projects got the green operational certificates. Some interviewees mentioned the facility managers and end users failed to fully realize the sustainable design elements, and some designers only designed for green design certificate since they had only limited control of the construction processes and almost no control of building operations. In order to boost the efficiency and effectiveness of the sustainable practices, developers should focus on the efficiency of process management, collaboration and information sharing between project stakeholders during the whole life cycle of a building project rather than merely aiming to pursue a green certificate for a building (Ofori, 2009).

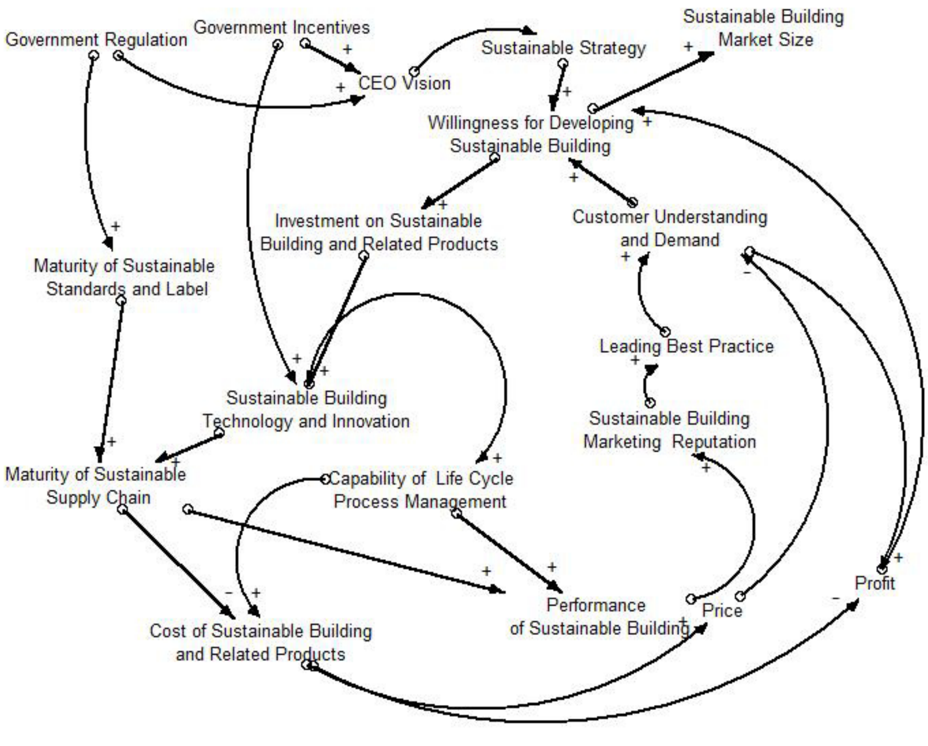

Figure 1. Influences for Sustainable Building Development

5. Conclusion

The demand for sustainable building is increasing rapidly throughout the global construction marketplace, and China is no exception. Based on the findings of twelve semi-structure interviews, the key drivers of sustainable building development *viz.* government regulation, incentives and CEO's vision are identified. The top barriers as identified by developers include the additional cost brought by sustainable initiatives, lack of customers demand and lack of mature green supply chain. By the use of causal loop diagram, it is possible to capture the key variables and provide a dynamic and holistic view to better understand the causal effect of these key variables so as to develop a set of suitable strategies for sustainable building development. The results of this research point to a greater effort from the government in China to regulate and provide incentive to promote sustainable technologies, innovation and sustainable building market expansion. On the other hand, developers should expand their emphasis from design process to the entire project life cycle in order to enhance the maturity and performance of the sustainable building supply chain and cultivate a more collaborative and information sharing culture between project stakeholders.

In the next stage of research, a system dynamics model based on findings of this research as well as the next round of interviews and case studies will be conducted to simulate the real world practice and to analyse the sustainable building development problems under different scenarios in a dynamic manner. The results of subsequent research stages will be discussed once they become available.

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Damage in critical infrastructures due to natural and man-made extreme events – A critical review

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Abstract

Critical Infrastructures (CIs) play a crucial role in the normal performance of economy and society. Over the last decades the amount and the variety of CIs grew rapidly, and the interdependency between them increased constantly. Consequently more and more essential services depend on the continuous performance of one, two or even more CIs such as power supply, communications, etc. It is thus of utmost importance to ensure reliable and robust performance of critical infrastructures on a continuous basis, particularly during and after the occurrence of extreme events. This paper presents a state-of-the-art review of the contemporary state of critical infrastructures' preparedness, through a comprehensive literature review of significant extreme events that occurred in the past two decades. This paper examine the Oklahoma bombing (1995), the Izmit earthquake (1999), the World Trade Center attack (2001), the Indian Ocean tsunami (2004), hurricane Katrina (2005), the London July 7th attacks (2005), the Haiti earthquake (2010), and the Fukushima-Daiichi Nuclear disaster (2011). The review exposes insufficient preparedness of CIs in cases of extreme events and raises several root patterns which led to the severe consequences of the extreme events: a gap between the preparedness of the CIs to the actual risk; higher than expected consequences due to evolution of critical infrastructures; high and increasing interdependencies between the CIs, and high vulnerability of critical infrastructures despite the known risk. The consequences of those events reveal a mismatch between the actual risk to the CIs and between the investments that were made by decision makers for their preparedness.

Keywords: Critical Infrastructures; Extreme Events; Preparedness; Risk

1. Introduction

Critical Infrastructures (CIs) consist of systems or assets that, if disrupted or destroyed, have a serious impact on the health, safety, security and wellbeing of society, or the effective performance of governments (Clinton, 1998). Subsequently, CIs such as water supply systems, telecommunications systems, electrical power systems, gas and oil transmission and distribution infrastructures have become a crucial component of civilized life. Thus the continuous performance of CIs is vital for the day-to-day operation of economy and society (Moteff & Parfomak, 2004).

Disruptions in critical infrastructure systems occurs as a result of several causes such as operating failures, poor design and mechanical failures, physical destruction due to natural and man-made extreme events. This manuscript focuses on disruption and destruction of CIs as a result of natural and man-made extreme events. Natural and man-made (sabotage and terror) extreme events are characterized by an uncertainty in the occurrence time and the magnitude of the event. Natural extreme events include extreme climate events such as Hurricanes, Floods, Tornados and Droughts, and seismic extreme events such as earthquakes and tsunamis. Man-made extreme events include intentional sabotage by explosions, steep path racket shooting, plane crash, and cyber terror.

2. Objectives

It is intended herein to develop and implement a quantitative method to assess risk that CIs' are exposed to in the occurrence of extreme event (natural and man-made). Different scenarios of natural extreme events (i.e. earthquakes, tsunamis, and hurricanes), terror activities (i.e. explosions, and plane crash) and their consequences are analyzed and the preparedness of CIs to extreme events are examined as a composite of three basic alternative strategies; (1) Redundancy, (2) Robustness, and (3) Resilience (Elkabets & Shohet ,2013). Eventually, alternative courses of actions are suggested to implement those strategies to effectively improve the preparedness and reduce the risk that CIs are exposed to in the case of an extreme event.

3. Review of extreme events

In order to comprehend the preparedness level of Critical Infrastructures, eight extreme events were reviewed through an examination of the contemporary preparedness of CIs to extreme events and identification of root patterns which may led to the severe consequences of the extreme events. Table 1 summarizes the eight extreme events reviewed in this study. Their return period and their annual loss are shown at the eighth and ninth columns, expressing the risk that CIs were exposed to.

Table 1. Extreme events summary

Extreme event	*Year*	*Type*	*Affected areas*	*Estimated damage and loss (10^6 $US)*	*Death and missing*	*Injured*	*Return Period of similar events (years)*	*Average annual Loss (10^6 US$)*
Oklahoma City Bombing	1995	Man-made	Oklahoma City, Oklahoma, USA	650	167	684	-	-
Izmit Earthquake	1999	Natural	Izmit, Turkey	6,000	17,000	50,000	<10	600
World Trade Center	2001	Man-made	New York City, NY,USA	22,000	2,764	9,349	-	-
Indian Ocean Tsunami	2004	Natural	Several Countries among Indian ocean	11,000	228,000	500,000	<25	440
Hurricane Katrina	2005	Natural	5 Countries (mostly Florida, Louisiana and Mississippi),USA	130,000	1,833	Hundreds	<15	8,600
London July 7th Bombings	2005	Man-made	London, England	2,500	56	700	-	-
Haiti earthquake	2010	Natural	Port-au-Prince, Haiti	7,800	316,000	300,000	>100	<780
Fukushima Daiichi	2011	Natural	Fukushima Daiichi, Japan	309,000	20,350	5,314	<60	5,000

The Oklahoma City terrorist bomb attack included a truck bomb equivalent to 1,800-2,300kg of TNT that exploded close to the Alfred P. Murrah Federal Building in Oklahoma downtown and claimed more than 800 victims In addition to this, the blast damaged buildings and cars within a sixteen-block radius. Vast majority of the fatalities were as a result of the collapse of the Murrah building while glass-related injuries were the most frequently reported cause of injury (Corley, Sozen, Thornton, & Mlakar, 1996; Gene Corley, Mlakar Sr., Sozen, & Thornton, 1998; Shariat, Mallonee, & Stidham, 1998). The Murrah building was built according to building codes at the time (mid-70's), which did not require design with resistance to horizontal loads; the building had no robustness to blast and no redundant load paths (Osteraas, 2006). Critical elements of the building were very easily accessible and exposed to such kind of attack and robustness of the surround buildings' glass could reduce significantly the amount and the severity of injuries.

The Izmit earthquake struck Turkey's most heavily populated and industrialized area while most of the people were asleep in their beds. Over 300,000 people suffered directly as a result of the earthquake, over 250,000 building were damaged (Marza, 2004; USGS, 2012), and CIs were severely damaged; the electricity power failed for several days within minutes after the earthquake, main highway bridges collapsed, and the water distribution system was interrupted. Since 1939, including the Izmit earthquake, eleven earthquakes with magnitudes equal or greater than 6.7 have taken place along the North Anatolian fault (Barka, 1999; Hubert-Ferrari et al., 2000), and several forecasts predicted high probability of occurrences of strong earthquake in the area (Pinar, Honkura, & Kuge, 2001; Stein, Barka, & Dieterich, 1997). The high probabilities of strong earthquake in the area combined with high density population, poor construction, and devastating consequences as a result of such event produce an extremely high risk. The earthquake's results revealed unsafe engineering and poor construction despite the high vulnerability.

Over 10,000 people suffered directly from the suicide terrorist attacks at the World Trade Center and on Flights UA175 and AA11. As well, hundreds of thousands of people were exposed or potentially exposed to dust, particulates, and other environmental contaminants on that day, and endured or witnessed deeply traumatic events. Buildings were damaged within a radius of several kilometers (Grossi, 2009; RISK MANAGEMENT

SOLUTIONS, 2001) and many buildings in the area suffered from fire, pressure wave, massive projectile debris, airborne debris and layers of thick dust that required a clean-up and caused mechanical damages. The area was densely inhabited by many critical infrastructures such as underground train lines, main bus stations, electrical power system, banking and financial services. The concentrations of many critical infrastructures and the high interdependencies (McAllister & Gene Corley, 2002; Mendonça, Lee II, & Wallace, 2004) between the CIs produce severe consequences in case of such attack and made the region extremely vulnerable to man-made extreme events.

At 2004 an earthquake struck the west coast of Northern Sumatra with a magnitude of 9.1 and triggered a series of tsunami waves that spread out from the epicenter across the Andaman Sea and the Indian Ocean. The arrival time varies from 15 minutes to nearby shores (such as Indonesia and Sri-Lanka) to several hours for distant shores (Annunziato & Best, 2005; National Oceanic and Atmospheric Administration, 2012; Pomonis et al., 2006). The height of the tsunami waves that struck the coastlines reached to an altitude over 20 meters and a depth of several kilometers inland (Borrero, 2005; Monecke et al., 2008; Paris et al., 2009; Telford, Cosgrave, & Houghton, 2006; Telford & Cosgrave, 2007). The death and missing total is estimated at over 200,000 people, and over 2 million people were injured or displaced. The tsunami severely damaged the tourism and the fishing industry in the region, due to destruction of tourist sites and thousands fishing boats. Despite a rich history of earthquakes in the region and high risk of tsunami evaluations, there were no tsunami warning alert systems in the region that could notify about the oncoming tsunami. An appropriate alert system combined with evacuation routes, preparation and proper event management, could significantly reduce the loss and reduce almost entirely the amount of fatalities (Srinivas & Nakagawa, 2008). Most of the CIs and the buildings onshore were destroyed because of lack of robustness to tsunamis; therefore, CIs built on shores should be designed with a consideration of tsunami consequences.

Hurricane Katrina cross along Florida, Mississippi, and Louisiana leaving a trail of destruction and fatalities (nearly half of victims were over the age of 74). (Beven et al., 2008; Comfort, 2006; Graumann et al., 2006). The combination of rains and winds damaged hundreds of houses, downed trees and power lines. The rain and the storm surge caused more than 50 breaches in levees across the city of New Orleans and in the navigational canal levees that caused flooding 80% of the city (Grossi & Muir-Wood, 2006; National Oceanic and Atmospheric Administration, 2013). More than half a million housing units across Louisiana region were damaged and many critical infrastructures were damaged or destroyed. Katrina created a widespread shortage of electricity (U.S. Department of Energy, 2005), when at the outage peak more than 2.7 million consumers were left without electric power (Moore & Kellogg, 2007).

The July 7th bombing were a series of four suicidal terror attacks on the public transportation infrastructures lines of London. The blast destructed the lines of the underground transportation and it took several weeks to recover all the underground lines (Aylwin et al., 2006).

On January 2010 an earthquake with Magnitude of 7.0 occurred in Port-au-Prince region in Haiti (U.S. Geological Survey, 2013), followed by at least 90 aftershocks with magnitude 4.0 or greater in a range of 300km from the epicenter. Over 600,000 people were killed or injured (Saito et al., 2010; Spence & So, 2011) and over 300,000 building were damaged. As a result of the earthquake there were massive infrastructure destruction, including destruction of transportation, medical, governments, and educational infrastructures (Daniell, Khazai, Wenzel, & Vervaeck, 2011). Moreover part of the country's main port was damaged and was left non-operational. The combination of high density population and poor construction without seismic resistance (Baldridge & Marshall, 2011) made Haiti highly vulnerable to such seismic extreme events.

As a result of a magnitude 9.0 earthquake that struck in Japan, a series of seven tsunami wave hit the Fukushima Dai-Ichi Nuclear Power Plant (NPP), with a maximum hitting wave height estimated to be 15 meters, which exceeded the design basis of the tsunami breakwater walls and was above the site grade (Blandford & Ahn, 2012; INPO, 2011; NOAA, 2012; Srinivasan & Gopi Rethinaraj, 2013). As a result of the earthquake and the following tsunami series, at least 20,000 people were killed or missing, over 500,000 residential buildings were damaged or destroyed, 2,000 roads, 50 bridges and over 25 railways destroyed or damaged by the earthquake and the following tsunamis (International Atomoc Energy Agency, 2011). CIs such as gas and water supplies, telecommunications and railway service were also severely disrupted. Despite the history of Japan, which include tsunami waves over 15m (Choi, Min, Pelinovsky, Tsuji, & Kim, 2012; Goto, Kawana, & Imamura, 2010; Liu et al., 2013; Miyoshi, 1987), the design of the Fukushima-Daiichi NPP consider underestimated scenarios and insufficient protection systems of critical infrastructures to tsunami event. To prevent such severe consequences, the governments and the operators have to prepare for the worst case, considering the risk.

4. Implementation of preparedness

Preparedness to extreme events was examined as a composite of three basic strategies: redundancy, robustness, and resilience (Elkabets & Shohet, 2013). Insufficient preparedness of CIs to extreme events was observed through the events review resulted by of non-implementation of those strategies.

- Robustness - Lack of robustness was found at almost all the reviewed extreme events, it is reflected substantially in the Murrah federal building when critical components of the building were built without resistance to blast and explosion and their destruction caused a progressive collapse of the north side of the building. Similarly, the poor construction in Izmit and Haiti, and the insufficient tsunami protective systems at the Fukushima-Daiichi NPP represents lack of robustness.
- Resilience - the ability of Critical Infrastructure to recover quickly from extreme event relies mainly on mantle preparedness for the event. Appropriate preparedness and a good and effective event management will significantly reduce the consequences of the event, prevent the rippling effect and avoid cascading effects. A resilience of power supply after tsunami hit Fukushima Dai-Ichi NPP could prevent the core meltdown. Another example of insufficient resilience was noticed after hurricane Katrina; when areas across Florida and Louisiana remained without power supply for over a month and caused disturbances and losses of the public and private sector. Another aspect of resilience can be reflected in scenario analysis in case of an extreme event and planning courses of action such as evacuation and damage mitigation, actions that were not performed in cases of WTC and Indian Ocean tsunami.
- Redundancy of critical components or functions of Critical infrastructures will increase the reliability and the performance of the CIs system, especially in case of extreme events. A lack of redundancy was noticed in the Izmit earthquake, when after collapse of bridges there were no alternative routes to the affected area which made it difficult to access for rescue operations, another lack of redundancy is reflected in lack of alternative loads paths in the Murrah Building in Oklahoma and the lack of alternative power source in Fukushima-Daiichi nuclear plant. Critical and vulnerable components of CIs must be duplicated (or even tripled in the case of Fukushima-Daiichi) in order to ensure full functionality of the critical system in cases of failures.

5. Conclusion

Eight significant extreme events that occurred in the last two decades were studied and the level of preparedness of critical infrastructures during these events was examined. The examined extreme events reveal the gap between the design of CIs and the actual risk the CIs are exposed to in case of extreme events. A solid evidence of lack of preparedness and lack of implementation of resilience, robustness and redundancy in the design of CIs was observed. Design of the critical infrastructure should be distinguished due to the internalization of the CIs crucially in case extreme events. Standards and regulations should take into account the increasing risk portfolio over the years and be more stringent with regard to critical infrastructures preparedness. Furthermore, the design stage of critical infrastructure should include a comprehensive scenario analysis in order to discover all potential events and vulnerabilities and propose a design that provides stability to those scenarios. The design of Critical Infrastructures should embrace resistance to variety extreme event scenarios and the required preparedness level should reflect the evolution progress of the critical infrastructures.

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Benefit-cost analysis of the seismic risk mitigation for a region with moderate seismicity: The case of Tiberias, Israel

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Abstract

While high seismic-active regions have been widely investigated, areas with low seismic hazard has not been adequately addressed as being exposed to high risk of significant losses due to their vulnerable built environment and high exposure of population. A risk-based methodology for determining a cost-efficient risk mitigation plan, along with comprehensively seismic risk assessment, is needed for seismic-quiescent areas in facilitating cost efficient seismic mitigation plans. This article presents a methodology for investigating the economic feasibility of the building retrofit by means of benefit-cost analysis. The objectives of this study are (1) to assess the seismic risks with building and demography parameters which can fully represent the characteristic of local built environment, (2) to conduct benefit-cost analysis of the seismic mitigation activities, and (3) to verify the applicability of the present methodology by a case study. This study intends to provide public decision makers a standardized methodology for justifying the economic feasibility of seismic risk mitigation alternatives so that a cost-efficient public earthquake mitigation strategy can be achieved.

Keywords: benefit-cost analysis; casulty rate, earthquake hazard; earthquake loss assessment; HAZUS.

1. Introduction

While high seismic-active regions have been widely investigated and understood, areas with low seismic hazard has not been fully recognized as being exposed to high risk of significant losses due to their vulnerable built environment and high exposure of population. As a result, comparing with those high seismic-active regions with corresponding well-prepared seismic risk management plans, a moderate earthquake could cause more significant consequences to those low-probability/high vulnerable regions due to their lack of awareness and preparation for seismic hazards. Several studies indicate that public policies for earthquake risk mitigation commonly fail in those areas as a result of the lack of thoroughly seismic risk estimation, awareness in the general public and unclear economic drivers for seismic mitigation plans (Prater and Lindell, 2000), (Smyth et al., 2004), (Bostrom et al., 2008).

A substantial amount of researches have focused on loss assessment for high seismic regions. For instance, (Kircher et al., 2006) estimates building damage and human loss due to a repeat of the 1906 San Francisco earthquake using HAZUS software package. Also by operating HAZUS, (Schmidtlein et al., 2011) examines the spatial correlation between social vulnerability and potential earthquake losses under differing earthquake scenarios in South Carolina. These studies address on the seismic loss assessment for those areas which are identified as highly seismic-active, or have historical occurrences of major earthquakes. On the other hand, although loss assessment in the areas with infrequent damaging earthquakes starts to grab attention, there are comparatively few studies addressing this significant issue. (Tantala et al., 2008) investigates the potential high seismic risk of New York City due to its tremendous assets and vulnerability of its structures, which were not seismically designed as strong as most in the West Coast. (Remo & Pinter, 2012) compares the result of loss estimation from HAZUS to the damage surveys for the 2008 Mt. Carmel, Illinois earthquake and finds that the HAZUS overestimated the losses from the surveys. (Rein & Corotis, 2013) assesses potential consequences of major earthquakes for the Denver Region in the U.S., which is presented as a case of the seismic vulnerability of an area that is not generally considered seismically active and finds out that potential losses due to earthquakes would be amplified as a result of the low preparation of public and perception of people for earthquake risk. In sum, aforementioned researches all show the potential high risk in a low seismicity region due to its vulnerability on built environment and social-economic.

This article presents a methodology for investigating the economic feasibility of the building retrofit to the portfolios of buildings by means of benefit-cost analysis of the structural intervention. The particular objectives of this study are (1) to assess the seismic risks with building and demography parameters and casualty rates which can fully represent the characteristic of local built environment, (2) to calculate the benefit-cost ratio of the seismic mitigation activities, and (3) to verify the applicability of the present methodology by a case study. This study intends to provide public decision makers a standardized methodology for justifying the economic feasibility of seismic risk mitigation alternatives so that a cost-efficient public earthquake mitigation strategy can be achieved.

2. Background

Applying the framework of the catastrophe risk model, a basic seismic risk assessment model can be comprised by four modules: (1) hazard module, characterizing hazards in a system at risk to be investigated. In this study, a ground motion hazard is defined by its location, magnitude and frequency of occurrence; (2) inventory module, collecting data of geological characteristics such as site effects and soil attenuation for calculating local seismic intensity, and data of built environment such as occupancy types and building structural types; (3) vulnerability module, calculating social and physical vulnerability of built environment exposed to hazard. The social vulnerability generally includes social-economic information like income, ethnicity, age or ownership of property. The information of social vulnerability is the main factor in estimating the number of displaced household and temporary shelters after earthquakes. Physical vulnerability is usually defined by the fragility curve of a structure, which determines the expected building damage in a particular level of seismic intensity; and (4) loss module, evaluating the loss to the inventory by interpreting its corresponding vulnerability to the hazard. Losses, characterized as direct or indirect, can then be assessed in terms of social, economic and environmental losses.

Several risk assessment methodologies have been developed based on the typical seismic risk assessment model. (Korkmaz, 2009) provided losses assessment models for long-term disaster management considering probabilistic seismic hazards. Also, different methodologies and frameworks for seismic loss estimation have been developed and used to conduct a benefit-cost analysis for different seismic retrofit alternatives. (Smyth et al., 2004) (Boylu, 2005) (Kappos & Dimitrakopoulos, 2008). In addition, various seismic loss assessment models have been widely adopted in estimating the probable maximum loss by exceedance probability curves for assisting insurers or reinsurers in pricing the insurance policies. Examples of such studies include (Hsu et al., 2006) (Hsu et al., 2013). However, the complicated mathematical formulas and large number of variables make these loss assessment models difficult to be understood and operated by a wide range of stakeholders. Moreover, the nature of their non-standardized and proprietary code source prevents other users from modifying the models accordingly for their specific needs.

Correspondingly, a number of standardized software packages have been developed with friendly user-interface and open-source database. Most of them also utilize Geographic Information System in presenting the geographic distribution of losses for analyzing particular issues like emergency facilities layout. Examples include: Taiwan Earthquake Loss Estimation System developed by (Yeh et al., 2006) is designed to estimate the losses under different earthquake scenarios; moreover, the module of Early Seismic Loss Estimation of this program can obtain real-time estimates of seismic hazards and losses soon after the occurrence of earthquakes. KOERILoss, a Turkish-based seismic loss assessment program developed by Department of Earthquake Engineering of Bogazici University, can also estimate the losses by earthquake hazards (Erdik et al., 2003). Earthquake Loss Estimation Routine is a European-based software package for rapid estimation of earthquake shaking and losses throughout the Euro-Mediterranean region, developed under the Joint Research Project entitled Network of Research Infrastructures for European Seismology. (Hancilar et al., 2010). Although having the merit of being standardized and straightforward, these regional-based software packages have not been widely validated for their applicability to international setting and thus the international adaption of these local-based tools is still under a question mark.

3. Methodology

3.1. Benefit-Cost Analysis

Ideally, in order to protect properties and lives, all those buildings which are considered to be vulnerable to seismic hazard should be structurally strengthened to prevent them from severe damage in earthquakes. However, it may not be such a simple decision because for the purpose of the most effective means of limit resources, building retrofit is not always economically justified in some cases. For this reason, Benefit-Cost

Analysis (BCA) can serve as a straightforward and systematic tool for public and private sectors to perform a long term economic analysis in evaluating the tradeoff between safety and investment in risk mitigation alternatives. (Smyth et al., 2004) provided a detailed description to the procedures of BCA for seismic mitigation activities, including five steps: (1) specify the nature of problem, including the stakeholders, alternative options and the status quo, which can serve as a reference point for evaluating the performance of structural interventions, (2) determine the direct and indirect cost of the mitigation alternatives, (3) determine the benefits of mitigation alternatives, including the direct benefit such as the reduction of physical damage and the indirect ones such as the save in the cost for displaced households, (4) calculate the attractiveness of the mitigation alternatives, using appropriate discount rate to compare cost of mitigation alternatives to reduction in loss over a structure's lifetime though Benefit-Cost Ratio (BCR), and (5) choose the best alternative in terms of the highest BCR. To efficiently achieve a cost-efficient earthquake mitigation strategy for public decision makers, a straightforward risk-based methodology for evaluating the economic feasibility of structural retrofit is important. For this reason, BCA have been widely adopted for the evaluation of the economic feasibility of public investment in seismic mitigation measures of: (1) upgrade of seismic design code (Peterson & Small, 2012), (2) retrofit of bridges (Nuti & Vanzi, 2003), and (3) retrofit of old concrete frame buildings in California U.S. (Liel & Deierlein, 2013), existing vulnerable buildings in Turkey (Smyth et al., 2004), in Greece (Kappos & Dimitrakopoulos, 2008), in China (Zhang et al., 2011) and in a broad scale of fourteen Latin American countries (Valcárcel et al., 2013).

Following the aforementioned procedure, in the case of seismic mitigation analysis for a public sector, the costs include the expenditure for retrofit or replacement of buildings and the benefits come from the reduction on the risks of casualties and damage of those buildings which are structurally improved by retrofit or reconstruction. Considering that the benefits of mitigation actions would be realized at some points in the future with an average annual probabilities of occurrence (FEMA, 1992), the expected annual benefits are constant in each year over the lifetime of buildings. In this regard, the future benefits are discounted to present values for comparison with the up-front costs of mitigation alternatives. The expected annual benefits of a mitigation action EAB_T, using Eq. (1), are the summation of the expected annual benefits due to the reduction on direct economic loss EAB_E and the benefits due to reduced fatalities EAB_F. The benefits in behalf of reduced direct economic loss EAB_E are calculated using Eq. (2) from the difference in expected annual economic losses for mitigated buildings $EALE_R$ and the original buildings $EALE_O$. Similarly, the benefits associated with reduced fatality loss EAB_F are calculated using Eq. (3) from the difference in expected annual fatality losses for mitigated buildings $EALF_R$ and the original buildings $EALF_O$.

$$EAB_T = EAB_E + EAB_F \tag{1}$$

$$EAB_E = EALE_O + EALE_R \tag{2}$$

$$EAB_F = EALF_O + EALF_R \tag{3}$$

The benefits in present monetary value $E[B_T]$ over a time horizon T are calculated using Eq. (4) with discount rate r_p. The benefit-cost ratios BCR are obtained using Eq. (5) by dividing the expected benefits $E[B_T]$ by the reduced cost of mitigation, which is the up-front cost of mitigation C_O minus present salvaged value of the retrofitted or rebuilt buildings V_S, which considers the increase in the value of the retrofitted or rebuilt buildings. When the BCR is greater than one, it is economically justified of the investment in the designed pre-earthquake structural intervention to a building stock.

$$E[B_T] = \sum_{t=1}^{T} \frac{EAB_T}{\left(1+r_p\right)^t} \tag{4}$$

$$BCR = \frac{E[B_T]}{C_O - V_S} \tag{5}$$

4. Results

4.1 Building damage and economic losses

Five categories are defined in HAZUS for building damage: no damage, slight, moderate, extensive and complete. The number of damaged buildings is converted from the probability of damage to the buildings for each building type. Analyzing the number of damaged buildings of unreinforced masonry for scenarios Jordan 6.0 Mw and Jordan 7.0 Mw, as depicted in Fig. 2, 79% and 95% of URM buildings are damaged, respectively, as expected that URM is recognized as one of building types which is most seismically vulnerable (Spence et al., 2011). For concrete frame, as depicted in Fig. 3, 55% and 77% are damaged under scenarios of 6.0 Mw and 7.0 Mw, respectively. Here we investigate the vulnerability of a building type with its built year by measuring the percentage of damaged buildings with associated built year to the total number of buildings for each building type. As depicted in Fig. 3, the buildings built before 1980 account for most damaged buildings for both concrete frame and URM. 44% and 64% of URM built before 1980 are estimated to be collapse under scenarios of 6.0 Mw and 7.0 Mw, respectively. For concrete frame, 55% and 77% are damaged under scenarios of 6.0 Mw and 7.0 Mw, respectively. It can be observed that the vulnerability of a building type is increased along with the ages of the building. In this study, the economic loss considers both the loss due to direct physical damage of structural components represented by repair cost, and the loss comes from damaged contents. The economic losses under scenarios of Mw 6.0 and Mw 7.0 are $29,413,892 and $76,476,119, respectively.

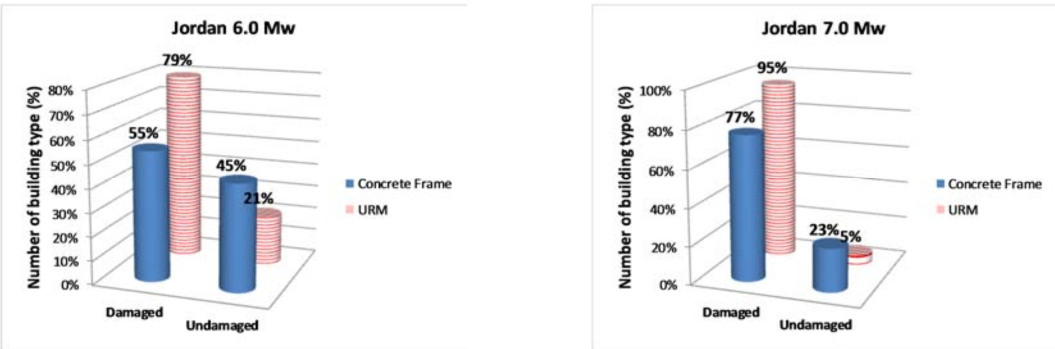

Figure 2. Building damages for different building types in given earthquake scenarios

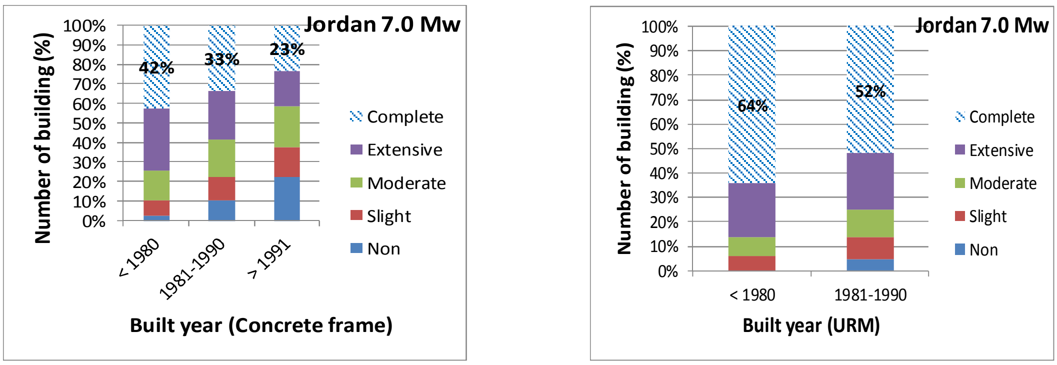

Figure 3. Building damage for different building types with associated built year in given earthquake scenarios

4.2 Benefit-Cost analysis of building retrofit

We examine the benefit-cost ratio of retrofitting all concrete frame (CF) and unreinforced masonry wall (URM) buildings which were built before 1990 to the level of seismic performance of modern buildings designed based on the Israel Standard 413. Table 1 summarizes the result of benefit-cost analysis under the Jordan 6.0 scenario. As shown in Table 1, casualty losses are reduced by structural retrofit. Since the buildings built before 1980 are most venerable to earthquake, the casualty losses of these buildings are significant reduced by upgrading seismic performance. The benefit-cost ratios for both CF and URM built before 1980 are 1.1 and 1.3, respectively; in other words, retrofit mitigation strategies are economically feasible. On the other hand, the benefit-cost ratios of CF and URM built between 1971 and 1990 are 0.9 and 0.8, respectively. The reason for the relatively smaller BCR is that the benefits of human live avoided are not significant since these buildings are considered partially resistant to the earthquakes. It is therefore conclude that the investment in retrofitting the buildings built between 1981 and 1990 is not economically justified.

Table 1. Benefit- Cost analysis in Jordan 6.0 scenario

Building type (built year)	Benefit from economic losses avoided ($, million)	Live saved	Total benefit ($, million)	Cost of retrofit ($, million)	*BCR*
CF (< 1980)	$2.1	59	$3.6	$3.3	1.1
CF (1981-1990)	$1.8	14	$2.7	$3.0	0.9
URM (< 1980)	$0.4	35	$0.8	$0.6	1.3
URM (1981-1990)	$0.2	12	$0.5	$0.6	0.8

5. Conclusion

This study first investigates the attributes of local built environment for seismic risk assessment, including building stock, demographic data and casualty rates of concrete frame and unreinforced masonry wall buildings. Adopting HAZUS software, we examines the economic feasibility of seismic retrofitting for both buildings built before 1980, and between 1981 and 1990, which do not comply with modern Israel seismic design code launched in 1991. The benefits of retrofitting those seismic-valuable buildings are measured in terms of reductions in economic and casualty losses in future earthquakes. The result shows that retrofitting the buildings built before 1980 is economically justified as a result of significant number of saved human live. On the other hand, since the buildings built between 1981 and 1990 hold stringer seismic-resistance and thus account for fewer casualty loss, structural mitigation activities are not economically feasible for these buildings. This study provides public decision makers a standardized methodology for justifying the economic feasibility of seismic risk mitigation alternatives so that a cost-efficient public earthquake mitigation strategy can be achieved.

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G-BIM framework: A feasibility study for the adoption of generative BIM workspace for conceptual design automation

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Abstract

The integration and automation of the whole design and implementation process has become a pivotal factor in Architecture, Engineering, and Construction (AEC) projects, especially regarding recent technological developments and emergent drivers in the field. Extant literature has highlighted a series of recurrent problems in process integration, especially at the conceptual design stage. This study presents the adoption of Generative Building Information Modelling (G-BIM) workspaces as an emerging technology. This has the potential to leverage conceptual design innovation in AEC projects. It builds upon the findings of an initial survey, and proffers a framework for using generative BIM workspaces at the conceptual design stage. This framework highlights the link and dependencies between generative/parametric tools and BIM applications to expedite information transition using generative tools primarily based on neutral BIM standards. Limitations of tools and approaches for providing accurate project information models are also captured in this framework. This paper demonstrates an overview of the G-BIM framework and the developed conceptual tool. Moreover, it reports on the challenges and opportunities associated with existing software applications. Findings reveal that the application of Generative Design (GD) can significantly enhance the design experience by assisting designers in the iterative generation of design alternatives and parameterisation processes. This framework purposefully integrates BIM with GD to enhance the design process at the conceptual design stage. This forms the rubrics for a working prototype which actively engages GD methods into a single dynamic BIM environment – the results of which will be presented in later works.

Keywords: AEC; automation; BIM; computational design; generative design; parametric design

1. Introduction

In AEC design practice, designers often put considerable [unnecessary] effort into design solution generation, often going through repetitious stages to seek viable solutions. Currently, designers usually take advantage of computational support such as Computer Aided Design (CAD) and BIM at later stages. However, during the early stages of the design process, decision making is a vital part of solution generation. The degree of automation through the design process is of great importance to the procurement of design alternatives. Cognisant of this, it is acknowledged that the use of generative systems as a design automation system at the early design stages could be very helpful for presenting viable [defendable] solutions quicker and more efficiently than conventional approaches. However, this should not obfuscate the need to satisfying the requirements of requirements capture, information modelling and data management; especially as projects are becoming increasingly more complex. Given this, multi-criteria design problems can be considered through the application of GD, the outcomes of which offer new innovative benefits to designers (and the design team).

Designers in current AEC projects, make use of advanced visualisation and modelling techniques at later stages, which result in almost losing the design knowledge of early conceptual phase, which is the origin of most of major decisions. Rahimian and Ibrahim (2011) linked this problem to the non-intuitive interface of the conventional Computer Aided Design (CAD) tools which make them not suitable for supporting the type of reasoning and cognition which appear during conceptual design phases. To tackle this problem, Lee *et al.* (2013) recommended the application of parametric design interfaces as a new pattern in CAD and BIM, as the mechanisms which are capable of producing design alternatives controlled by certain rules or limits, regardless of modelling and visualisation skills of designers. This approach proved beneficial for developing designers' creativity by equipping(providing) designers with synectics as an technique for forming idea (Blosiu, 1999) and supporting the design process through the unproblematic generation of design alternatives (Kim and Kang,

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2003) through altering various design parameters and observing (and reflecting on) the results in real-time (Goulding and Pour Rahimian 2012. To address this problem, the development of 'Generative BIM workspace' to provide design creativity, fluidity, and flexibility by the application of generative design approach was proposed by Abrishami *et al.* (2013). Using such an integrated platform (plan), this work considered the information relevant to the design requirements as the input to the system and the design algorithms as the design output. They also regarded this platform integration helpful for designers to solve complex multi-criteria design problems.

This work presents a G-BIM framework and conceptual tool, developed on a questionnaire survey conducted by Abrishami *et. al.*(2014). The survey aim was to explore different User Requirements Specifications (URSs) and various angles of integration of generative design algorithms to the existing BIM platforms, and to assist in identifying the conceptual framework's requirements for the G-BIM platform to maximise the efficiency of design teams and outline a new method for BIM applications to support throughout the design process; *i.e.* from very early conceptual design stages to final detailed design phases.

In this paper a new method for BIM applications is introduced, which supports conceptual design by incorporating GD into the BIM applications. A genotype of the design within a BIM application is proposed to allow the designer to give rise to new design alternatives by changing the pre-defined parameters with respect to the design constraints and requirements. Then the design team amend and improve the population of generated designs by the application of BIM capabilities. This method enables users to make use of BIM capabilities (such as collaboration, simulation, parametric features, etc.) through design. An overview of the framework and the conceptual developed tool is represented in this paper. It initially describes the integration using the framework, and then each element of the suggested framework is presented in Section 4. The conceptual tool development process is also discussed. G-BIM adopts the same approach as conventional and existing design process. Although the adoption of G-BIM develops design creativity, fluidity, and flexibility; it brings about minimal changes to the common design process. Therefore, relevant information to the design requirements forms the system input, and relatively the design algorithm generates the design output. The suggested system offers a design solution based on the input data (site data, constraints, and requirements); and during the conventional design process the same data is taken into consideration by the designer. G-BIM is fully making use of the potential of two existing individual generative systems; employ parametric change management of BIM applications and changes dynamically according to the generative mechanism attached the generated model(s).

2. Background study

The focus of contemporary AEC design projects is increasingly moving from an architecture with aesthetical emphasis towards performance (structure, environment, construction, socioeconomically and cultural, etc.) based architecture (Roudavski 2009). This shift in design attitude is inviting architecture to adopt new technologies that can support this transition. The AEC designers started adopting technology from industrial design, mechanical engineering and product developments, where performance tends to play a crucial role, as well as adopting new computational design methods such as generative and parametric approach, isomorphic surfaces, kinematics and dynamics, topological space are also being engaged. Given these changes and new inertia, this research study explores the potential of a BIM design environment integrated with new computational design methods in order to maximise their opportunities. G-BIM exploits generative design for creation of alternatives at early design stages, and existing parametric algorithm in BIM tools for modification of the chosen alternative(s) and change management during the late design stages up to the construction level.

3. Methodology

In this research, during the development of the theoretical foundations of the study, the employed qualitative approach provides a broad and deep understanding of the current state of computational support during the conceptual architectural design phase. In addition, the new empirical assessment techniques which are utilised in this study led to the possibility of investigating design protocols in a quantitatively manner (measures of diversity, time-related events and derived design processes) besides the using standard statistics possibilities when dealing with design protocol data. Therefore relying on both theories, the research seeks for clues of design support tools' quality by investigating design protocols and artefacts. Figure 2 presents an outline of the research design methodology. The research uses process modelling concepts to develop multi-disciplinary computational framework containing three main levels; process metal-level, process model, and development. This paper presents the process model stage of the project and highlights the potentials of the developed framework at the process meta-level phase.

The conceptual framework was developed using a process-centred environment for describing and evaluating evolving software process (Finkelsteiin, 1994). This development process consists of three levels: meta-process modelling, process model, and development iteration. During the meta-level, required information and key concepts are gained and classified; which will provide guidance for the development process (Rolland, 1998). Thereafter, the framework will be analysed and compiled through interviews and observations from experts in BIM and GD. The research aim will be achieved by developing a new design methodology based on Schön's (1983) "reflective practitioner" theory, Fitts' (1964) "motor learning" theory, and then verifying its effectiveness with empirical data. The research adopts 'sequential mixed method research' approach which starts with qualitative approach and continues with quantitative approach (or vice versa). Hence, the study follows Creswell's (2002) guidelines in designing the sequential mixed method research by pursuing a single research aim. This paper presents the meta-level of the project and highlights the potentials of the proposed framework. This paper is purposefully aligned to tease out both the philosophical underpinnings of design theory continuum per se, matched against the practical constructs of research practice (including the technology and tools used to deliver this).

This paper builds on the work of Abrishami *et. al.*, 2014, which conducted a detailed study using qualitative approach to adopt process modelling to develop a conceptual framework for Generative BIM Workspace. This paper presents part of an ongoing research study investigating the automation of conceptual design by integrating of GD and BIM as the central conduit; particularly by comprising both design method and computational architecture. This is expected to improve BIM's performance during conceptual architectural design process. The research aim is to examine the feasibility and applicability of the integration of GD and BIM. The main focus of this paper is on the formulation, implementation, and presentation of G-BIM which supports conceptual design automation through a generative process. First part of the paper explains the construct of the research study, including the detailed framework, potential, and barriers. The second part of the paper reports the tool interface and development, reaffirming how the framework/tool can overcome these problems.

4. G-BIM Framework

Integration of generative tools with information modelling combined with advanced 3D knowledge-rich systems is creating new potential for designing and coordinating amongst various stakeholders in AEC (Kocaturk and Medjdoub 2011). The use of GD can be defined as exploitation of parameters created at the early design stages. Since the generated solutions to the design problem (population of design alternatives) are the results of an algorithm (consisting design constraints, routines, and data files) by changing the inputs of the algorithm, the final design would be altered accordingly, like creating a basic model based on '*Routines*', and generating different design alternatives by adjusting very basic design parameters.

Using this approach, the design character to be generated can be defined by the design team in order to reach an appropriate level of variability. When G-BIM is used, a large number of design alternatives (solutions) can be studied by the design team through the generation of the initial information mapped by the design team along with G-BIM's generative mechanisms. All the modifications take place in the central BIM software using the advanced BIM modelling features. The following section demonstrates how the G-BIM framework is used to develop the preliminary conceptual tool.

5. Demonstration

The research adopts Janssen's (2006) evolutionary design approach, comprising design method and software system. As it is shown in G-BIM framework (**Hiba! A hivatkozási forrás nem található.**), the proposed method is described in three phases; coding, generation, and modification. Coding phase is formed by routines and data-files. At the routine coding stage a generative process is defined with the capability of metamorphosing a genotype into a phenotype (like generating a 3D model of a design). At the data-file coding stage design context and constraints are specified. The generation system uses the Industry Foundation Classes (IFC) for representation of the generated designs. Using IFC model, make the representation of the information-data associated with the model available for using in advance analysis and simulation features of BIM application. Using the G-BIM, an existing BIM application (Autodesk Revit) is used at the modification phase. As the generation system is integrated with Revit, designer(s) can make use of its advanced modelling and analysis features. The generative evolutionary design assists designers through the early design stages, while the BIM parametric capabilities provide a direct relation to physical production process (construction). The presented example illustrates how G-BIM supports and enhances conceptual design through a flexible exploration of design solutions using a fully automated BIM system. The generated models interact with the BIM parameters and information data.

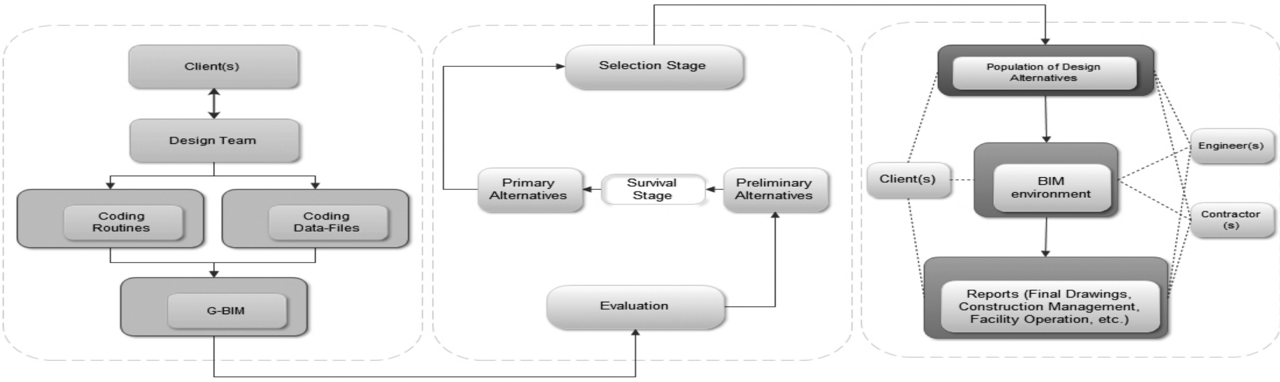

Figure 1. G-BIM framework

The system will be developed using a programming language embedded in Revit, allowing the generative process to make direct use of Revit modelling functions. Moreover, the Revit will also be used for visualisation, with all feedback from the evolutionary process being displayed in the system interface. There are evolutionary systems developed (Frazer & Connor 1999) using AutoCAD and Sun's systems (Sun 2007) integrated with MicroStation. G-BIM captures the information associated to the users' way of designing as well as design requirements, and simplifies the process of mapping this information by using Visual Dataflow Modelling (VDM). Moreover, it supports designers' interactions throughout the different design phases. Also there has been several attempts to make a link between generative and parametric tools and BIM tools like Geometry Gym, to enable exchange of generative tool models primarily using neutral BIM standards like SDNF, CIS/2, and IFC2x3 (Mirtschin 2011); but due to limitations of generative tools in providing accurate information models, these solutions often fail to provide an overall enhanced solution (to some extent); whereas, it is intended that the proposed system will enhance BIM applications for both generating and visualising forms. Thus, the evolutionary system will be developed and fully integrated in the BIM environment.

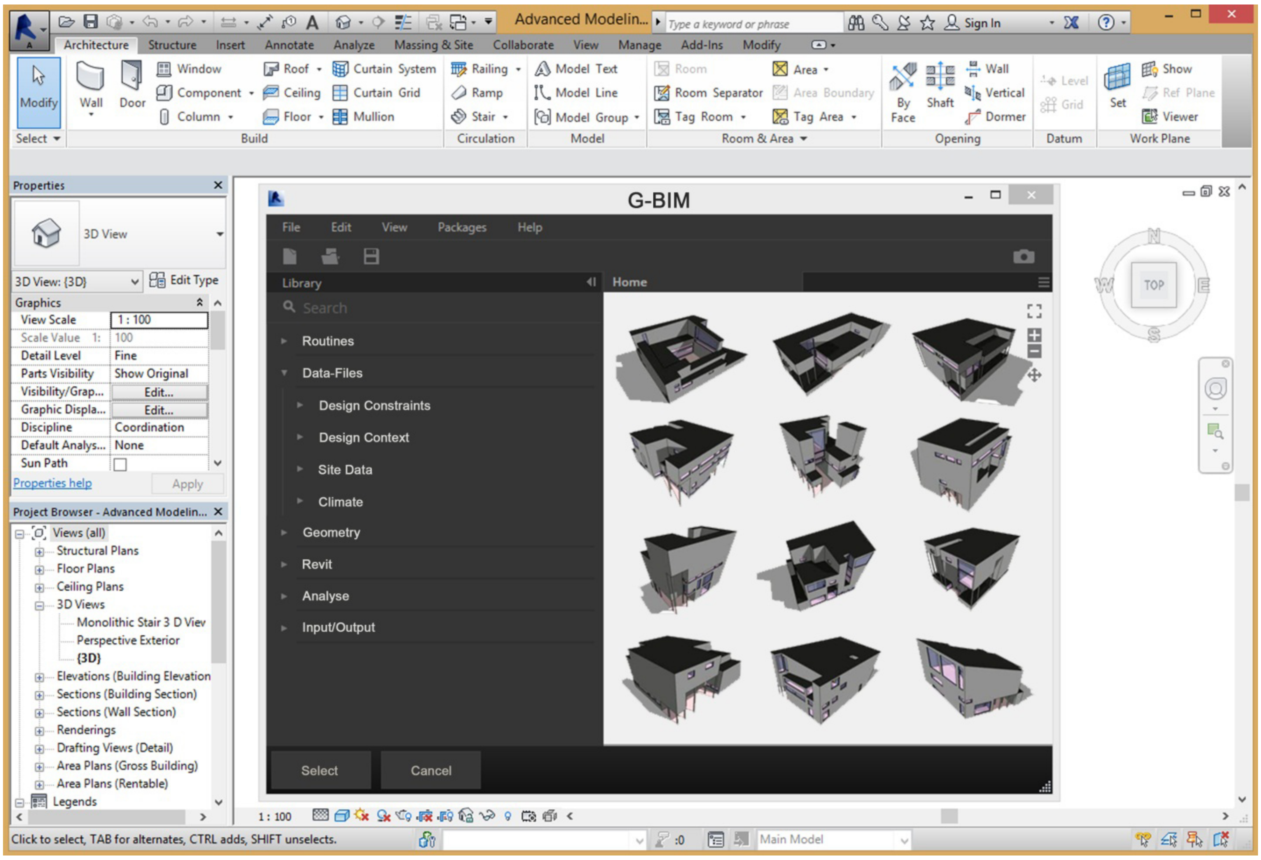

Figure 2. Conceptual Tool Interface: A set of generated designs

6. Conclusion

The paper presented a valuable set of rubrics for discussion in order to support automation in conceptual design stage. The paper presented a single, flexible, and dynamic 3D environment conceptual prototype which covers a wide range of architectural design requirements through the design process. G-BIM is developed based upon previous research, including Abrishami *et al.* (2013) conceptual framework, and Abrishami *et. al.*(2014) questionnaire by survey. G-BIM has the potential to enable automation at the conceptual design stage, by analysing a large number of possible design solutions. Moreover, G-BIM is capable of filling the gap in the current AEC projects, and meet the required automation level throughout the design and construction by its innovative integrated approach.

The developed framework and conceptual tool will be used to develop the final prototype. This will actively engage generative design methods into a single dynamic BIM environment. This study contributes to extant knowledge in this area by providing a 'stepping stone' for digital integration of all stages of an AEC project, especially concerning the implementation of BIM Level 3 (Cloud).

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Development of a 5D BIM based management system for building construction

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Abstract

Construction projects are experiencing great issues in communication, particularly amongst the major project stakeholders (e.g. designers, planners, contractors, supervisors, consultants etc). The issues are especially evident within the management process of such a large number of stakeholders. Current developments in Building Information Modeling (BIM) suggest that, besides 3D modeling, BIM can assist in the management of construction projects. This paper presents outcomes of a research project carried out at the University of Zagreb, which introduces a novel BIM model for managing building construction projects. The initiative for initiation of the project came from the industry and was executed through joint effort of the university team and a construction company. In this paper, we will describe the BIM-based structural framework and its software application that integrates 3D design with budget and schedule and thus provides a 5D tool for managing construction projects. We also show how we used the current databases of work and cost normative and preset construction standards to produce an application tailored for specific construction processes (e.g. generating bills of quantities (BoQ), work diaries, invoices, project schedules, histograms and S-curves etc.). Moreover, we present the use of a remote web service mechanism for exchanging data openly based on Industry Foundation Classes (IFCs) standard. Although the application showed to be a success in the Croatian industry and BIM has been having an expansive knowledge domain within the Architecture, Engineering, and Construction and Operations (AECO) industry, further development is needed and forthcoming, especially in collaboration abilities, connection with Enterprise Resource Systems (ERP) and sustainability.

Keywords: 5D modeling, BIM, construction industry, software application, South East Europe

1. Introduction

The construction industry is slow in utilizing information technology (IT) and managing projects (Mak, 2001). In the area of South East Europe (SEE) construction has even lower performance than what the developed countries have (Vukomanović et al., 2012). Thus Croatian construction industry has a lack of standards and incompatibility with modern ICT applications, which stands as the top IT disadvantage (Pavlović, 2013). Another important feature of the construction industry in Croatia is fragmentation of various participants in the projects, which are usually pre-defined by law regulations.

Today Building Information Modelling (BIM) has become a necessity in the Architecture, Engineering, Construction and Operations (AECO) industry. Thus the top project-related benefits that contractors are receiving from BIM are seen in: reduced errors and omissions and reduced rework. Reduced construction cost, reduced project duration and improved safety. Round out the top five project benefits and they have big impact on success (Smart Market Report, 2014). Accordinly, the construction industry should be informed about the benefits and accept the use of BIM whilst supporting its development. There are different levels of adoption; they largely depend on the originating country. This is understandable as it is dependent on the specificities of certain markets and aspects of a developing country.

Although many researchers and practitioners espouse collaborative working environments, there are still challenges to be met in many parts of the world. Particularly, in relation to a fully integrated collaborative multidisciplinary mode of operation (Gu& London, 2010).Good examples of BIM adoption can be found in North America, where BIM usage had increased from 28% to 71% between 2007 and 2012. Similar results can be found in other developed countries in Europe, UK being a prime example (Smart Market Report, 2014). There is a lot of research on the topic of Building Information Modeling (BIM); in which benefits are presented and models are shown that integrate individual components such as documentation, cost, time, etc. (Goedert and Meadati, 2008; Staub and Fisher, 1998; Koo and Fisher, 1998; McKinney et al., 1996; Heesom and Mahdjoubi, 2004; Akinci, Fischer and Kunz, 2002; Tanyer and Aouada, 2005; Dawoodet al., 2002; Wang et al., 2004; Kang et al., 2011). We have found, despite the before mentioned research, that the most commonly used BIM are still 4D models that visualize the physical project characteristics in time.

Relating to the SEE market Izet Begović et al. (2002) had found that although 88% of respondents included the IT development and BIM into the companies' long-term development plan, the situation has not changed. Thus, most of the companies operating on the SEE market do not see the neediness of IT strategy (Pavlović, 2013).

In this paper, we would like to present features of IT application building information management that developed through research and practice in the construction industry in SEE. We will describe the BIM-based structural framework and its software application, which integrates 3D design with budget and schedule, and thus provides a 5D tool for managing construction projects. We will also show how we have integrated databases of material, labour and equipment into the BIM concept. Furthermore, the application will show its closeness with the construction industry of SEE by showing specific construction processes (e.g. generating bills of quantities (BoQ), work diaries, invoices, project schedules, histograms and S-curves etc.). Finally, we will show how this data could integrate into the Industry Foundation Classes (IFCs) format and thus help the local construction industry in improving their ICT processes.

2. Literature review

Most of the world's leading AECO firms have already left behind their earlier, drawing-based, CAD technologies and have used BIM for nearly all of their projects. The majority of other firms also have the transition from CAD to BIM well underway and are on various levels of development (Chuck, Teicholz and Sacks, 2008). According to SmartMarket Report (2014) the contractors around the world will focus most highly on investing in their internal collaborative processes, BIM training and BIM software. In this chapter, we will present the contemporary literature review in usage of BIM technologies.

ArhiCAD is the oldest continuously marketed BIM application for architectural design. Graphisoft, the parent company, began marketing ArchiCAD in the early 1980s. It is simple to use but with limitations in its custom parametric modeling capabilities (Eastman, Teicholz and Sacks, 2008).

There is a practical approach to data collection that is incorporated into the BIM model. The objectives were to capture 3D as-built data into the BIM model, document the actual construction schedule and use BIM to capture and store construction documents including specifications, submittals, shop drawings, change orders, and RFI (Request for Information) (Goedert and Meadati, 2008). Staub and Fisher, (1998) in their research on 4D constructability analysis, use 4D CAD not only as a visual tool but also as an analytical tool. The intention of analyzing a 4D model for cost and productivity was to evaluate a given schedule and the 3D model of a facility by identifying the time-space conflicts between activities, and considering the cost and duration impacts of these conflicts. It is an interesting fact that in their case study the project manager wanted to primarily use the 4D model as a presentation medium for prospective and current clients. They wished to use the 4D model as a presentation tool rather than a planning tool. Using 4D models as presentation tools for clients can be a positive first step towards raising awareness of the new technology, and allowing the Architecture, Engineering and Construction community to gradually accept its usage. However, it should be much more valuable. (Koo and Fisher, 1998). 4D models integrate the spatial, temporal and logical aspects of constructions planning information, misinterpretation of the project sequence can be minimized.

McKinney et al.(1996) developed 4D tool called CIFE 4D-CAD which produces 4D simulates and models in both symbolic and graphic form. Product and process information is related within the 4D model and the 4D animation. Furthermore, the function of the CIFE 4D-CAD tool is to produce interactive 4Dmodels for 4D animations which empower construction designers to build a schedule directly related to a 3D model. Their view is that this tool should serve as a 'decision' tool, which supports both the process of building the schedule as well as the evaluation of its viability. In addition, 4D technology enables planners to predict potential problems at the construction stage, which could have considerable costs and time implications. Where 4D technology has been successfully implemented direct savings and an increase in productivity has been seen (Heesom and Mahdjoubi, 2004).

The schedule simulator initially developed by Jacobus Technology also performs 3D graphic simulations of the construction process. 3D design data can be imported from various CAD based design packages, which made this program easy to use. The schedule data can be obtained from either Primavera Project Planner or Microsoft Project (Heesom and Mahdjoubi, 2004).

Akinci et al. (2002) wanted to create mechanisms that automatically generate project-specific work spaces from generic workspace ontology and a project-specific IFC (Industry Foundation Classes) based 4D production model. That model enables richer 4DCAD simulations, time-space conflict analysis and proactive workspace planning prior to construction.

Similar to Akinci et al. (2002) a 4D simulator called ProVis can visualize occupied spaces, available spaces and potential space conflicts (Dawoodet al., 2002). Furthermore, Wang et al.(2004) extended 4D technology into the areas of resource management and site space utilization. Kang et al.(2011) attempts to develop a 5D CAD system by linking 4D object for progress schedule data with the risk data for visualizing construction risk degree of each activity. This system uses the fuzzy analysis and AHP analysis procedures to estimate the risk degree of each activity. The system also considers construction cost, and the duration and dangerous condition of work site as risk factors. As shown above a large amount of research has been done on the topic of 4D models. Most of the previous 4D CAD applications mentioned above have created simulation of construction but there are only a few which connect the 3D model with cost and time. E.g. Tanyer and Aouad (2005) paper presents the development and implementation of a new 4D planning tool which is a part of a product model-based project database. That tool brings the 4D simulation and cost estimation together and aims to contribute to what-if analysis in construction projects. Virtual Project Development is a concept, which was analyzed by Popov et al. (2010) and can be used as a 3D model for simulating the construction process and virtual work implementation management needed to be performed in advance to avoid possible collisions of cranes and structures. That is similar to the Akinciet al.'s(2002) model but additional Popov et al.(2010) emphasizes the possibility of identifying alternatives.

While developments have been extremely encouraging in the area of 3D design very little development has happened in the fields of 4D-linking time and scheduling data; and 5D - linking cost data to the 3D model (Mitchell, 2013). Integrating 4D (time) and 5D(cost) would deliver significant value at all levels of development and would help overcome various challenges that BIM implementation faces; such as a collaboration, liability and protection of intellectual property, know-how and technology (Mitchell, 2012). We believe that the business benefits of BIM will encourage the development of BIM in SEE. Reduced errors and omissions, collaboration with owners/design firms, enhanced organizational image, reduced rework and reduced construction costs are considered as top five BIM benefits in developed countries (Smart Market Report, 2014) and importance of these should be recognized in SEE.

3. Developing the 5D BIM

During our literature review, we could not find a single study, besides the BIM application of GALA (Vukomanović, Radujković and Nahod, 2012) which show the BIM application in the construction market of SEE. Furthermore, the construction industry of SEE has a specific nature, which blocks implementation of the BIM software developed in Western Europe and North America. The application was designed in accordance with common phases of a construction project and has been adjusted to the construction industry practices in Croatia and related industries of neighboring countries. Figure 1 shows schematic data flow. The application uses normative and standards in civil engineering, combines them with empirical normative and project information as the input to the process. Process generates output information, such as bills of quantities, analysis of costs, invoices, project schedules, histograms, S-curves (material, work, machine and cost), etc. Managers can then proceed with the monitoring phase (actual vs. planned) and if there is a need, conduct control. The figure 1 also shows how the project data could be represented by 3D design in IFC export version.

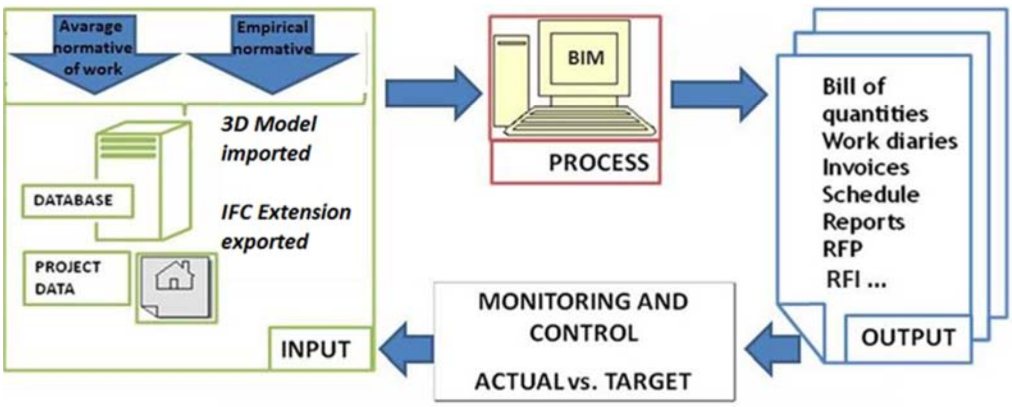

Figure 1. Application process diagram

Norms of work, materials and machines include 21 work types, 9750 groups and over 25,000 normative developed for building construction.

The database is open for updating, so the users can enter new data (norms based on experience) or change the existing ones. The total cost of the Project can be reached by calculating on the level of the bill of quantities, by changing factors of work, material or machines as well as by applying different price lists, which enables recalculations the whole bill of quantities or one of its parts. Users can change the price or particular items in the bill as well as give special discounts or bonuses on the overall bill.

Application imports the layout for every object with all of the pre-designed characteristics (dimensions, depth, density…) based on the IFC standard. The data is automatically transferred into the bill of quantities and associated with the normative of material, labor and equipment and respective bill of costs. In this way construction planners are gaining the ability to calculate the project cost and time in 5 dimensions.

Application directly transfers cost analysis and associated resources as activities onto the project schedule. They can be linked into one or divided into more activities for further use in different items of the work breakdown structure (WBS). Each activity can change their resources of labor and equipment, which enables managers to effectively use charts and numerical data to select the most appropriate technology and most favorable supplier. Activity duration is calculated by using normative of resources that have been assigned to the activities. The activities can be distributed within WBS. It is also possible to produce more detailed work plans based on different calendars and deeper WBS distribution.

By entering the realization of the scheduled activities and expended resources one creates tables of working hours, warehouse documents (requisition slips or internal delivery notes), work orders, a daily project log and final measurements for the construction book. Data is obtained on the condition of resource expenditure on the principle planned – spent – should have been spent. The state of the dynamic plan through a Gantt chart, as well as the automatic correlation of the activity duration, based on the data on the duration of activities that have already begun. With the dynamic plan, the “S curves” of all resources are obtained (of workforce, material, machines and money) in form of early and late curves and the realization curve. Project managers are thus enabled with resource control and are enabled to make proper decisions as well as revise the plan.

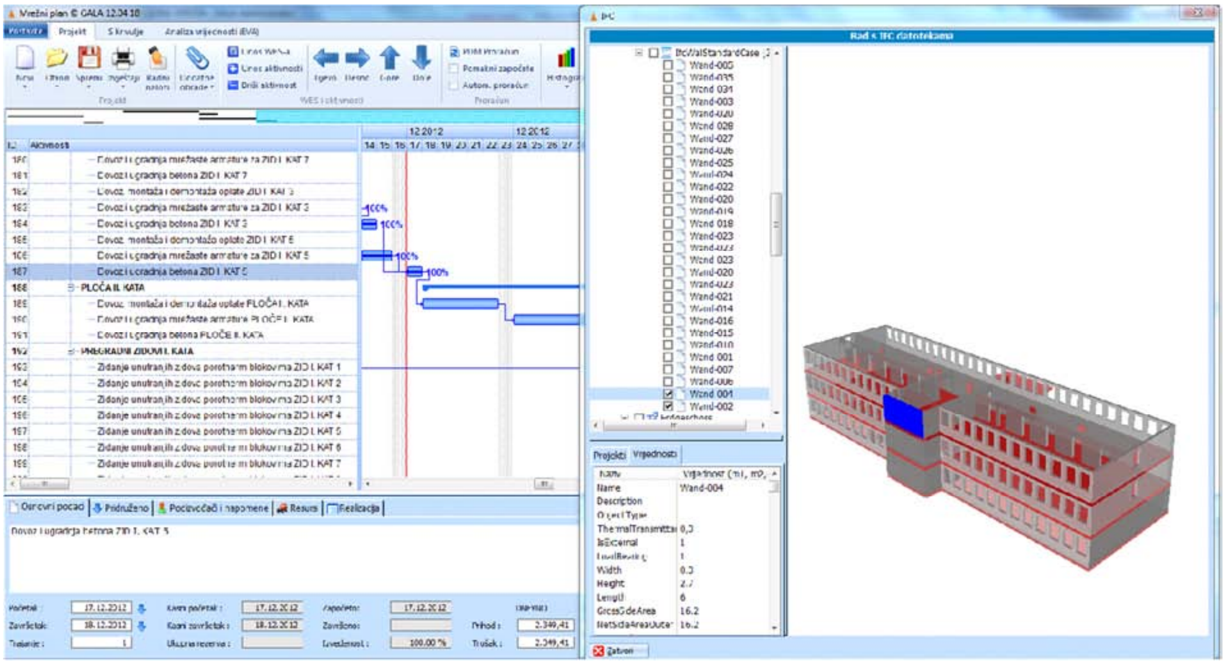

Figure 2. Schedule and 3D model

The application is also designed for the contractor type companies where the warehouse activities are a part of working processes on construction sites. By logging and creating receipts, requisition slips, internal delivery notes and delivery orders, each project manager can control the warehouse condition and the expenditure of materials. By entering the realization (on the daily base or for a period), the user can create a requisition slip from the work order and thus affect the warehouse, which makes it easier to monitor the warehouse condition.

4. Conclusion & Discussion

This paper has presented the development of a BIM concept mainly developed for the construction industry of SEE. This is important because the world practice has not proven to be successful within the Croatian construction market. The main reasons can be found in the specificities of the market, e.g. the internal parties are pre-defined by law regulation, following the end of the socialist regime. (Where software development was mostly carried out through the internal IS functions of large government controlled enterprises) (Travica et al. 2007), Economic and political pressures have been forcing the industry to change its everyday processes. Furthermore, Izetbegović et al. (2003) listed purposes for IS use in the SEE construction industry: 98% for accounting and book-keeping, 89.8% for personnel management, 79.6% for spreadsheets, 73.5% for cost prediction, bidding and Bills of Quantities (BoQ), 53.1% for CAD and only 28.6% for scheduling. This indicates that the sector is still trying to cope with traditional management procedures through accounting and that SEE is still a transitional economy, although some parts of it (i.e. Croatia and Slovenia) have already stepped into the European Union. Therefore, the construction industry of SEE is still in the early stages of computing, i.e. on a technical and operational level, which is similar to other emerging markets (He et al. 1998) and therefore needs a step forward in accepting the benefits that come out of the BIM technologies.

During the application development, and its implementation we found very positive feedback from its users. It is presently used in 250 companies in the SEE region, which operate in the AECO industry. The application is also used in educational facilities, high schools and faculties (Faculties of Civil Engineering in Osijek, Rijeka and Zagreb). Finally, since only limited research had been conducted in this area so far, especially in SEE, construction organizations should perceive these findings as very interesting. Because the SEE construction sector is still operating differently than developed countries do and still practices management mainly through financial procedures (Roztocki and Weistroffer, 2008) the AECO companies have inability to assess true costs of their operations and enhance risks of losses caused by poor decision making. Understanding these major issues should help construction companies in SEE in managing projects more successfully, increasing their learning capacities and influencing the degree to which new technologies are adopted and implemented effectively. Unfortunately, the SEE carries the legacy of the former socialistic regime, which represents one of the main adaption issues of implementing western BIM practices on to transitional economies. This study should be considered as a starting point for further research. For instance, it would be interesting to study the absorption capacity of the SEE construction industry in adopting BIM from developed economies, as well as the dependency of inadequate BIM and industry competitiveness. Finally, IT tools for BIM are definitely one of the pillars in achieving excellence in the AECO industry.

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A framework to leverage BIM for knowledge management in AEC projects

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Abstract

Knowledge is generated in projects throughout the design and construction processes in Architecture/Engineering/Construction (AEC) projects. The management of this knowledge has been implemented by various firms in AEC the industry through the development of lessons learned databases, best practices, project closeout interviews, communities of practice and various other informal techniques. In the traditional project processes which don't use building information modeling, the data generated through the project life cycle is typically stored in a fragmented manner in multiple formats. This makes it difficult to capture, catalog and disseminate the knowledge present in the data effectively. The objective of the research study described in this paper was to identify the ways in which Building Information Models can be used for effective Knowledge Management. Building Information Models are data-rich, object-based, intelligent and parametric digital representations of building structures. In this research, we hypothesize that the parametric models used in building information modeling can provide a centralized global context to the information stored therein and thus be an effective tool as a knowledge store; provide support other knowledge management processes. In this paper, we present a method to capture knowledge during the design and construction processes using the parametric, object oriented nature of the BIM models; extract the stored knowledge from the BIM models. Finally, we present a framework to enable the use of Building Information Models to support the organization wide Knowledge Management processes.

Keywords: Knowledge Management, Parametric Design, Virtual Design and Construction, Building Information Models

1. Introduction

AEC projects inherently involve the creation of unique designs to satisfy owner's aesthetic and functional requirements and construction processes to convert those designs into tangible products. In most circumstances, the stakeholders involved in the project collaborate to achieve the required outcome and once the project is delivered, they disband and move on to the next project. The uniqueness of the design, construction processes and the inherently uncertain nature of construction requires creativity on the part of designers and constructors to ensure successful execution of the project. The ingenuity and experiential knowledge plays an important role in the decision making regarding construction means and methods, identification and implementation of solutions to problems (Ferrada and Serpell 2014). The construction phase of every project generates hands-on experience, problem solving capabilities, understanding of various means and methods and highly contextualized solutions. (Y-C Lin et al.2006). The knowledge generated throughout the lifecycle of a project is one of the most important assets of an AEC firm. Effective capture, storage, dissemination and reuse of this knowledge are critical for the successful execution of construction projects and thus vital for competitiveness and survival of the organization (Tserng and Yu-Cheng 2004).

Systematic management of knowledge can help in encouraging continuous improvement, sharing tacit knowledge, faster response to customers, disseminating best practices, reduction in rework (Carrillo and Chinowsky 2004). Additionally, the adoption of such practices may help transfer new knowledge to innovative practices, while helping to improve project performance by contributing to a greater understanding of innovation knowledge (Yang et al. 2011). Effective management of this knowledge is challenging for AEC firms on account of several reasons. The projects are often executed by transient teams that come together for a project. These teams are disbanded as soon as the project is complete. The knowledge gained collectively by the group of individuals participating in the design and construction processes is scattered across project teams (Fong 2005). Sometimes, the lessons learned during the project are not properly captured, stored or communicated to the potential user of this knowledge (Dane and Koskela 2009). This results in the repetition of avoidable mistakes

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which often have deleterious consequences to the project performance. Many construction organizations face loss of knowledge when employees leave to pursue other opportunities on account of retirement. Extracting and documenting knowledge post-hoc can be very challenging because the information on which this knowledge is based is extremely fragmented. For example, the information may be stored in design documents which may be in proprietary formats. The lessons learned in knowledge generated during the design review process may be stored in a portable document file format. Additional knowledge may be scattered across the organization in value engineering proposals, change orders, requests for information by the construction contractors, text documents resulting from the post project reviews, organizational best practices etc. Building Information Models provide a platform to potentially integrate the dispersed construction information with the data rich three dimensional representation of facilities (Goedert and Meadati 2008).

1.1 A case for the use of BIM models for Knowledge Management

Virtual Design and Construction (VDC) / Building Information Modeling are revolutionizing the delivery of AEC projects. In the last decade, Building Information Models have been successfully used to enhance project performance by improving communication of the design between various stakeholders, by enabling the identification of clashes ahead of time, by enabling the simulation of the construction sequence, and improving the communication between various craft subcontractors and the general contractor. Building information models are inherently parametric, data rich, object based representations of the facility being designed and constructed. Alternately, building information models can be conceptualized as centralized, interconnected data stores which can contain design and some construction information about architectural, structural, MEP and HVAC systems. This centralized and integrated nature of the design information can potentially provide a very context rich platform for the capture, storage and dissemination of the knowledge generated during the design and construction processes. One of the requirements of an effective knowledge management system is its ability in communicating and preserving knowledge effectively across various stages of a construction project (Dave and Koskela 2009). BIM models can be effective in this regard because they span and evolve through the entire design cycle from programming through the construction phase. Additionally, it is important to capture knowledge as soon as the knowledge is created or identified so as to ensure that there is no loss of the generated knowledge due to time loss or other constraints (Tan et al. 2012). BIM models can be thought of as stores of knowledge (Meadati and Irizzari 2010). In this paper, we present a mechanism for "live" capture and storage of the lessons learned during a project using building information models. This paper is structured as follows: firstly provide a brief overview of the techniques and processes currently used by the AEC industry for knowledge management. Secondly, we review published research on the subject. Thirdly, we describe a mechanism to use BIM to capture and store, extract lessons learned. Finally, we discuss a framework for integrating BIM into existing KM processes and scope for further research.

2. **Review of the State of the Practice**

AEC organizations around the world are recognizing the competitive advantage in managing their repository of Knowledge. Some of the techniques commonly used include Post Project Reviews, Communities of Practice (Tan et al. 2012), documentation and dissemination of best practices, lessons learned (Carrillo and Chinowsky 2004) expert directories and various tools based on intranets or extranets. Post Project Reviews is one of the most commonly used tool for capturing the knowledge generated during the construction process. These review sessions are typically conducted at the end of the project to discuss the lessons learned, problems addressed during the course of the project (Egbu et al. 2003). This practice suffers from two key shortcomings. Oftentimes, the knowledge generated in the project is forgotten by the end of the project if not documented regularly. The participation of all key personnel is essential for the success of post project reviews. In practice, project teams are disbanded before the formal completion of the project and key personnel move on to the next project. Without a significant commitment in terms of organizational time and resources, the reviews may not be an effective tool. Even when the reviews are done with proper care, the dissemination and real time access are a challenge. These documents may not serve any purpose if they are placed in archives that are not easily and universally accessible (Dave and Koskela 2009). Communities of Practice, also known as knowledge communities, and knowledge networks, typically consist of experienced design and construction professionals who share expertise and passion about a discipline specific subject. They usually provide a platform for their members to pool their experience, expertise, and ideas, and to find solutions (Wu et al. 2012). Web based communities of practice can pool expertise of inter and intra organizational experts from around the world. The capture and storage of lessons learned in every project is another commonly used knowledge management tool. On the Information Technology side, Groupware, Intranets and Extranets are some of the technologies that are being used to support various KM processes. Groupware systems typically support communication, coordination of activities and knowledge sharing among groups of people from multiple organizations and geographically dispersed locations. Its functionality can help manage and track information, documents, users and the applications they use. These systems offer the potential to maintain the project memory (Rezgui & Miles, 2011). However, groupware systems are not efficient for the exchange of more complex knowledge (Robertson et al., 2001).

3. KM Research in Construction

Knowledge Management has received a significant attention from the US construction industry and the construction research community world-wide over the last decade. Carrillo et al. (2003) developed a framework (IMPaKT) to enable AEC organizations to understand the business impact of their KM strategies. Tserng and Yu- Anumba et al. (2005) developed a tool (CLEVER_KM) to provide a structured approach to KM problem definition and strategy formulation for an AEC organization. Cheng (2004) presented an activity based Knowledge Management system for capturing the knowledge generated in the construction phase. Lin et al. (2005) proposed the use of knowledge maps for capture and reuse of knowledge in construction projects. Lee et al. (2005) developed a framework (Knowledge Document Management) for a web based portal which enables the user to search and read construction documents in different formats. Tan et al. (2007) developed a web based KM system (Capri.net) which allows for "live" capture of knowledge which can be subsequently used in the same project as well as future projects. Researchers have studied the issues associated with the definition for appropriate Ontologies and Taxonomies for the organization and useful retrieval of knowledge (Regzui 2006; El-Gohary and El-Diraby 2010,2011; Wang et al. 2011; El-Diraby 2013). A significant amount of research has also focused on the "people", state-of the practice, and implementation aspects of knowledge management (CII 2013, Ferrada and Serpell 2014, Zhang et al. 2013, Javernick-Will 2012). Solibleman et al. (2003) discussed web based systems developed by the U.S. Army Construction Engineering Research Laboratory to collect personal experiences and lessons learned on projects, success stories and best practices and incorporate these data into corporate knowledge. Caldas et al.(2009) identified effective management practices and technologies for implementing lessons learned programs in construction organizations.

It is important to note that the social systems, such as communities of practice, Lessons Learned programs, Post Project Reviews etc. for knowledge sharing and the Information Technology tools for KM are complementary to each other. The information generated in a construction project resides in various formats across organizational boundaries. Despite their limitations, Dave and Koskela (2009) warn against underestimating the impact of Information Technology (IT) tools for management of Knowledge in AEC organizations. A majority of the problems associated with the use of IT technologies seems to be around how it is implemented and managed rather than the capabilities of IT tools. If used in conjunction with KM strategies, IT tools have the capability of positively influencing project performance in terms of schedule and cost success and quality and safety performance (Yang et al. 2012). In this paper, we propose that BIM models can be used to capture knowledge as it is generated throughout the design and construction processes.

4. Capture of Knowledge

The parametric, object oriented design is one of the defining characteristics of Building Information Models. The model consists of objects which are defined by various parameters. Each object is not defined by the geometry alone, but rather by parameters. These parameters and the parametric relationships between objects define the behavior of the object inside the model. Software vendors typically provide a basic set of objects which are universally required during the structural, architectural and mechanical systems designs of a building. In the AutoDesk REVIT® software, these objects are known as *System Objects*. Objects are classified in various families based on their function in the structure. For example in AutoDesk REVIT®, a typical concrete beam belongs to the "Concrete-Rectangular Beam" *Family*. Each concrete beam is defined by two parameters that define the dimensions of the beam (breadth and depth) and a number of descriptive parameters under the Identity Data category (Uniformat II Assembly Code, Description, Model No., Manufacturer Information etc.). Within each Family, multiple "Types" representing combinations of width and depth may be created. For example, 18" X 24" and 24" X 32" are two different Object "*Types*" within this *Family*. When the object is placed within a model, an "*Instance*" of the object is created.

In addition to the default parameters defined in the software, the user can also create a user defined "Shared Parameter" and associate it with a specific set of objects in the BIM model. For example, a *"Shared Parameter"* called “Lessons_Learned_Concrete” was created and associated with Structural beam systems family. When an instance of a structural beam system is created in the model, the shared parameter is displayed as a property of the system (Figure 1).

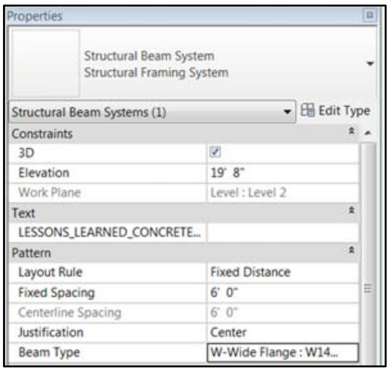

Figure 1. Shared Parameter for a Structural Beam System

The Shared Parameters can be defined either as “*Instance Parameters*” or “*Type Parameters*”. If the shared parameter is created as an Instance Parameter, the information entered therein by the user will only be available at that particular instance of beam system in the model. On, the other hand, if it is defined as a type parameter, it will be available to every instance of that type which exists in the model. Each of the strategies has its own advantages and pitfalls. The first strategy (defining as an “*Instance Parameter*”) can allow for vetting the information before it is published throughout the model, while the second strategy allows for instantaneous distribution within the model. An AEC firm can develop shared parameters strategically and deploy them to allow the users to enter the information as soon as the user learns something new / unique during the design or construction processes.

5. Extracting Stored Knowledge

The Shared Parameters discussed in the previous step can be deployed as early as the schematic design phase. The lessons learned and the new ideas generated can be extracted using two strategies. The organization can extract all the knowledge generated at the end of the project, vet it and share it across the organization. This strategy would potentially create a significant lag between knowledge generation and its dissemination. In the second strategy, the organization can set milestones during the design and construction processes when the knowledge generated and stored in the model can be extracted. This would allow for a shorter lag in dissemination of knowledge and spur continuous improvement.

As discussed previously, a BIM model can be conceptualized as a centralized object database. The knowledge stored in the database can be extracted in two ways. An application specific program can be written using the appropriate Application Programming Interface (API). This could potentially prove to be an effort that requires significant resources for the initial development and upkeep to stay current with the changing API. The second, easier, approach would involve the use of the Industry Foundation Classes (IFC) for data extraction. The IFC specification is an international platform neutral standard specification (ISO 16739) which is used to describe, exchange and share information between various software applications used in the AEC industry. AutoDesk REVIT® software allows the export of the BIM model as an IFC file, which is a structured ASCII plain text file.

The Shared Parameters and the information added by the users can easily be extracted from this file. The background information on the project can be extracted using the information associated with the relevant *IfcPropertySingleValue* and the associated *IfcLabel.* For example, the following line shows the information from the following line from the IFC file can be used to extract the project name (Birmingham Labs).

#1202= IFCPROPERTYSINGLEVALUE('Project Name',$,IFCLABEL('Birmingham Labs'),$);

Similarly information regarding the location, type, owner name, project stage, name of the designer can easily be extracted. This information can be valuable in the future when a user wants to know more information about the context in which knowledge was generated.

Once the relevant project related information is extracted then the user / program can extract the lessons learned / innovative ideas generated in the project. This information will be located in the *IfcPropertySingleValue* 'Lessons_Learned_Concrete', the corresponding *IfcLabel* will provide the actual text of the lesson learned / innovative idea. Additionally, one can also extract the "Mark" of the element. This will identify the location of that particular element in the model. If another person wants to get the complete context under which this information was entered, they can open the BIM model and look for that particular element. Once all the lessons learned are extracted, they are then classified. This classification can be performed using a classification system that is appropriate for the organization. The classified information should then subsequently be vetted by subject area experts for its accuracy and appropriateness. Once vetted, the new knowledge can be published to personnel working in the same specialty and stored in a centralized database for future reference and use.

6. Building Information Models and Knowledge Management

The following figure (Figure 2) describes a conceptual framework for using the method described in this paper for enhancing Knowledge Management Systems in an AEC organization.

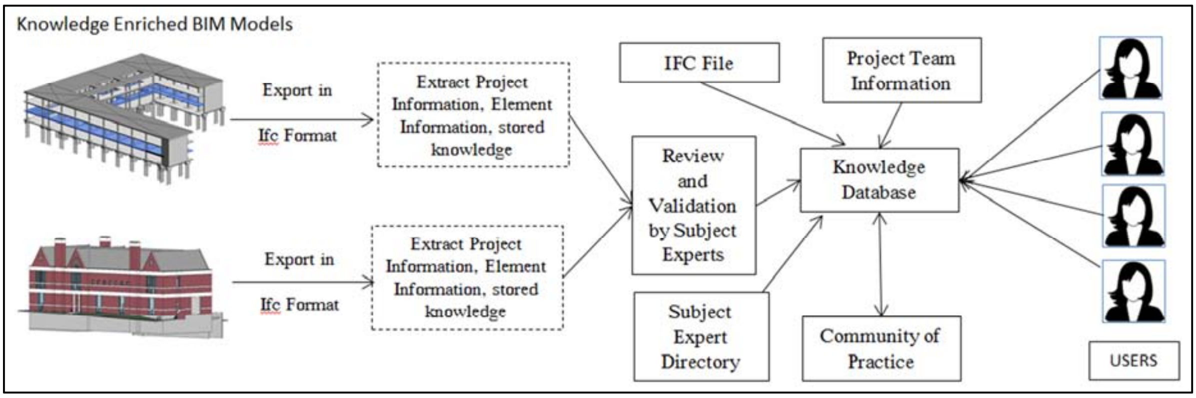

Figure 2. Conceptual Framework

In the first step, appropriate Shared Parameters are created and deployed, preferably at the beginning of the project. As new lessons are learned, knowledge is generated through design reviews, errors and ommissions, request for information from contractors and unique situations encountered at the site, these can be entered in the BIM model. At various stages of the design process and during the construction phase, the BIM model is exported in IFC format. The relevant knowledge can then be extracted. This information is then classified and vetted by experts in the subject area. After this, the knowledge generated can be published to other BIM projects in the organization using project standards. At the same time, the Knowledge can be archived for future use in a database. This database can contain information abount project team, lessons learned and a link to the location of the IFC file. The IFC file can be easily viewed by free software such as the Solibri Model Checker. As many experts have pointed out, information technology is only one of the tools for effective knowledge management in an organization. BIM models should be
used in conjunction with other KM methods such as Communities of Practice to get its full benefit.

7. Concluding Remarks

Building Information Modeling is increasingly being used by AEC organizations to improve project performance. The centralized and integrated nature of the design information in BIM models can provide a very context rich platform for the capture, storage and dissemination of the knowledge generated during the design and construction processes. A methodology for leveraging the inherently object oriented, parametric nature of BIM models for capturing lessons learned, innovative ideas, and knowledge generated during design and construction processes is presented in this paper. A framework for integrating this methodology in the existing KM practices is also presented. We are currently continuing this research. The remaining work includes the identification of appropriate ontologies and taxonomies for this method and the design of database for storage of the knowledge. We are also in the process of identifying an AEC firm to implement some of these ideas in a live project environment. Lastly, this could be one of the tools in a toolbox for management of knowledge generated in AEC projects.

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Creative Construction Conference 2014

A new approach to building design modularization

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Abstract

In this research a graph-based methodology has been developed to support modular building design. A graph-theoretic algorithm is used to decompose the design into modules that facilitate the future replacement of building components, allowing buildings to be more easily adapted to changing user requirements. The future flexibility of the building is increased by decomposing it into custom-designed modules, containing adjacent components that currently belong to different systems, but need to be replaced at the same time in the future. The reduction and standardization of the interfaces between the modules can also reduce the interdependencies between the activities for installing the building components, which are currently carried out by different subcontractors. It is shown that this approach to modularization increases the flexibility of the design, as well as reducing expected time overruns during project execution. Such overruns normally occur due to the knock-on effects of a delay in one construction activity on other interrelated activities that are carried out by different subcontractors. The methodology is demonstrated through a case study of a residential housing unit.

Keywords: Automation; Design Management; Modular Construction

1. Introduction

A Work Breakdown Structure (WBS) is commonly used in the planning of construction projects, in order to systematically break down processes into individual activities. The WBS can serve as an effective tool to identify and manage the interfaces between activities carried out by different teams or organizations (Chua and Godinot 2006). However, the WBS is currently often not sufficiently differentiated from the Product Breakdown Structure (PBS) (Lamers 2002). The PBS is based on a decomposition of the building into distinct systems and components, and the consequent division of labor between the different design consultants. Each of these components satisfies certain performance requirements. But such a decomposition of the design is based on the project's user requirements, not on those of the construction and renovation processes. When the WBS is merely regarded as an ersatz-PBS, the numerous and poorly managed interfaces between different activities, many of which are a result of physical connections between the components constructed in these activities, exacerbate project overruns. A delay in one activity immediately has knock-on effects that cause additional delays in other activities. The fact that interrelated activities are often carried out by different subcontractors increases this problem, as each subcontractor seeks to optimize the allocation of his resources among a number of projects he simultaneously carries out, and is less concerned with the effect that delays in his activities have on other subcontractors in the same project.

One solution to this problem is to use buffers in project planning. However, buffers generally involve the allocation of additional resources, such as time and manpower, which carry a cost. An additional solution, which this study seeks to explore, is to modularize the design of a building. As will be demonstrated, modularization can reduce the interdependencies between activities carried out by different subcontractors. The term modularization is used here to refer to custom designed assemblies of components, which have standardized interfaces with other assemblies. Such custom-designed modules diverge from the classical approach to modularization in construction, which seeks to divide the building into identical repetitive units. The standardization of the interfaces between modules, rather than the modules themselves, puts fewer constraints on the design, and makes it easier to accommodate the user's requirements for the performance of the project.

In order to take into account the entire life cycle of a building, modularization should also accommodate the future renovation and adaptation of buildings to varying user needs. Increasing the adaptability of buildings is one of the most effective ways to increase their value, and their users' satisfaction (Manewa, Pasquire, Gibb, & Schmidt, 2009). In practice, most buildings are, however, designed and constructed to suit their use at that time,

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and their future adaptability is ignored (Beadle, Gibb, Austin, Fuster, & Madden, 2008). As a consequence, components with different replacement rates are currently often physically and functionally connected to each other, with the result that minor changes require the demolition and replacement of many components. The hypothesis of the present research is that modularization can increase the adaptability of buildings through the systematic separation of building components whose replacement occurs at different intervals in the future.

In this study, a methodology has been developed to support a modularization of building design. Such a modularization would follow the preparation of an initial design, and precede the detailed planning of the construction (Figure 1). It is assumed that the modularized design would better serve the requirements of the construction and renovation processes. The design is decomposed into distinct modules, each of which contains several components that may belong to different building systems, but have the same replacement rates. The application of such an approach is particularly challenging in the design of large buildings, which contain thousands of different components that are interconnected through various types of relationships. Consequently, the present research focuses on the development of a semi-automated methodology that can support the definition of such modules. The methodology enables the functional and geometric coordination of the design of the modules.

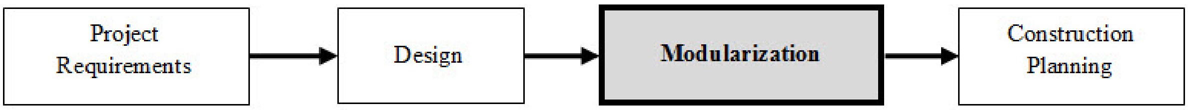

Figure 1. The proposed modularization phase, within the construction process

2. Methodology

The separation of building parts to allow adaptability has been studied in previous research. In Open Building systems, the 'base-building' and its interior are separated (Habraken, 2003). Most of the previous research has focused on the separation of entire building systems (Hansen & Olsson, 2011; Leupen, 2006). Durmisevic and Brouwer (2002) have proposed to extend this approach in order to include the separation not only of entire building systems, but also of individual components within a system, which may have different replacement rates. Following a similar approach, the modularization of the design is supported in the present research through a methodology composed of the following steps:

1. Representation of the building design and project requirements as a graph
2. Ordering the components according to their relative replacement rates
3. Implementation of a clustering algorithm to identify the optimal modularization
4. Verification of the adaptability of the design by calculating the betweenness centrality of the components.

1.1. Graph-based representation

The proposed methodology is based on the use of graphs to represent the design of building components. This information is extracted in IFC format from a Building Information Modeling (BIM) database, in which building components are represented as objects (Bock and Isaac 2013). It is then translated automatically into a graph-based model in which a set of nodes $i \in N$ represents the components in the design, and a set of links $(i, j) \in A$ represent physical connections between these components (e.g. when one component is covered by another component).

1.2. Ordering of the components

Components are ordered according to an initial assessment of their replacement rates, in order to define modules that contain components with the same replacement rates. The replacement rates r_i are stored in a generic database, and are based on pair-wise comparisons by experts, rather than on an assessment of the actual size of the life expectancies of the systems. It may be clear, for example, that the building structure is likely to last longer than engineering services components, and that some of these components will last longer than finishes and fittings, but it can be very difficult to determine the exact number of years they will last. It is therefore more feasible to use an order topology for such an assessment, instead of a metric topology. In other words, it is possible to assess which component is likely to be replaced sooner, even when it is difficult to assess when exactly this will happen. In addition to allowing the assessment of relative, rather than actual replacement rates, pair-wise comparisons have the advantage of being transitive, i.e.:

$$If\ r_i > r_j\ and\ r_j > r_k, then\ r_i > r_k.$$

Ordering the components in this way enables taking into account their technological and economic lifecycles.

1.3. Implementation of a clustering algorithm

Graph-theoretic measures of topology facilitate an identification of the optimal modularization of the design, in light of the physical connections between components and their expected replacement rates. Specifically, a clustering algorithm is applied to identify groups of components that are connected and have similar replacement rates.

The assessed relative replacement rates r_i are defined as attributes of the building components (Figure 4). A weight a_{ij} is added to link (i, j) to represent the difference between the relative replacement rates of components i and j:

$$a_{ij} = (1 + |r_i - r_j|)^{-1}.$$

Here a_{ij} is an entry in the adjacency matrix A of the graph, which is symmetrical (i.e. $a_{ij} = a_{ji}$).

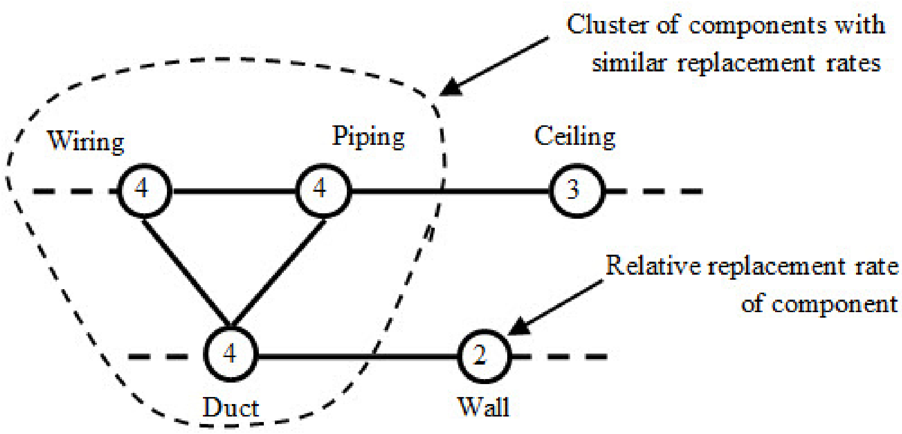

Figure 2. Relative replacement rates of the components (Bock and Isaac 2013)

A hierarchical clustering algorithm, based on lambda sets, is applied to identify clusters of nodes in the graph-based model. The link connectivity $\lambda(a,b)$ of a pair of nodes a and b is the minimum number of links that must be deleted so that there is no path connecting them. A lambda set is a maximal cluster of nodes S with the property that the link connectivity of any nodes within the cluster $a,b,c \in S$ is larger than the link connectivity of any pair of nodes, one of which is in the cluster and one of which is outside (Borgatti et al. 1990): $\lambda(a,b) > \lambda(c,d)$.

Thus, we expect the components within a module to share more connections than components belonging to different modules. When λ is large, the lambda set describes an assembly of components that are relatively difficult to disconnect from each other. These should be components which are installed onsite by the same team, and are unlikely to be replaced at different intervals in the future. Such a strategy can also enable the future disassembly of modules in order to upgrade and reassemble them, thus prolonging their sustainable life cycle.

A software called Visone was used to apply the clustering algorithm (Baur 2008). Visone was originally developed for the analysis and visualization of social networks, but was found to be useful in the present research for the analysis of construction projects as well. The two-step clustering algorithm employed first computes the link connectivity between all pairs of nodes. In the second step, the algorithm uses this information to construct the lambda sets.

1.4. *Verification by calculating betweenness centrality*

The clustering algorithm is used to support decisions regarding the modularization of the building design, in order to increase the constructability and adaptability of this design. These findings are verified by comparing the assessed replacement rates r_i of individual components with the betweenness centrality *g(i)* of corresponding nodes in the graph. The betweenness centrality *g(i)* indicates the importance of a node *i* in the organization of flows in the network, defined as the fraction all shortest paths between nodes in the network that pass through *i*:

$$g(i) = \sum_{a \neq i \neq b} \delta(a, b|i) = \sum_{a \neq i \neq b} \frac{\sigma(a,b|i)}{\sigma(a,b)}$$

where $\sigma(a, b)$ is the number of shortest paths between nodes a and b, and $\sigma(a, b|i)$ the number of those paths containing i as an inner node.

The correlation between the replacement rate r_i and the betweenness centrality *g(i)* should be negative. If the relationship is positive, this either implies that the replacement rates of these components are not low enough, or that they connect too large a number of other components. In the first case, the replacement rates of these components can be reduced through the use of buffers in the design. Such buffers are applied by designing components with a capacity larger than that required in order to fulfill the present user requirements in the building program. This extra capacity can be used in the future to absorb the impact of changes in user requirements, without requiring a change in the components. In the second case, relationships can be reduced through modularization, and the introduction of easily disconnected interfaces.

3. Case study

The proposed methodology was implemented in a case study of a typical housing unit, containing components such as interior partition walls, HVAC ducts and electricity piping (Figure 3a). To implement the methodology, a BIM model in ifcXML format was automatically translated into a graph representation in GraphML format. The links in the graph were weighted according to the assessed replacement rates of the components. For this, the components were divided into 3 groups with different relative replacement rates: 1) Structural and building envelope components; 2) Main ducts and pipes of the M&E systems; 3) Partition walls, and local ducts and pipes.

A clustering algorithm was then executed in the Visone software, and a number of clusters identified as potential modules. These included assemblies of components belonging to different M&E systems, as well as partition walls and the pipes they contain. Following the identification of these potential modules, the design could be adjusted, for example by replacing existing partition walls with a Robotic Service Wall that was developed in another funded research project – "Living Independently In South Tyrol Alto Adige" (Figure 3b) (Linner, Georgoulas, & Bock, 2012). This wall can be custom designed according to various configurations, and can be easily installed in any residence without requiring specific space dimensions. The choice of modules was verified by comparing the assessed replacement rates of the components in the modules, with their betweenness centrality. As expected, those partition walls that were identified in the clustering algorithm displayed a high betweenness centrality, yet also had a high replacement rate. This confirmed that the changes that were likely to be required in the future for these walls would also affect many other components, unless a strategy of modularization was implemented.

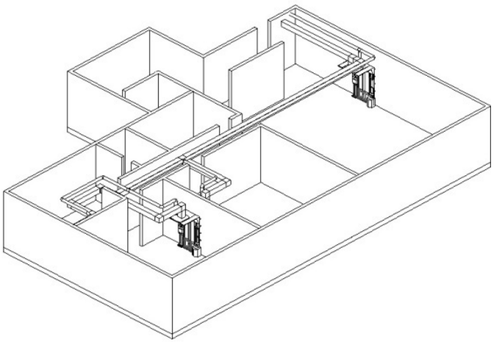

Figure 3a: Model of housing unit

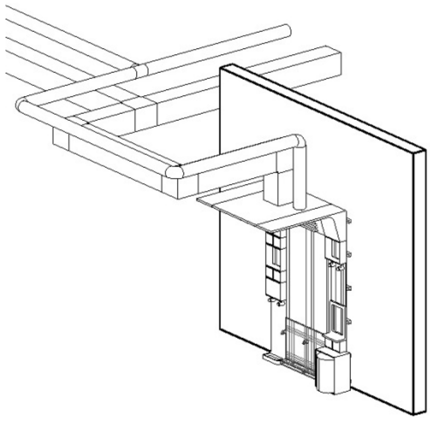

Figure 3b: Modular service wall

Figure 3: Case study

The impact that the modularization would have on the duration of the initial construction process was also assessed, through a Monte-Carlo simulation of the sequence of activities required to install the different components in the housing unit (Figure 4). The assessment of the durations of the individual activities in which the modules would be installed was very conservative. In fact, these durations were defined as being identical to the durations of the activities for installing the components in the original design – while in practice it is highly likely that they would be much shorter, due to the relative ease of installing a small number of modules with standardized interfaces. Despite this, the simulated duration of the entire construction process was found to be shorter for the modularized design, with a 90% probability that it would take up to 16 days. This, in contrast to a 90% probability for a duration of up to 19 days for the construction process according to the original design. Since the durations of individual activities were assessed to be identical in both versions, this change can be entirely attributed to the reduction of interfaces between activities carried out by different subcontractors, when modules are introduced.

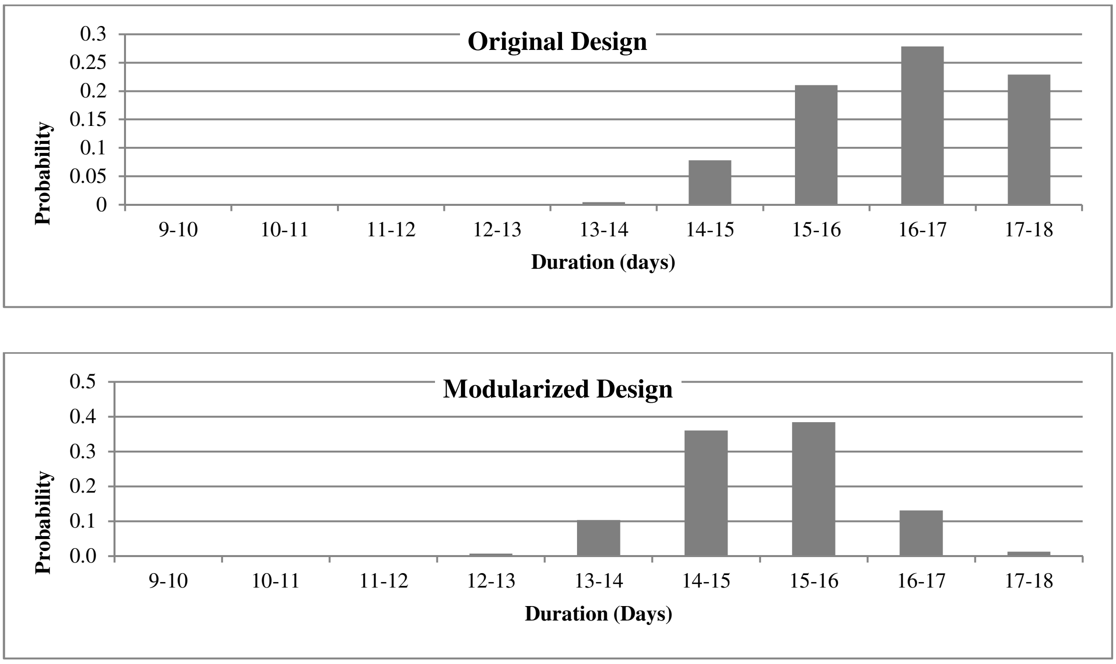

Figure 4: Simulated duration of construction process according to the original design and the modularized design.

4. Conclusions

The design of buildings can have a major impact on the way they are constructed and renovated. Changing the design of a building can improve its constructability and the efficiency of construction processes, and enable future physical changes to be made in the building with greater ease, in accordance with changing user needs. The design of a building should therefore take into account its entire lifecycle, including onsite construction and renovation activities. In the present research, a graph-based methodology has been developed to support a modularization of the design that would better serve the requirements of the construction and renovation processes. The implementation of the methodology in a case-study demonstrates that modularization can ensure a more distributed construction plan, replacing the tightly coupled structure of current construction plans.

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An ontology framework for rule-based inspection of eeBIM-systems

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Abstract

Simulations enable detailed studies about the behavior of the building for optimizing the energy-efficiency. While this is an absolute advantage there are also problems regarding the daily work of experts because the simulations costs much time and before simulations can be done the configuration can be very huge and the pre-processing erroneous.

To overcome these problems an eeBIM-ontology-based (Energy Enhanced BIM) framework is proposed applying inference rules to pre-check the input data and to pre-analyse the energy performance on a lower detail level, before the simulation phase will start. The ontology specification provides the concepts and relations to describe the building, the external data like the climate data as well as the linking between the BIM-concepts and the external data. Furthermore, constraints and calculation methods are transferred as far as possible into logical rules. The surrounding ontology platform enables the integrating of the input data and manages the process of the calculation methods. It also defines certain external connection points for calculating methods, which cannot appropriate represented in rules.

The ontology framework helps to identify building designs which have problems to fulfil energy performance requirements even at a very early stage of the design phase. So, the ontology follows the idea of typical engineering regulations including simplified methods for easy and practical use.

Keywords: BIM, eeBIM, Energy, Knowledge Management, Ontology

1. Problems and Challenges

Building energy performance analyses require a certain quality of the given domain models serving as input for the envisaged analyzing tools. According to the three layers of semiotics syntactic layer, semantic layer and pragmatic layer the domain model quality can be divided into three quality levels:

- **Syntactic Quality**: The domain models fulfill syntactic quality, if the analysis can be executed and analysis results can be delivered.
- **Semantic Quality**: The domain models fulfill syntactic quality and the analysis shows meaningful results (e.g. the energy consumption of a building is realistic and follows energy regulations).
- **Target Quality**: The domain models fulfill semantic quality and the analysis shows results following a task specific target function (e.g. the energy consumption of a building variant has to be lower than the energy consumption of the existing building variants).

The inspection of the model quality needs next to the domain models the descriptions of the requirements of the analyzing tools and the certain context description the domain models and the analyzing tools are used. The type of inspection proposed in this paper aims at pre-checking the domain model syntactic quality by describing the domain models, the analysis requirements and the context information in a holistic model called system analysis model. In most cases theses three kinds of information are separately considered and the combination of these information is be carried out manually. This has the consequence that pre-checking of domain models is done for each process step separately avoiding the overall inspection of the whole analysis process. So, the International Alliance for Interoperability (IAI) defined the IFC Model View Definition Format to specify which data should be in the building information model (BIM) (Hietanen, 2006) for a following completeness check. Here, capabilities for inspecting process steps in an overall context are missing. For achieving such a holistic model approach the analysis and the analysis context has to be specified. This will be done in a process model, which supports the different levels of building design by providing different levels of detail for the process modeling. Next to this, the input and output of the processes has to be described. Therefore, the BIM-model has to be semantically enriched to an energy enhanced BIM-model (eeBIM) integrating the additional energy relevant information like climate data, occupancy data, etc. This integration comprises the specification of new

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BIM-elements extending the existing elements to serve as connection points for the additional non-BIM information. The development of such an extended BIM-model (eBIM) deriving the extending elements mostly automatically and supporting the linking with the non-BIM data is the first step towards eeBIM.

Several modeling technologies were published to overcome the interlinking or integrating of different heterogeneous data formats in a sufficient model quality. (Fuchs, et al., 2010) showed how the linking of different raw data models, called elementary models, can be interlinked with a light-weight XML format. The elements of elementary models are connected and the raw data is leaved unchanged. (Curry, et al., 2012) presented a similar approach by using RDF (Resource Description Format) which allows the usage of semantic web features like querying with SPARQL. They used IFC as representation of BIM and mapped elements to RDF. (Beetz, et al., 2008) presented an approach how to map EXPRESS to OWL (Web Ontology Language) which can be used to transform IFC to the ontology representation (IfcOWL). In this paper an ontology is proposed as modeling technology forming the framework for the rule-based eeBIM pre-inspection. Thereby, this system analysis ontology uses IfcOWL for describing the BIM domain.

2. Analysis Context

The inspection of the correctness of the domain models and their combinations (eeBIM) starts with the question in which analysis context they will be used. The analysis describes a process consisting of different sub-processes and process steps. So, the analysis context is formed by the process description and the required input and output. The domain models and their linking as well as the analysis tool description and the related analysis models summarized in an environment model represent the input and the output of the analysis process (Figure 1, left).

Along the process flow the necessary input and output depends on the process or process step, which will be executed. This implies that a model checking is always process bound. Thereby, the description of a certain domain represented by its corresponding elements can be more detailed, but also more abstract at the end of the process. So, according the process flow and the level of detail (LoD) between the IO-models a general qualitative interdependence and a generic specification of process rules cannot be formulated, because also the LoD of the IO-models is process bounded.

The ontology supports the process inspection on different level of process. Here, in contrast to the process flow the detailing of a process requires more detailed information of the input and the output for describing the sub-processes. So, a higher process detailing implies a higher LoD of the IO-models and an inspection fails, if the IO-models of the sub-process are not presented in a higher LoD.

Following the formulated dependencies the ontology process model provides the definition of different process levels starting with process areas, guidelines, etc. and ending with certain process steps specifying a certain view of the domain models. Thereby, the ontology description lays the focus on the static properties of a process. This means, the ontology checks the correctness of the IO-models, but not the correctness of possible alternative IO-models, which will be generated during the process execution. For the model checking each process is related to a set of logical rules specifying restrictions, cardinalities, etc. for the domain model and environment model schemas (Figure 1, right). These logical rules represent the requirements the given models and their instances have to fulfill for the related process. The environment and domain models with their certain instances represent the resources, which have to follow the given model schema and the related rules. Thereby, two processes can be related to the same model-schemas, but to different logical rules. This would mean that the processes are operating on the same domains and the same environment, but they need a different view for the process execution. So, the process model comprises both the “To-be” description represented by the model schemas and logical rules and the “As-is” description represented by the model instances.

The simultaneous use of model description and rule definitions shows the advantage of ontologies as modeling technique, which allow specifying domains and interpreting these specifications by applying common semantic tools.

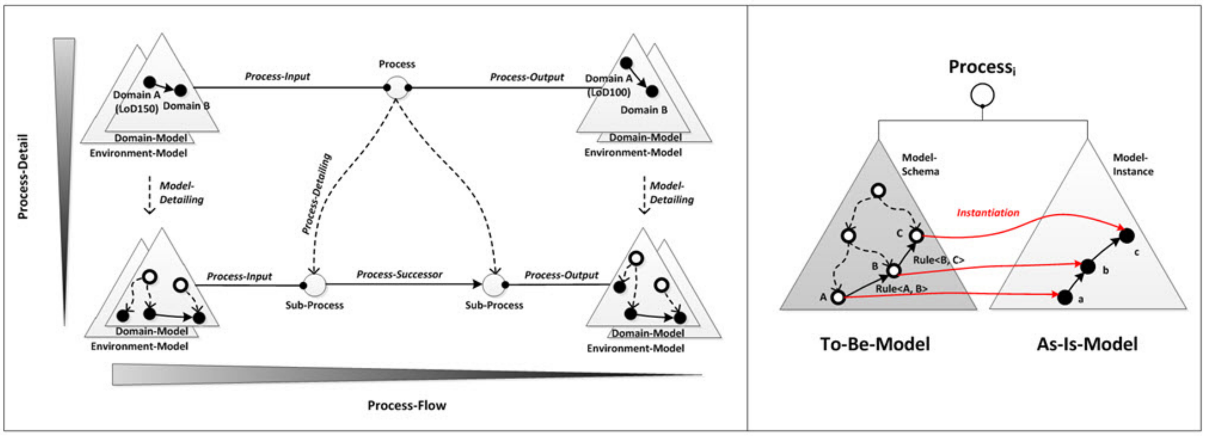

Figure 1. Ontology Process Model

3. eeBIM

For the certain engineering analyses the use of one domain model is mostly not enough. Often, additional information coming from other domains are required and have to be combined creating an overall information basis and providing the input information for the envisaged external simulation tools and their related simulation models. In particular, the focused energy performance analysis of buildings needs next to the BIM information describing the architecture of the building, information about the climate, the user behavior, etc. To combine these different domain information two core strategies can be distinguished: Centralized information integration and decentralized information integration. By using the centralized approach only one domain model representing the center model is related to the other domain models. The decentralized approach is characterized by domain models, which can be combined arbitrarily with each other. Caused by the fact, that for building design issues the building and the corresponding BIM model is focused, the ontology approach follows the centralized integration with the BIM model as center model. BIM model implementations like the IFC aim to provide general concepts to cover common building design scenarios, but for specific engineer tasks additional BIM information are required to extend the architecture model. This extended BIM (eBIM) has to offer the connection points needed to link the information of the non-BIM domain models and to complete the overall energy enhanced BIM model (eeBIM).

In the ontology approach the BIM model is represented by the BIM ontology, the extension of the BIM model is represented by the Interface ontology and for realizing the eeBIM model the non-BIM ontologies have to be linked (Figure 3, left). To transform the raw data into ontology information they have to be mapped and linked:

1. 1 to 1 mapping just transforms the data format into ontology format. In the most cases it is a XML to OWL or IFC to OWL transformation.
2. The reduced mapping does not map the complete data into the ontology. To achieve a lean ontology model not all data are integrated (e.g. geometry data are not considered). Instead of the whole geometry model only derived abstract data are included (e.g. the width or height of a room instead of the whole room geometry).
3. N to 1 mapping combines several data to get one ontology element. Vice versa 1 to N mapping splits one data element into several ontology elements.
4. Direct linking is done in the course of the element mapping operations or manually, if corresponding elements cannot be identified by algorithms.
5. Implicit linking is based on ontology rules used to interpret implicit information for generating explicit links. This is mainly done for linking the BIM- with the Interface-ontology.
6. External linking describes the linking between an ontology and a data element (mapping ops/manually).

4. eBIM

In order to come to an energy interpretable BIM we defined a step-wise data extension so that energy-related entities are explicitly given and forming the connection points to non-BIM data (see section 3, point 5). For doing so, we check the LoD the information is structured first. As an absolute requirement we suppose that space boundaries are given where associated building elements can be considered geometrically as external or internal (Bazjanac, 2010). With such information we can consider if e.g. a wall is an outdoor or indoor wall etc. Figure presents an excerpt of our rule set for bringing the BIM entities to an extended BIM representation which is more type-safe and tool interpretable. Rule number one checks if at least one space boundary is described as “EXTERNAL” and if this is the case the whole window is inferred as outdoor window. Rule number two checks if a building element is a façade element by analyzing the space boundaries in the same manner as in the orange rule. Rule number three expresses that all façade elements are part of the building façade.

In another rule set we make a similar analysis where IfcSpace entities are evaluated. For example, based on the name of the room and the definition given by a room book an IfcSpace is assigned to be an office room (defined as OWL class “WorkRoom”) or a technical room (“TechnicalRoom”) which both extends IfcSpace. With such an association heated rooms (e.g. office, living area etc.) can be isolated from unheated rooms (e.g. cable funnel, elevator etc.) in a next step.

After the extended elements were generated and linked, a check is performed if all individuals were inferred correctly. When rule sets which bring the BIM to an eBIM cannot be applied (and validated), it indicates that there is a problem regarding the possibility to perform an energy analysis. The checking against constraints and reasoning with rules are big advantages when working with BIM. While there are many existing specifications how a well-modelled building should be provided (e.g. through LoD), it is not explicitly defined in the model schema and therefore not mandatory. The way of expressing model requirements through rules leads to a consistent workflow later and saves time in the case, that an energy simulation fails or produces wrong results.

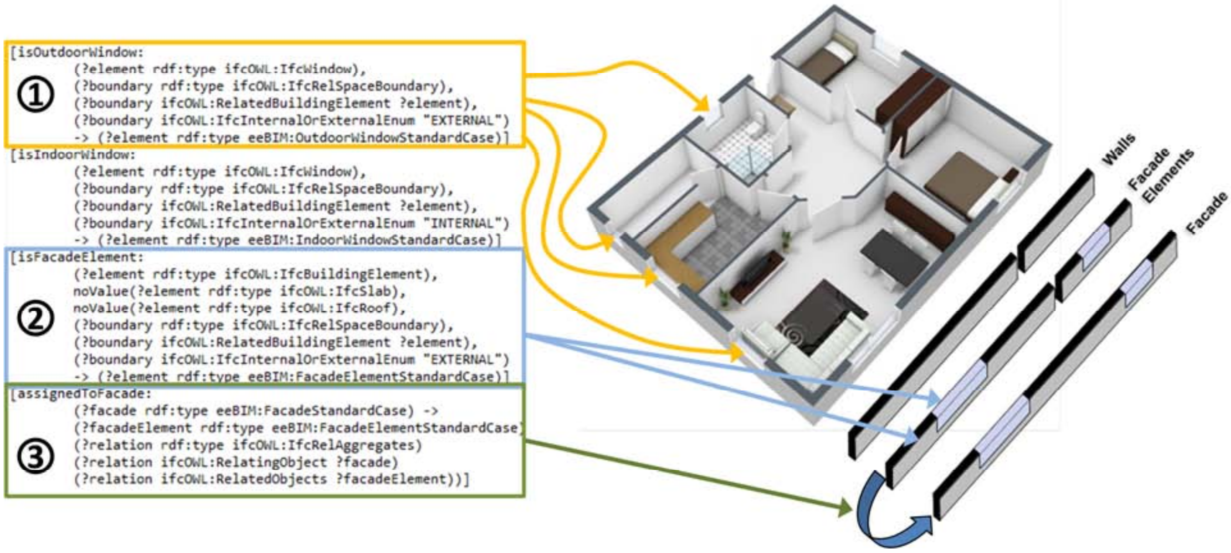

Figure 2. Rule set for finding outdoor walls, outdoor slabs, outdoor windows, indoor windows, façade elements and the façade

5. SemeeLab

To integrate the overall system analysis ontology and its functionalities a specific platform called SemeeLab (Semantical energy efficiency Laboratory; Figure 3, right) was developed. SemeeLab is a web platform for building energy performance analyses based on BIM. It allows assignments to BIM entities, performs thermal energy simulations and simple cost calculations based on energy resources like materials, climate and occupancy. SemeeLab brings together architects, energy planners and facility managers while integrating their specific software tools for design and result validation ((Baumgärtel, et al., 2011), (Baumgärtel, et al., 2012)) and store needed resources in a BIM server.

The web platform consists of a middleware, called SemeeCore, which controls the data management, tool management and workflows. SemeeCore is connected via web service with a BIM server where all the resources are stored and versioned and is connected to a cloud environment where the energy analysis computation will be executed. End user applications like design tools, e.g. CAD tools, and validation tools, e.g. room requirements or cost calculation tools, are connected to SemeeCore via web clients and have access to prepared ready-for-simulation data and energy results of previous simulations.

For integrating the heterogeneous data models into the system analysis ontology according to the needed level of detail a multi-layer approach is used (Baumgärtel, 2013). This multi-layer approach comprises seven layers: Data Models, Model Services, Unified Information Model, Business Services, Process Definitions, Access Layer and Apps. Thereby, the integration process begins at the bottom in the data model layer and ends in the application layer.

Data models are models represent domain related information like the building model for the architectural domain, climate data and occupancy data for the energy domain or the product data catalogues of manufacturers. They are provided in different data formats like IFC2x3, XML, STEP or CSV. The purpose of the platform is to keep each data model as it is and only change it by the user who is responsible for that model.

For doing so, Model Services comprise in first place parsers (e.g. IFC parser like BIMfit (Windisch, et al., 2012), XML parser) which read the models and bring them in computational state. For other data like eeData there exist XML parsers or other text parsers to allow the data exchange. To fill the ontology triple store (subject-predicate-object) an ontology model service (Multi-Model Combiner) based on Apache Jena (Jena, 2010-2013) is implemented and can be used by all other model services. When parsing the models the multi-model combiner checks the LoD of the model and integrates the needed model elements.

From this point of time all information will be retrieved from business services. Business services are top-level services which mainly use the system analysis ontology to retrieve needed information, e.g. to process user requests and to bring BIM to eBIM and finally to an eeBIM representation. These workflows are aligned in the process definition layer and can be started through the access layer which provides web interfaces (with REST) to external applications where users can configure simulations and can take a view on the energy building performance.

The Application Layer contains all programs, tools web and desktop applications which are using SemeeLab for data visualization, information management, simulation management or report management. The clients have to implement the functionality to call the REST interface provided by the access layer. The other layers are hidden behind the access layer so that the applications only have to fulfil the contract of the web interface.

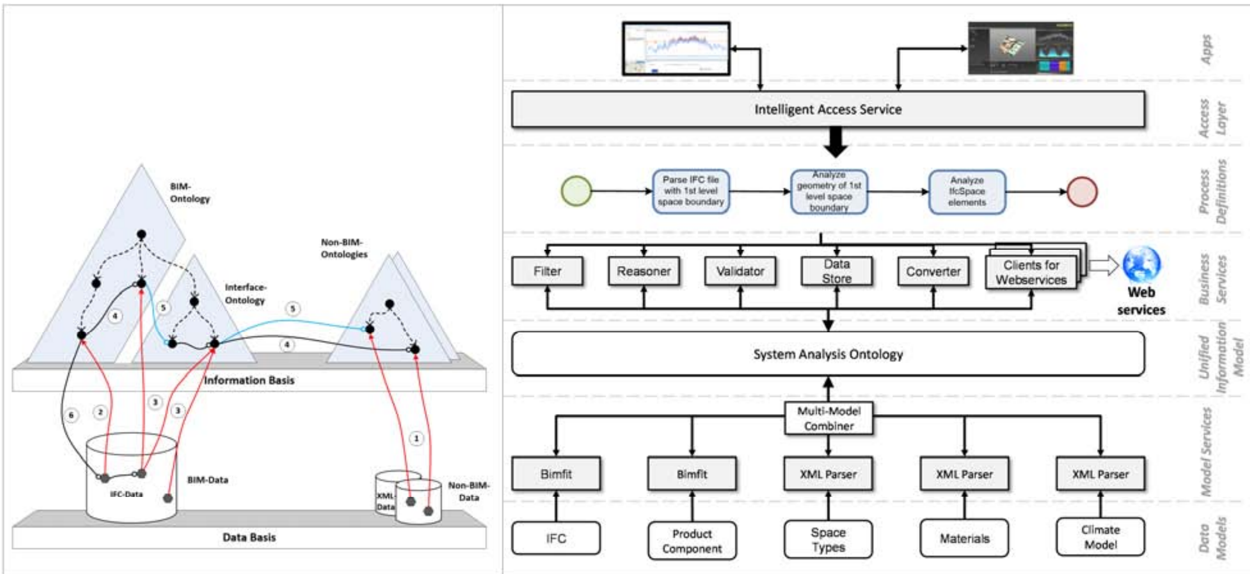

Figure 3. Multi model integration

6. Conclusion

In this paper an ontology approach was presented forming the base for a semantic integration of different domain models for supporting the design of an energy efficient building. Here, the advantage of ontology-based description was used to consolidate the heterogeneous resources and to inspect the given model quality with regard to the envisaged energy performance analysis. So, on the one side the ontology provides the description of the domain models by specifying certain concepts and on the other side the underlying mathematical basis enables the definition of logical rules and in this way the interpretation of the made specifications and their interoperable use. Cause of the reason, that simulations costs much time and before simulations can be done the configuration can be very huge and the pre-processing erroneous, the ontology approach aims to pre-check the given input data by defining and applying appropriate logical rules. This kind of inspection allows the identification of modeling mistakes in a very early stage of the design process by using only common semantic tools. For achieving such a holistic model approach the analysis context was specified formulating a process model and the BIM-model was semantically enriched to an energy enhanced BIM-model (eeBIM) integrating the additional energy relevant information like climate data, occupancy data, etc.

The ontology and the corresponding ontology platform were developed and will be further developed in the European *ISES* project. It could be shown, that the application of the ontology approach helps to identify modeling mistakes as it was planned. At the moment there exists only a small set of inspection rules checking the syntactic quality of the eeBIM model. This set of rules will be extended in further work. Furthermore, rule implementations are planned checking the semantic and target quality of the eeBIM model and reducing the time simulation software will use for quality control.

Acknowledgments

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BIM CAVE for 4D immersive virtual reality

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Abstract

The CAVE (Cave Automatic Virtual Environment) system, first introduced in 1992 during SIGGRAPH, was designed to facilitate users to feel the sense of presence in a 3-dimensional computer model. Those who were in the CAVE system and surrounded by walls of screens and floor projecting viewer-centered images felt that they were actually in the 3D computer model.

As Building Information Modeling (BIM) technology has been widely utilized in the construction industry, especially for informed decision making during preconstruction coordination meetings, one may wonder if the CAVE system would enable them to better review the model. Knowing that the original CAVE system was not designed to handle BIM data, our research team developed a BIM CAVE system on top of a commercial BIM application so that one can review the model in the CAVE system without having to convert BIM file formats. Our BIM CAVE system is currently consisting of 3 video walls and 3 personal computers projecting the rendered images of a NavisWorks model. The BIM CAVE application we developed controls the camera location and its aiming angle in the NavisWorks model, so that 3 video walls can project the viewer-centered images synchronously.

Although our BIM CAVE system successfully enabled users to walk through a Building Information Model in real time, the BIM CAVE was not able to display the sequence of construction. Our research team recently updated our application for the BIM CAVE to display 4D construction sequence.

This paper presents how our new application was developed. It also presents technical challenges we experienced and solutions we came up with for those challenges. Some example uses of the BIM CAVE are also presented in the paper.

Keywords: 4D, BIM, CAVE, Virtual Reality

1. Introduction

Due to increase in the complexity of projects in Architecture, Engineering, and Construction (AEC) industry the focus of visualization techniques has shifted from two-dimensional (2D) graphical representations to three-dimensional (3D) graphical representations, more specifically Building Information Modeling (BIM). BIM is more effective than the 2D drawings as it makes the visualization process easier. Apart from using BIM for the purpose of visualization, engineering analysis, conflict analysis, checking code criteria, cost engineering, as-built data, and budgeting it is also used to develop 4D models where activities of a schedule are attached to 3D components to simulate the construction sequence.

As the projects become more complex, the complexity of 3D models also increases. The way humans interact with computers is totally different from their natural tendency of doing the same action in real world as visualizing 3D models on 2D screens limits the amount of information that can be gathered. Immersive virtual reality systems can narrow this gap between the real and the virtual world. Immersive Virtual Reality (IVR) is a technology enabling the users to feel the sense of presence in an artificially immersive environment. Construction professionals can use the immersive nature of the virtual reality to gain a better understanding of both qualitative and quantitative nature of space that they are designing (Bouchlaghem et al., 2005). In an immersive environment, Moreover, the increased field of view, both horizontal and vertical, will increase the sense of presence (Hatada et al., 1980). This is the main concept in CAVE (Computer Aided Virtual Environment) virtual reality systems to have the user surrounded by screens to create an immersive environment.

Several documented studies have shown 4D CAD as a good visualization and schedule review tool. More project stakeholders can understand a construction schedule more quickly and completely with 4D visualization than with the traditional construction management tools (Koo and Fischer, 2000). 4D construction sequence in currently available commercial software on a single screen limits the spatial perception. In the case of large and complex facilities, use of these tools for schedule review may be time consuming as 3D objects are visualized on

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a 2D desktop screen (Yerrapathruni, 2003). This reflects in the longer durations of schedules developed and visualized using the timelining of construction on a single screen as the work force interference between trades is not visualized and taken into account while planning parallel activities (Whisker, 2003).

2. CAVE

CAVE™ (Cave Audio Video Environment) is an immersive virtual reality environment designed in 1991 at the Electronic Visualization Laboratory (EVL), University of Illinois at Chicago. It was designed to display the work of computational scientists on high-end workstations attached to large projection screens interactively. It was implemented and demonstrated in late 1991 as a response to the challenge by SIGGRAPH '92 showcase effort to develop and display one to many visualization tools which used large screen projectors (Cruz-Neira et al., 1993). The CAVE™ that was exhibited had a $10^{ft}\times10^{ft}\times10^{ft}$ theater made up of three rear-projection screens for walls and a down-projection screen for the floor. These projectors throw full-color workstation fields (stereo images). A user's head and hand are tracked with electromagnetic sensors. Stereographic LCD stereo shutter glasses are used to separate the alternate fields going to the eyes. Some of the shortcomings listed in the research include: cost, inability to project on all six sides of the CAVE™, light spillage, fragility, and ability to document.

The CAVE virtual reality environments that were built previously operates on custom made application developed using standard set of libraries (e.g. CAVE™ libraries). To view a model developed in commercially available 3D modeling applications in the CAVE system, they need to be converted into the custom format recognized by the IPD system, where they could be displayed in one-to-one scale. StarCave, the immersive virtual reality system developed at SEALab supports 3D model files in VRML (Virtual Reality Modeling Language) format (DeFanti et al. 2009). The VRML format mainly contains only geometrical information of the 3D components (DeFanti et al. 2009). BIM models created using some of the commercially available application have to be converted to the VRML format before viewing them in the CAVE environment (DeFanti et al. 2009). The custom made application used by the CAVE systems also has their own tool to create 3D models rather than importing from the commercial application.

3. BIM CAVE

It is reasonable to assume that the process of transforming the BIM data into the CAVE system may not be simple, and engineering data attached to the BIM could be lost while they get transformed because of lack of interoperability between major BIM applications and CAVE systems. These challenges could hinder professionals in the construction industry from best utilizing the CAVE system to review the Building Information Models. One then might be wondering if we can imitate the functions of the CAVE system using commercial BIM applications. If it is possible, we might be able to review the Building Information Model in the CAVE without having to worry about the conversion process or any data loss. For example, if the CAVE system can be developed on top of Autodesk NavisWorks, which is one of the popular commercial applications developed to review the Building Information Model, the file conversion process would be seamless because NavisWorks is designed to open the model created by major BIM applications.

In Fall 2011, in order to remedy the shortcomings of the existing CAVE systems in terms of reviewing the Building Information Models (BIM), we developed a system that creates an immersive virtual environment using three video walls and Autodesk NavisWorks. As shown in Figure 1, each video wall consisting of four 46-inch ultra-thin bezel LCD flat monitors is placed to create a partial octagonal space. Each video wall is connected to a dedicated personal computer. Autodesk NavisWorks is use to create the rendered images of the Building Information Model in real time. In order to produce the viewer-centered images of the Building Information Model for the users in the middle of the partial octagonal space, we developed a computer application that control the camera location and aiming angle in the NavisWorks model. We used the NavisWorks application Programming Interface (API) to develop this application. Our application is designed to enforce NavisWorks installed on three computers to place the camera at the same location in the model. The camera's aiming angle in each NavisWorks model is determined by the interior angle between two video walls. Therefore, when the same NavisWorks model is loaded on each computer, our application enforce each NavisWorks application to place the camera at the same location in the model and create the rendered images of the model with different aiming angle. The collection of these rendered images projected on each video wall is creating the viewer-centered image for the users sitting in the middle of these video walls.

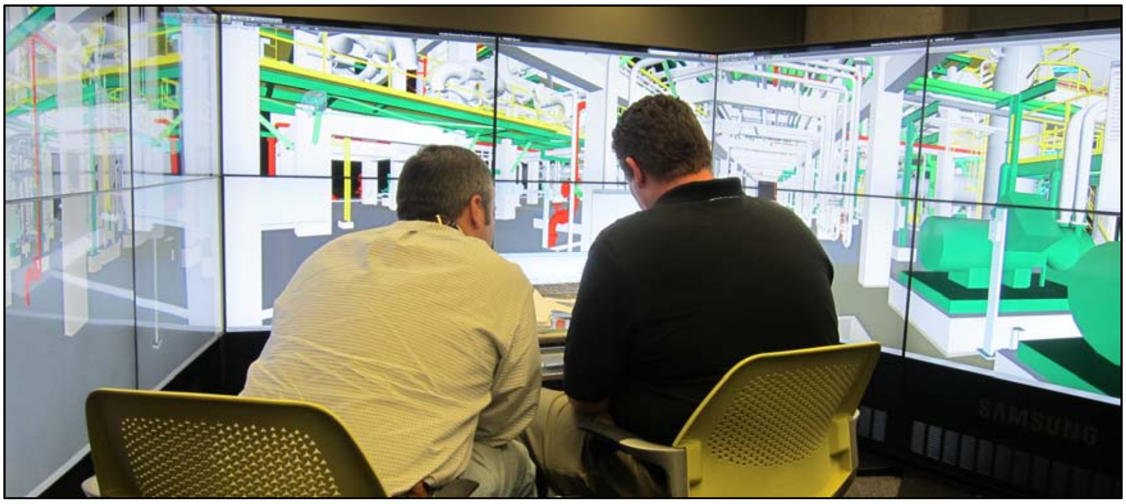

Figure 1. BIM CAVE at Texas A&M University

4. BIM CAVE for 4D Simulation

With the increasing complexity of the projects, the models are getting equally complex. This creates a demand to have an effective immersive visualization system to view and browse the 4D models. Previous research has shown that by interactively generating the construction schedule in the immersive virtual environment, the construction professionals developed a plan that resulted in a 28% savings to their original schedule (Yerrapathruni, 2003). The existing BIM CAVE system only achieved control over the camera position and its orientation while navigating through the model. It does not have a mechanism that helps in visualizing construction sequence, which depicts the project schedule. The .NET API's (Application Programming Interface) provided by Navisworks Manage 2012 further motivated to investigate the benefits of timelining the construction sequence in BIM CAVE.

5. BIM CAVE Application

As the .Net classes and methods controlling timelining in Navisworks Manage 2012 are not exposed to be used in Automation, plugin applications controlling the timelining in Navisworks Manage 2013 had to be developed. These plugin applications play the 4D construction sequence forward by one day, forward by one week, backward by one day, backward by one week, and bring the construction to the 1st day. These plugins uses methods which are defined under the class "LcTISimulationHelper" under the namespace 'Autodesk.Navisworks.Api.Interop" which is defined under the assembly "Autodesk.Navisworks.Timeliner". These plugins are developed in Microsoft Visual Studio C# using the methods "Step()", "ReverseStep()", and "Stop()". After building the solution in Microsoft Visual Studio C# two files are developed under the folder bin\Debug. They are: 1) DLL file, and 2) Program Debug Database. These files are copied to a folder in the Plugins folder under C:\Program Files\Autodesk\Navisworks Manage 2012 in all the three computers in BIM CAVE system. The name of the folder should match the name of the files generated. This ensures the loading of plugin under Add-Ins tab whenever the Navisworks Manage 2012 application is opened to view a model.

The BIM CAVE server application performed two main functionalities to achieve immersion as follows:

- Captures the current camera view of the Navisworks application running in the server computer (using Navisworks API) and applies a mathematical algorithm to the camera coordinates.
- The server application after collecting and manipulating the camera coordinates will send those coordinates over the network to the client computers. The camera coordinates will be sent to the clients whenever the camera position in the Navisworks running on the server changes.

As a part of this research an additional functionality has been added to the previous BIM CAVE server application to achieve immersion during timelining the 4D construction sequence.

- Captures the action performed in the server application to change the day of construction in 4D construction sequence (like StepForward, Forward, ReverseStep, Rewind, and Stop) and forces the Navisworks application to show the model on that specific day during construction.
- The action performed in the server application is sent over the network to the client computers. These actions performed in the server application will be sent to the clients whenever the action is performed along with the camera coordinated and orientation.

The client application is similar to the server application and it is also a stand-alone executable file, which is loaded only into the client computers.

- The data packets sent by the BIM CAVE server application containing the camera coordinates will be received by the client application.
- Once the data packets are received, the BIM CAVE client application will process the information sent and use it to update its current camera orientation in the Navisworks application.

We recently added some functions to the BIM CAVE:

- The data packets sent by the BIM CAVE server application containing the action performed in the server application with respect to timelining will be received by the client application.
- Once the data packets are received, the BIM CAVE client application will process the information sent and uses it to update the day of construction in 4D construction sequence in the Navisworks instance running in the client computer synchronous to the server application.

6. BIM CAVE Application Interfaces

The BIM CAVE's server and client application should be installed in the server and client computers respectively. The server and the client application have a button 'Start Navisworks', which will let the user select a Navisworks file and open the same. Essentially all the four computers run a separate instance of the same Navisworks file and only their views and stage of construction in 4D construction sequence are synchronized using the BIM CAVE application. It is highly important to make sure that the files that are opened in the server and client computers are the same to have a meaningful view across the screens. The server application has a dropdown list box that lets the user specify a camera rotation angle for the clients, which is dependent on the orientation of the screens. The 'Connect' button in the server application opens the port to allow the clients to connect with the server. The server application has a textbox that gets the port number input from the user. The default value for the port number is set as 8000 for both the serve and clients. The server shows a status message indicating whether the clients are connected or not. The five buttons in green shown in the Server Application Interface controls Timelining. Figure 2 shows the server BIM CAVE application interface.

Figure 2. BIM CAVE Server Application Interface

The client application has a textbox to get the IP address input from the user. The server computer's IP address displayed in the server BIM CAVE application should be entered in the textbox and the port number should also be same as the server. The 'Connect' button in the client application will establish a connection between the server and client computers. Figure-5 shows the client BIM CAVE application interface.

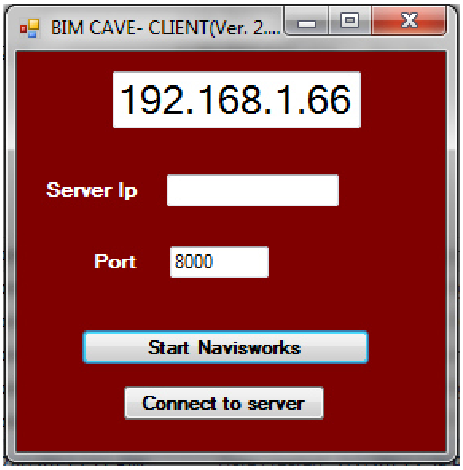

Figure 3. BIM CAVE Client Application Interface

The operating instructions of the BIM CAVE application are explained in the following steps:

- Using the 'Start Navisworks' button in the server and client BIM CAVE application, the same version of Navisworks file is opened in the server and client computers.
- After opening Navisworks, the server computer's IP address displayed in the server BIM CAVE application is entered in the textbox of the client BIM CAVE application.
- The server computer should be made to allow the client computers to connect to it by clicking the 'Connect' button in server BIM CAVE application.
- The clients are then connected to the server by clicking the 'Connect' button in the client BIM CAVE application.
- Once the clients are connected, the angle of rotation for the right and left clients are specified in the drop down list box of the server BIM CAVE application.

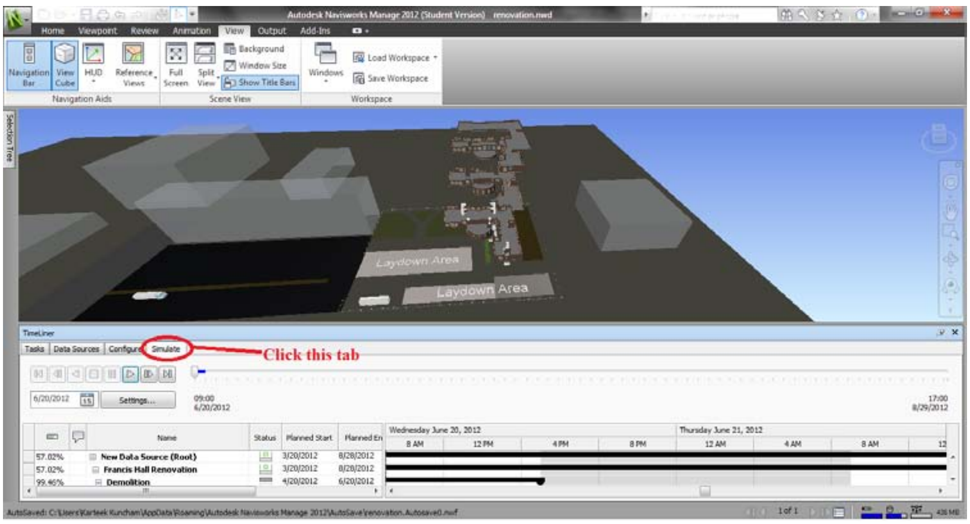

Figure 4. Navisworks Application Showing Simulation Mode

7. BIM CAVE Application Mechanism

The BIM CAVE application developed for this research integrates the hardware and the software components to achieve an immersive virtual reality environment. The BIM application executes the three algorithms Server-Client, Navisworks API and Mathematical Rotation in a particular order to achieve a coherent view in all the four screens. The following steps explain the working process of the BIM CAVE application developed:

- First, the Navisworks API algorithm is executed in the server BIM application. The API algorithm will collect the camera parameters like position, view direction vector and up vector whenever the current view of the camera changes. It also captures the button pressed (which control timelining) in the BIM CAVE server application interface and assigns a number to it.
- Once the server's camera parameters are generated, the mathematical rotation algorithm will be applied to the gathered camera parameters and the axis and angle of rotation for each of the clients will be calculated.
- The Server-Client algorithm will be used to transfer the data packets containing the axis, angle of rotation, and unique number generated corresponding to the button pressed (which control timelining) in the BIM CAVE server application interface to each of the clients connected with the server.
- Clients receive the data packets sent by the server using the Server-Client algorithm.
- The received data packets will be used by the clients to update their camera position with respect to the server and synchronize the stage of construction during 4D construction sequence in order to achieve an immersive view using the Navisworks API algorithm.

8. Challenges Faced

The .NET API documentation provided with the Autodesk Navisworks Manage 2012 did not release the classes which control timelining in Navisworks. There is no documentation from the Autodesk for these classes because they did not want it to be public. After going through the .dll assembly files which are installed along with the Navisworks application, the class which controls timelining has been found. “LcTISimulationHelper” is a class under the namespace Autodesk.Navisworks.Api.Interop in the Autodesk.Navisworks.Timeliner assembly which has the methods which control the Play, Pause, Stop, Step, ReverseStep, ReversePlay, ReverseWind, and Wind buttons of the Timelining animation. Only Step, Stop, and Reverse Step methods have been used for this research.

However, these methods could not be used directly in the Server or Client application to control timelining in Navisworks application as Autodesk did not release them to be used in Automation. So, Plugins for each of the methods had to be developed which in-turn were executed through Automation whenever the corresponding button is clicked in the server application interface.

As this information was not readily available at hand, a lot of time was spent on trials, and debugging. After contacting the Autodesk Developer Consultant these issues were recognized and a way around was discovered to gain control over the timelining in Navisworks Manage 2012.

9. Conclusions

The previous BIM CAVE version had limitations in terms of synchronizing the 4D construction sequence, which resulted in loss of immersion during the simulation process. To overcome the problem of visualizing timelining in the existing BIM CAVE, a new BIM CAVE has been developed to synchronize the 4D construction across all the three computers in the BIM CAVE system. This research used the existing BIM CAVE hardware, which used the new BIM CAVE application. The BIM CAVE setup was then validated using qualitative research methodology. Qualitative methodology involved conducting descriptive interviews with subject matter experts. The interviews revealed that timelining in BIM CAVE makes the visualization process of 4D construction sequence more effective than visualizing 4D construction sequence on a single screen as it gave a better sense of spatial perception of the space in the building and accommodates many project stakeholders who can collaboratively resolve construction related issues compared to single desktop screen. Timelining in BIM CAVE has several other advantages like getting to know how construction sequence in one place affects the construction sequence in a space adjacent to it, effective communication of the construction schedule to all the project participants, collaboration between trades to resolve issues related to space interference before going on site, defining the installation path and sequence of building elements using heavy equipment with much more confidence and justification, and training the workforce. As a conclusion, with some limitations the industry professional's evaluations of the BIM CAVE prototype provide evidence that the 4D visualization in immersive virtual environments such as BIM CAVE is effective compared to 4D visualization on a single desktop screen.

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BIM-based intelligent acquisition of construction information for cost estimation of building projects

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Abstract

Construction cost estimation, which is normally labor-intensive and error-prone, is one of the most important works in the architecture, engineering, construction, and facilities management industry during a project's lifecycle. With the development of information technology, it is expected that the efficiency and accuracy of cost estimation for tendering of building projects (TBP cost estimation for short hereafter) can be greatly improved if it can be carried out automatically based on the design results using building information modeling (BIM-based design results for short hereafter). One of the major obstacle to realize the automatic TBP cost estimation is the acquisition of the construction information (e.g. construction method, equipment), which are necessary for TBP cost estimation but often not included in the design results. This paper aims to establish an approach to identify the construction information systematically in order to facilitate the automatic TBP cost estimation based on BIM-based design results. First, the process of TBP cot estimation based on BQ method in China is introduced and the related specifications are classified. Then a typical specification for TBP cost estimation is analyzed to identify the construction information that are required in TBP cost estimation and a typical specification for the requirement on design detail fulfillment is analyzed to identify the construction information that can be obtained from the design result. Next, based on the above results, the construction information that need to be established during TBP cost estimation are highlighted. Finally, the applicability of the approach is discussed. For simplicity, the scope for the analysis is confined to TBP cost estimation of concrete construction of reinforced concrete structures in this paper.

Keywords: BIM, construction information, cost estimation, intelligent acquisition, specification.

1. Introduction

Cost estimation is one of the most critical tasks concerned by all participants in the architecture, engineering, construction, and facilities management (AEC/FM for short hereafter) industry throughout the lifecycle of building projects, especially in the tendering phase after the completion of design. In practice, cost estimation for tendering of building projects (TBP cost estimation for short hereafter) generally consists of three major processes, i.e., classifying all construction products into items, computing the quantities of each item, and calculating the price of each item and summarizing them to obtain the project cost. Specifications for specifying the items, such as UniFormat (CSI and CSC, 2010) and MasterFormat (CSI and CSC, 2014), need to be strictly complied with for the accuracy and fairness of tendering. Due to the complexity of buildings, TBP cost estimation is generally labor-intensive, time-consuming and error-prone.

With the development of information technology, it is expected that the efficiency and accuracy of TBP cost estimation can be greatly improved by implementing specifications in computer programs to automatically conduct the processes based on Building Information Modeling (BIM for short hereafter). Over the past decade, BIM technology has become one of the most promising solution to store and utilize information of buildings including design results. Due to its object-oriented and three-dimensional nature, the BIM-based design results facilitate intelligent extraction of the data from construction products, which is necessary for the automatic TBP cost estimation.

Several BIM-based software applications for cost estimation have emerged, such as Innovaya (2010) and Vico Estimator (2014), in which the BIM-based design results can be imported to conduct effective quantity takeoff for TBP cost estimation. However, the processes of classifying all construction products into items and assigning related unit item prices still require the estimators' manual operations. In addition to these commercial systems, there have also been studies aimed at BIM-based semi-automatic or even automatic cost estimation by using knowledge-based technologies such as semantic web and ontology, which are used for representing concepts, relations and rules. Staub-French et al. (2003) suggested an ontology-based approach to describe

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construction activities in specifications so that estimators could assign and adjust unit item prices more consistently and completely. Ma et al. (2011) proposed a BIM-based approach to classify construction products according to specifications, and then developed a prototype system to conduct semi-automatic and specification-compliant TBP cost estimation (2013). To assign unit item prices intelligently according to related specifications and construction methods, Ma et al. (2013) established an ontology-based framework for the computerized representation of specifications for TBP cost estimation. Lee et al. (2013) recommended an ontology-based process to infer unit item prices from BIM-based design results according to the predefined rules. But the attempt is limited to the tiling work in the schematic design phase, thus its usability in TBP cost estimation requires further tests. It is obvious that, there is still a long way to go in order to realize the automatic TBP cost estimation. One of the major obstacle for this is the acquisition of the construction information related to the construction processes (e.g. construction method, equipment), which are necessary for TBP cost estimation but often not included in the design results, since the designers have no responsibility to define them.

This paper aims to establish an approach to identify the construction information systematically in order to facilitate the automatic TBP cost estimation based on BIM-based design results. First, the process of TBP cost estimation based on the BQ method in China is introduced and the related specifications are classified. Then a typical specification for TBP cost estimation is analyzed to identify the construction information that are required during TBP cost estimation (required construction information for short hereafter), and a typical specification for the requirement on design detail fulfillment is analyzed to identify the construction information that can be obtained from the design result (determined construction information for short hereafter). Next, based on the above results, the construction information that need to be established during TBP cost estimation (undetermined construction information for short hereafter) are highlighted. Finally, the applicability of the approach is discussed. For simplicity, the scope for the analysis is confined to TBP cost estimation of concrete construction of reinforced concrete structures in this paper.

2. Analysis of required construction information for TBP cost estimation

Nowadays, the bill-of-quantity (BQ for short hereafter) method is well-accepted for TBP cost estimation in practice in many countries and regions of the world. Generally speaking, according to the BQ method, first the tender or its agent breaks a building down into products and classify them into groups, i.e. BQ items. Then the quantity for each BQ item is calculated and the result is announced to invite for bidding. The construction firms who join the bidding thus assign the BQ items with unit item prices to obtain the price for bidding. The unit item prices are normally computed by multiplying the unit consumptions of labor, material, and equipment specified in quotas with corresponding market prices. In the processes, the information of products, including their construction information, are necessary. Two kinds of specifications, i.e. BQ specifications and quota specifications are needed in the TBP cost estimation. The BQ specifications are used to standardize the breakdown structure of buildings and the classification of BQ items for different specialties in the AEC/FM industry, while the quota specifications are used to specify not only unit consumptions but also the reference prices of the related quota items, the latter of which can be adjusted according to market prices. In China, both the national BQ specification and the national quota specification exist to provide a framework for the corresponding regional specifications that account for the regional differences in specific construction methods and productivity levels. For example, in Beijing, the capital city of China, the specification that are used include the national BQ specification and the quota specification of Beijing for the tenders to compute the base price limit for bid. Due to the tradition, few construction firms have their own quotas, so that they normally compute the item price based on the regional quota specification.

In principle, both the BQ specification and the quota specification need to be analyzed to obtain the required construction information for TBP cost estimation. But because the quota specification is more detailed than BQ specification and the construction information specified in the former can cover that in the latter, only the quota specification need to be analyzed to identify the required construction information.

In this paper, a typical regional quota specification, "Quota set for building construction and fitting out woks in Beijing" (Beijing Quotas for short hereafter) (BMCHURD, 2012), is analyzed. It originates from the national quota specification published in 1995 so that it shares a common framework with other regional quota specifications in China. In addition, it has been revised several times to adapt to the classification of BQ items specified in new BQ specifications and new material and technique in the AEC/FM industry. It means that the construction information specified by the specification are up-to-date. In the following, an example of the information specified in the specification is illustrated first for better understanding, then the approach of the analysis is presented and the results of the analysis are summarized.

2.1. Illustrating the information specified in the quota specification

The Beijing Quotas consists of numerous quota items that are organized in the form of tables according to the hierarchy of "specialty – section – subsection – quota item". An example of this hierarchy is "building construction and fitting out works – concrete construction of reinforced concrete structures – cast-in-place concrete column – cast-in-place concrete rectangular column". Except that some common information, such as "the concrete in this specification has no additive" is not included, most information are included in the tables of quota items. For each group that share the same type of works (e.g. pouring, vibrating, and curing of concrete for cast-in-place concrete column), there is a table where the reference prices of labor, material and equipment corresponding to the construction work, are listed, followed by the unit consumptions for each quota item. In theory, the reference prices represent the average price of the society instead of a certain construction project. An example of the tables is shown in Table 1, which indicate typical quota items for cast-in-place concrete columns and corresponding concrete forms.

Table 1. Example of tables of quota item in the Beijing Quotas

Subsection: Cast-in-place concrete column									
Work: Pouring, vibrating, and curing of concrete, for $1m^3$ of volume of column (CNY)									
Code	Name	**Item**	**Labor**	**Material**			**Equipment**	
				C30 premixed concrete	C30 mortar	Other	Mortar mixer (200L)	Other
		Unit	day	m^3	m^3	CNY	day	CNY
		Price	74.30	410.00	480.00	-	11.00	-
5-7	Rectangular column	**Cost**	0.686	0.9860	0.0310	6.37	0.0052	2.17
5-8	Structural column		1.231	0.9860	0.0310	6.36	0.0052	3.79

Subsection: Concrete form for column											
Work: Manufacture, installation, uninstallation, storage, transportation and cleanness of concrete form, for 1m2 of surface of column (CNY)											
Code	Name		**Item**	**Labor**	**Material**				**Equipment**		
					Combined wood form	Composite steel form	Diesel oil	Other	Auto crane (16t)	Truck (15t)	Other
			Unit	day	m2	m2 • day	kg	CNY	day	day	CNY
			Price	83.20	30.00	0.35	8.98	-	915.20	392.90	-
17-58	Rectangular column	Combined wood form	**Cost**	0.402	0.1617	-	0.1787	10.96	0.0014	0.0022	1.36
17-59		Composite steel form		0.390	0.0104	4.6065	0.2415	8.75	0.0019	0.0030	1.31

2.2. Analysis of quota items to identify required construction information

In order to conduct the analysis on the quota specification to identify the required construction information, a framework is needed to express the specification in a structured way to facilitate the analysis of the specification. In the previous study, the authors have established such a framework by using the ontology technology (Ma et al. 2013). In the framework, ontology is used to express the contents of the specifications. Each item of the specification is expressed based on objects and their features. For example, corresponding to a certain quota item, e.g. "Concrete column", as soon as the object "Product", "Column" and "Concrete", and the features "ProductType", "Material of column" are established, they can be used to establish an expression. Such expressions constitute the knowledge base for judging the quota item that a product should belong to. According to the framework, it is necessary to decompose the quota items into objects and features. Based on the consideration, the analysis is carried out in the following way to identify the required construction information.

Generally speaking, a quota item is related to three aspects, i.e. labor, material, and equipment. Since the labor is not related to the construction information in TBP cost estimation, only the other two aspects are considered. As explained in section 2.1, the construction information are not explicitly expressed in the specification, so the authors read and analyzed the items one by one to understand the meaning, and then process each item in a systematic way. Since the authors have the background on civil engineering, there were no problems in understanding the items.

For the material aspect, after each item of the specification is analyzed, the related contents are filled into a specially designed form, as shown in Table 2.

Table 2. Example of the form used for the analysis of objects, features and feature values in quota items

Code	Work	Description	Object	Feature value	Feature	Process-related
5-7	Pouring, vibrating, and curing of concrete	Cast-in-place concrete column Rectangular column (No additive) C30 premixed concrete	**Product:** column	Cast-in-place	Cast method of concrete	Y
				Rectangular	Section of product	N
			Material: concrete	No additive	Additive of concrete	Y
				C30	Strength grade of concrete	N
				Premixed	Mix method of concrete	Y
17-58	Manufacture, installation, uninstallation, storage, transportation and cleanness of concrete form	Concrete form for column Rectangular column Combined wood form	**Product:** column	Rectangular	Section of product	N
			Material: (concrete) form	Combined	Type of concrete form	Y
				Wood	Material of concrete form	Y

In doing so, three steps are included. In the first step, the contents of the columns "Code" and "Work" in Table 1 are copied into the corresponding columns in Table 2 respectively, then the contents of columns "Subsection" and "Name" are copied into the column "Description". By this step, the contents of the quota item are rewritten in a form that is easier to relate among the contents and understand. In the second step, the product and material related to the quota item are identified and filled into the column "Object", then against these two objects, the related feature values are identified from the column "Description" based on the column "Work", and then the feature is induced and they are then filled in the columns "Feature value" and "Feature". In the third step, the features are judged respectively to determine whether it belongs to construction information. Obviously, it is easy to make such a judgment if one has the background on civil engineering.

For the equipment aspect, similar analysis can be carried out. But because there are few variations for each equipment in the specification, for example, the trunk have only one variation (15t), for simplicity, only two features are summarized, i.e. "Availability of the related listed equipment" and "Acquisition way of the related listed equipment". It should be noted that, there are duplicated features and feature values, especially for the quota items in the same group. Thus, all quota items in the same group are analyzed together to reduce reduplicative works and improve the efficiency. In total, all 363 quota items related to concrete construction of reinforced concrete structures are analyzed and all 14 items of required construction information are summarized in Table 3. For each item of required construction information, the related quotas items are also listed for better understanding.

3. Analysis of determined construction information from design

In China, all design results of building projects must be reviewed and approved by the certificated experts of the design institutes that are authorized by the Ministry of Housing and Urban-Rural Development (MOHURD for short hereafter) before bidding and construction. In order to insure the quality and completeness, the MOHURD has published a series of specifications and regulations for designers to carry out the design and for the certified experts to review the design results.

Among the specifications and regulations, the specification "Requirement on design detail fulfillment in construction" (MOHURD, 2008) applies regarding the contents of design that must be specified by the designers. The specification is organized according to the hierarchy of "design phase –specialty – design drawing and calculation report – component (or section in the calculation report) – information". According to the specification, the designers are supposed to produce the design drawings and calculation reports for each specialty, including architecture, structure, mechanical, electrical and plumbing engineering (MEP for short hereafter), etc. for the design review in the shop drawing phase. Since the design results that have passed the design review are supposed to be used in the TBP cost estimation, the specification is analyzed in order to find out the determined construction information. Similar to the analysis on the specification for TBP cost estimation, the analysis is confined to concrete construction of reinforced concrete structures. The specification takes the form of statement articles and the number of the target statement articles is 24, covering 6 pages. For example, according to the statement articles for cast-in-place concrete components, the profile, length, position, detail of reinforcement assembly, bearing of beams and slabs, etc. should be included in the detail drawings of concrete component.

Table 3. 14 items of required construction information identified by analyzing quota items in Beijing Quotas

Required construction information			**Related quota items in Beijing Quotas**			
No	**Feature**	**Feature values**	**Section**	**Subsection**	**Quota items**	**Total number of quota items**
1	Cast method of concrete	Cast-in-place, Pre-cast	Concrete construction of reinforced concrete structures	Cast-in-place/pre-cast concrete column/beam	5-7~5-17 5-61~5-71	83
				Cast-in-place/pre-cast concrete slab	5-22~5-36 5-77~5-98	
				Cast-in-place/pre-cast concrete stair, etc.	5-40~5-50 5-99~5-111	
2	Connecting method of rebar	Weld, Mechanical fastener		Reinforcement steel works	5-112~5-127	10
				Bolts and iron casting	5-138~5-141	
3	Pre-stressing method of rebar	None, Pre-tensioning, Post-tensioning		Reinforcement steel works	5-112~5-117 5-128~5-135	10
4	Bond between pre-stressed rebar and duct	None, Bonded			5-128~5-131	4
5	Anchor type of rebar	Single anchor, Multi-anchor			5-133~5-134	2
6	Additive of concrete	No additive, Additive		All items made by cast-in-place concrete	5-1~5-36 5-40~5-60 5-150~5-154	62
7	Mix method of concrete	Premixed, Mix-in-field				
8	Type of scaffold	Composite scaffold, Hanging scaffold, Double-pole scaffold, All-round scaffold	Preliminary construction related to reinforced concrete structures	Scaffolding	17-1~17-43	43
9	Acquisition way of scaffold	Rent, Owned				
10	Type of concrete form	Combined concrete form, Composite concrete form, Set-shape concrete form, Fair-face concrete form		Formwork and support	17-47~17-144	98
11	Material of concrete form	Wood, Steel				
12	Acquisition way of concrete form	Rent, Owned				
13	Availability of the related listed equipment	Available, Unavailable		All items using any equipment	*	*
14	Acquisition way of the related listed equipment	Rent, Owned				

As a result, five required construction information related to the concrete work and the cast-in-place/precast concrete components, i.e. "cast method of concrete", "connecting method of rebar", "pre-stressing method of rebar", "bond between pre-stressed rebar and duct" and "anchor type of rebar", are specified, which means that they are determined construction information and should be provided by structural designers in the detail design phase. Figure 2 shows the structure of the targeted part of the specification and the result of the analysis. By comparing with the required construction information established in Table 3, it is observed that 9 items of required construction information are undetermined construction information, and need to be established during TBP cost estimation.

4. Discussion and conclusion

In order to facilitate the automatic TBP cost estimation based on BIM-based design results, this paper established an approach to identify the construction information systematically. First, the process of TBP cost estimation based on BQ method in China was introduced and the related specifications were classified and a typical specification was analyzed to identify the required construction information. Then a typical specification for the requirement on design detail fulfillment was analyzed to identify the determined construction information. Next, based on the above results, the undetermined construction information were highlighted.

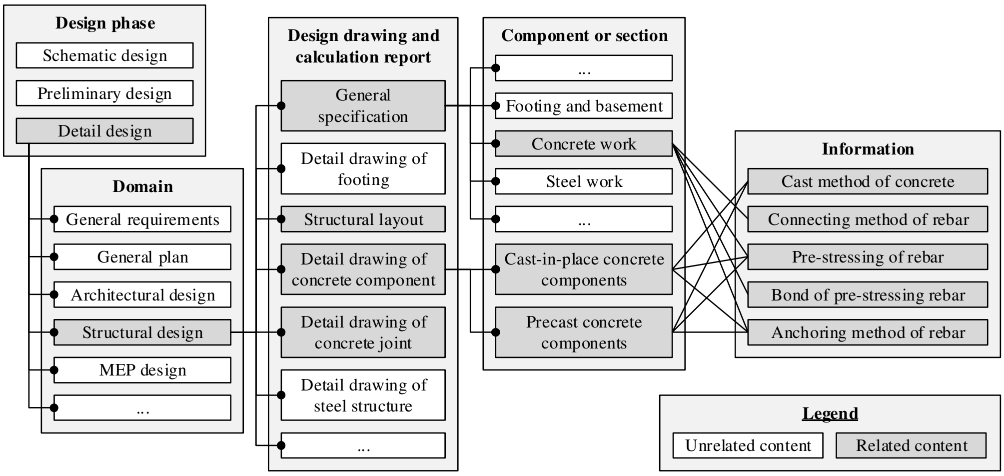

Figure 2. Structure of the specification for the requirement on design detail fulfillment" and determined construction information

For simplicity, the scope for the analysis in this paper was confined to TBP cost estimation of concrete construction of reinforced concrete structures based on a typical quota specification in China. For other subsections of building construction, such as earth work and decoration, the construction information can be identified in a similar way. In addition, the quota specification in China is similar to the quotas of construction firms in other countries. Thus, the approach proposed in this paper is applicable for general cases of TBP cost estimation not only in China but also in other countries.

The results of the analysis lays a sound foundation for developing system for automatic TBP cost estimation. Further studies will focus on the establishment of mechanism combined with rules, cases and evaluation to acquire undetermined construction information and the formulation of rules.

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The impact of BIM on risk management as an argument for its implementation in a construction company

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Abstract

This paper examines the impact of the Building Information Modeling (BIM) implementation on the construction market, where BIM is not common yet. As long as the client does not require using BIM, construction companies often struggle when trying to find arguments for BIM implementation, which would outweigh all obstacles encountered during the way. Several BIM benefits can be identified of which one of the most important is the BIM impact on risk management. The objective of this paper is to investigate the importance of risk management and BIM relations as an argument for implementation of BIM in a construction company. It focuses on the risks related to BIM implementation processes, i.e. processes related to implementing new systems in a construction company, and risks related to BIM application processes, i.e. processes related to actual BIM use in a construction company. Although there are serious threats involved in the first group, there are many opportunities emerging from the second one. Risk (threats and opportunities) identification in both of these groups and finding their correlation can then be used as a supporting argument for BIM implementation. The research methods are based on conducted surveys and literature research. These sources were analyzed and used for the case of explanation and for the identification of key risk and BIM related issues. The research reveals whether the topic of BIM related risks is mostly treated only on a common level and whether BIM regarding risk awareness of those who have not been using BIM is sufficient enough to evaluate all advantages and disadvantages of BIM implementation. In the end, the paper suggests a possible method to describe BIM related risks. The understanding of these risks and their connections allows construction companies to build arguments better when considering BIM implementation into their practice.

Keywords: BIM, BIM Related Risk Awareness, Building Information Modeling, Implementation, Risk Management.

1. Introduction

The Building Information Modeling (BIM) is a highly discussed topic nowadays. In some parts of the world, BIM has become common, usually by the means of some degree of standardization and government support. For example, such is the case of Finland (buildingSMART Finland, 2012), the United States (National Institute of Building Sciences, 2007) or Singapore (Building and Construction Authority, 2013). There are other countries, like the United Kingdom, where there is a big BIM boom. In case of the UK, it means there is huge government support, aiming to use a certain level of BIM in all centrally procured projects by 2016 (UK Cabinet Office, 2011). Then there are countries, especially in the southern and eastern Europe, which are starting to develop their interest in BIM. The usual propagators of this new technology are big construction companies (whose parent companies are already BIM ready or at least included BIM in their longer-term targets) and smaller young enthusiastic companies (because they are more flexible and more interested). Another very important part is played by government (Eastman, et al., 2011), which create an environment for BIM implementation (especially in the form of standardization and public contracts). They all need to ask these easy but very specific questions, which are not easy to answer: What are the benefits of BIM? What are the drawbacks of BIM? What will BIM cost me?

This paper targets issues connected with BIM implementation in construction companies on the market, where BIM is not common yet. It tries to provide a rough explanation of how the aforementioned questions can be partly answered by looking at risks during the BIM implementation process and actual BIM use.

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1.1. BIM overview

BIM is a modern construction management process, which allows users to create object-based multidimensional parametric models as a tool for construction projects management during their whole life cycle. For this purpose, various tools and methods are being used. There are also procedural adjustments, aimed especially for collaboration, revisions and efficiency. Therefore there are the two main groups, which define the role of BIM in a project - tools and methodology (Race, 2012). Tools are not only software tools, although these are the most important. Heavy machinery, fabrication machines, computers, tablets, geodetic tools, visualization tools, GPS or microchips and RFID technology are also part of the tools group. Methodology group is much more complicated, since it defines how tools will interact, how they may be used by people and how people interact with each other. This second group defines the success of BIM implementation in a construction company nowadays.

The concept of BIM is not new. An object-based parametric modeling has already been used in different sectors, for example in chemistry, mechanical engineering or electronics (Eastman, et al., 2011). It just took a little bit longer until these technologies found their way to construction industry, mainly because construction projects are unique, very complex and long-running. They also demand a very high amount of resources. Because of this nature of construction projects, the whole process of BIM adoption is not simple. BIM is a hot topic nowadays, spreading around the whole world, promising better, more efficient and higher quality construction projects with a positive impact in reducing whole life-cycle costs. BIM on the national markets differs a great deal and is based on a country's technological level and degree of government support.

BIM can be used during the whole project's life cycle. From programming, design phase, construction phase and operating phase, ending with demolition or renovation. During this cycle, BIM can be used in many different fields. These include a long list of different areas. This list includes current conditions modeling, budgeting and quantity takeoff, time planning, programming, and site analysis. Other areas that can use BIM are project review, certification and standardization, project design, engineer analyses, sheets and documentation creation, 3D coordination and planning, and site design. And lastly could include operational planning, digital fabrication, planning and management, as-built modeling, construction analyses, facility management, maintenance and reconstruction plans, space management, and crisis management. In each of these fields, there is a risk involved and this risk has to be managed.

1.2. Risk Management overview

According to ISO 31000:2009, a risk is the "*effect of uncertainty on objectives*" (Anon., 2009, p. 11). Every part of project life cycle is subject to risks (Tichý & Erben, 2006), which have to be treated adequately to stay in control of the project and to achieve its goals in an optimal way. Risk management is a set of activities, aimed to analyze (identify, assess), evaluate, treat and monitor risks.

Risks are defined by their defining *events* and *levels* (*likelihoods* and *consequences*). It is possible to look at the risk as a two-dimensional quantity. The first dimension is its likelihood, which means it is the probability that event will occur. The second dimension is its consequences, which means the severity of risk (event) impact in case risk scenario happens. The severity may be described numerically or verbally on the appropriate scale. The combination of risk likelihood and consequence results in the creation of *risk level*. The risk matrix is when levels of all identified risks are plotted into a diagram, where two dimensions mentioned are the two diagram axis. Other important terms regarding risk management are the *risk owner*, *risk source* and the *risk recipient*. The risk owner is a system entity, which has authority and is responsible for managing risk (ISO 31000, 2009). The risk source refers to a system entity, which is a possible cause of the risk (event). It means when the risk source is removed from the system, the risk scenario cannot happen in the system, which also means it cannot be managed. The risk recipient is the entity of the system which will suffer the consequences of the risk in case the risk scenario is realized. There may be one or more (or none) risk owners, risk sources and risk recipients, related to one risk. It is advised that relationships between risk owner, sources and recipients are clearly identified. The risk recipient may or may not be the risk owner. Risks may also be characterized by their context, which may be *external* or *internal* (ISO 31000, 2009). External context describes relationships between an organization and the environment, while internal context describes relationships inside an organization.

1.2.1. Threats and opportunities

In common language, risk is usually referred to as something negative. In the risk science, the risk is neutral in its nature and it is subjective. When an event happens, it may be understood as positive or negative, based on the risk owner and risk recipient perspectives. A benefit for one, may bring harm to another. This dimension is called *polarity*. Therefore there are positive and negative understandings of events and risk, which are called *chances* and *hazards* (for events) and *opportunities* and *threats* (for risks). In practice, these terms are often used interchangeably, for example a hazard is often used as a reference to an event (Edwards, 1995). When risk happens, it may bring *benefit*, or it may cause *harm* or both. The ability to see risks not only as threats, but also as opportunities, is very important.

1.2.2. Risk correlation

Every risk may be objectively characterized by its likelihood, subjectively by its consequences. But there are other risk attributes, which can be identified. These attributes are usually linked with risk events and risk sources. Based upon these attributes, it is possible to classify risks and to identify their common characteristics. Sometimes, attributes are connected. This connection may be mathematically described as a correlation, usually represented by specifically designed coefficient or function. The most common coefficient is the Pearson coefficient, which is defined on the interval from -1 for anti-correlation to 1 for full linear correlation, while 0 means no linear correlation at all. In case of more complicated correlation, non-linear functions need to be used (Dietrich, 1991). When there is proportionality in correlation between two risks, it's called positive risk correlation (one risk have positive impact on another risk and vice versa), analogically when there is inverse proportionality, it's called negative risk correlation (one risk has negative impact on another risk and vice versa). Sometimes, risk correlation may be one-sided, which means the relationship is only valid from one risk to another. The correlation may also be the combination of all cases mentioned above.

1.3. Risks in BIM

The topic of risks is very important in BIM. There are some major threats when BIM is being implemented in a construction company as there would be any time when innovation is involved. When BIM is being used, there are big impacts on standard risks levels, but there are also new threats and opportunities emerging. Since the topic of risks is very subjective and is often an objects of private know-how, there are not many sources, which would address BIM risks in detail.

In various BIM oriented publications, the risk is usually mentioned. These mentioned risks are usually referred to as the risks, which are influenced by the BIM use or its implementation, or the risks inherent in BIM as their risk source. Eastman in his preface of the *BIM Handbook* writes, that the "*BIM creates significant opportunity*" (Eastman, et al., 2011, p. xi). In this book, the risk is usually referred to in a positive way such as risk reduction or opportunities. It is said that BIM may "*reduce the financial risk*" (Eastman, et al., 2011, p. 151), "*reduce schedule-related risks*" and "*decrease the risk for errors and omissions*" (Eastman, et al., 2011, p. 247). The fact that BIM increases risks is considered a misconception (Deutsch, 2011). There are also tools specifically designed to minimize risks (Epstein, 2012, p. 80).

Based on the stakeholder role in the project, various BIM related risks may be addressed. During the design phase, there are opportunities involved (Eastman, et al., 2011, p. 197). Also there are some concerns about the risk increase for designers (Teicholz, 2013), especially in the field of deliverable definitions, ownerships and liabilities. The opportunities in automation (Eastman, et al., 2011, pp. 214, 295) are also mentioned, especially in fabrication (Eastman, et al., 2011, p. 333). For the contractor, BIM can reduce the risk over time (Eastman, et al., 2011, p. 302) and "*a detailed building model is a risk-mitigation tool*" (Eastman, et al., 2011, p. 276). For subcontractors, the risks "*associated with parts not fitting correctly when installed*" (Eastman, et al., 2011, p. 322) are reduced. According to Eastman, BIM also "*reduces risks for client*" (Eastman, et al., 2011, p. 268). Which Teicholz reaffirms in his *BIM for Facility Managers* (Teicholz, 2013). It is understandable, because of the costs during project operating phase and because owners are usually at the end of a normal cycle, where most of the BIM benefits are realized. Regardless of the stakeholder role, BIM brings opportunities in an increased level of communication (Deutsch, 2011). BIM is also said to have positive impact on the environmental risks (Krygiel & Nies, 2008). BIM can be "*effectively utilized by parties to assume more risk while reducing contingencies*" (Reddy, 2012, p. 43). The whole concept of Integrated Project delivery (IPD) is also considered as having positive impact on risk reduction and BIM may be considered to bring appropriate tools and processes according to IPD philosophy. There are also concerns about legal and financial risks (ownership, liabilities, insurance etc.), which, on the other hand, can easily be managed by proper communication and contracting.

In various case studies, the specific risks are sporadically mentioned, as they are a part of the construction process. Such case studies are easily found in the Eastman's *BIM Handbook* (Eastman, et al., 2011), Epstein's *Implementing Successful BIM* (Epstein, 2012) and Jernigan's *BIG BIM little bim* (Jernigan, 2008). Case studies aimed at BIM implementation in facility management can be found in Teicholz's *BIM for Facility Managers* (Teicholz, 2013), but these case studies rarely deal with the risk management.

In scientific papers, any BIM related risks are often mentioned while specific BIM tools are described. For example, these are clash-detection tools (HyounSeok, HyeonSeoung, ChangHak & LeenSeok, 2014) or safety planning (Sulkankivi, Makela & Kiviniemi, 2009), (Chan-Sik, Hyeon-Jin, 2013). Other papers examine BIM as a risk source, for example risks connected with legal issues (Su-Ling, 2014), (Arensman & Ozbek, 2012) or investment risks during BIM implementation (Tsai, Kang & Hsieh, 2014). In a very interesting paper called *Building Information Modeling (BIM) for existing buildings — Literature review and future needs,* describes the possible use of BIM for existing buildings. Various benefits of BIM for risk management are mentioned, but it is also mentioned that the sources for risk scenario planning are rare in literature today (Volk, Stengel & Schultmann, 2014). *The project benefits of Building Information Modelling (BIM)* defines various benefits of BIM for project management based on 35 case studies. One of these benefits is risk management (Bryde, Broquetas & Volm, 2013). The impact of BIM on risk management is described only briefly and there are no correlations identified

Based on interviews (Matějka, et al., 2012) and literature research, public knowledge about BIM related risks in the Czech Republic, which is a country where BIM is not being used yet, is not high. People often see the innovation risks as threats and they fail to see the opportunities of innovation. There are the two main reasons. The first reason is there is not enough clear information about BIM benefits, and the fact that they are not influenced by marketing materials of tool providers. The second reason emerges from construction industry itself, because it is hard to generalize BIM implementation harms end benefits as they are subject to specific project, company and market conditions.

2. BIM implementation

With new technologies, new issues arise. One of these issues deals with the topic of BIM implementation into a construction company. It is not just about switching between the tools used, it's more about adopting new work processes. Technology and quality of BIM tools were an issue ten years ago. Today, it is about successful and efficient BIM implementation into common use, which means especially a successful use of BIM by the personal on the project and at the project team level. When standardization occurs, the current practice shows, it does achieve a level of collaboration (Epstein, 2012). The question of implementation today is "How should we do that?" instead of "Is it possible?"

The whole BIM implementation process can be divided into the two main categories. The first category is the implementation phase. The second category is the post-implementation phase. These two phases are connected and may overlap. They also form a cycle, meaning after a post-implementation phase, there may be more implementation processes. Also, information gathered during previous implementation and following post-implementation phase may be used as a guidance for a different company or project. During its post-implementation phase, BIM may be utilized to obtain various benefits during the whole project's life cycle. These benefits are hard to categorize, because they may overlap and are often connected (Eastman, et al., 2011; Kymmel, 2008; Epstein, 2012). They are generally: lower cost of construction project during its whole project life cycle, higher quality of the construction project, more efficient design, construction and operating phases. This leading to faster construction phase, better safety during the whole project life cycle, lower waste production, better ways to manage risk, fewer errors, and higher productivity.

There are also factors, which may end up as failure during BIM utilization, if not properly managed. Some examples of the most important factors are: proper communication during project (especially during the design phase) and proper collaboration during project (not only in a company, but collaboration with other stakeholders is important too; also covers the topic of responsibility). This can lead to project continuity in the terms of its different phases (for example when construction phase is finished and operating phase starts (Teicholz, 2013)), dealing with the continuity and the long-term character of construction projects, readiness of legislative and legal environment, standardization and methodology (to understand each other), readiness of contractual environment (i.e. what is deliverable?), capital expenditure (not only acquisition costs, but qualification and innovation too), software and technological support. The best way to deal with these factors is firstly to adopt BIM and then implement it (Deutsch, 2011). It usually takes one or two projects to test newly implemented BIM processes (Epstein, 2012) and it usually takes around three years to anticipate results of BIM implementation process (Race, 2012), remember that it has been shown when using BIM, projects "*save 5-12%*" (Jernigan, 2008). Any time a firm implements any new process, which applies to BIM implementation too, quality control and risk management are often considered as the two most important guidelines for every firm owner and manager (Epstein, 2012) to consider.

3. BIM in risk management

BIM has impact on both the external and the internal risks in a construction company. These risks can also be divided into the implementation and post-implementation phase, as has already been explained in this article. It also differs based on the degree of implementation on the examined market. When in a market, where BIM is already being widely used, it is more about maintaining competitive advantage, managing opportunities and not staying behind. In the market where BIM is not common yet, the innovation risks which need to be managed are much larger, concerning both threats and opportunities. Successful innovation risk management is crucial (Smith & Tardif, 2009). It is important to build a business case for the use of BIM and there are many ways to do that, since there are new opportunities, which come with the BIM use (Race, 2012).

When BIM is used, it should have positive impact on risk management, i.e. it mitigates threats and raises opportunities. When BIM is being implemented, there are many risks involved during this process, of which the majority are threats. It is usual that every innovation carries risks, but "*the risk of implementing BIM technology is far lower than implementing CAD*" (Smith & Tardif, 2009, p. 33). It is advised to take a proactive approach to manage risks and to share these risks (Jernigan, 2008).

3.1.1. BIM related risks relations

As stated before, the BIM implementation phase is usually connected with many threats. These threats can cause harm to the risk recipients. This harm can be expressed as costs, and also their treatment. Implementation phase usually does not carry any opportunities for a construction company. Post-implementation phase is connected with both threats and opportunities. The situation is similar to the implementation phase. However, using BIM carries many opportunities, which may result in various benefits (i.e. competitive advantage, threats mitigation, lower costs etc.) When considering the BIM implementation, there are two rules of thumb, which have to be met. The first is that total costs of the implementation, together with their consequences, should be lower than total benefits, together with their consequences (on the examined time period). The second rule is, that costs during the implementation should be bearable on the operating level. One problem is calculating future costs and benefits and putting them together. This creates a big factor of uncertainty, which has to be dealt with. This uncertainty may be easier to manage, if proper relations between involved risks during implementation and post-implementation phases are properly identified and mathematically described so they can be used as correlations. Such information could then have two major uses. The first use is for the risk management. The second use is for decision-making during the BIM implementation process. Explained relations can not only help to understand risks involved, but they also help to identify crucial factors of BIM implementation to optimize the whole process. The key risk attributes, with some relation to other risk attributes are: likelihoods (probabilities), consequences, related events, polarity, risk owners, risk sources and risk recipients. Described principle can be easily used in every implementation process, but when implementing BIM, it is especially important. This is because of the very high BIM influence on risks, insufficient information about BIM and how it affect risks, unclear BIM-related risks relations, nature of construction projects and big differences between BIM implementation and post-implementation phases.

4. Conclusion

The presented paper examined and explained the topic of risks during BIM implementation process. It focused on the market where BIM is not common yet and it proposed that it is possible to analyze the BIM implementation process with regard to BIM-related risks and their relations between implementation and post-implementation phases. The identification of BIM-related risks correlations can then be used to not only to bring more efficiency to BIM implementation process, but also to better understand BIM threats and opportunities during both implementation and post-implementation phases. As the literature review shows, risks are often considered as an area which is heavy influenced by the BIM implementation. The impact of BIM on risk management processes can also be considered as the main advantage of the BIM. Unfortunately, the correlations mentioned are not clear and vary based on the project differences. Therefore further case-study oriented research is needed to describe proper risk correlations model. Such models could then be used to support BIM implementation process and to better utilize risk-related advantages of BIM in construction projects.

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Identification of problems with the creation, exchange and use of project documentation

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Abstract

Communication processes are crucial especially in fragmented industries such as Architecture, Engineering and Construction. The exchange of information between participants in a project is complex and has many risks. The risks can be associated with any of the parties involved, information and communication technologies, or process stages. In the paper we present research in which we tried to understand where in the construction process communications problems are most severe. The paper presents the results of a survey done on information flow and the understanding of project documentation among Slovenian AEC professionals. The survey results show that the main concern is not the quality of project documentation as such, but its interpretation and use. The results also indicate that although modern information technologies such as building information modeling have a positive impact on the quality of project documentation, their potential is not yet fully exploited. This raises the question of what can be done to further promote the use of existing commercial solutions, and where the main reserves to utilize the technologies which are currently in the domain of research institutions, are.

Keywords: Project documentation, information flow, collaboration, BIM, questionnaire

1. Introduction

The relations between the partners in Architecture, Engineering and Construction (AEC) industry is complex; it involves many parameters that extend across technical, functional, business and human dimensions (Wikfoss & Löfgren, 2007). New design paradigms, innovative products, technologies, and processes exponentially add to the amount of information that AEC professionals need to process. Therefore, it has been recognized, that an effective exchange of information is crucial in order to successfully carry out construction projects (Woo, 2004). Not only have the manual systems such as e-mail failed to satisfy this need, but computer packages which have sprung up have also not proven to be adequate for such communication. AEC stakeholders have already partly managed to optimize the production of project documentation with building information modeling approach to the construction. This is, however, only the first step towards a comprehensive digitalization of the construction process. A true holistic approach of digitalization of construction will only start to appear when all participants will be involved. In order to define future process, software and methodology development guidelines, it is crucial to find task and related stakeholders that slow down digitalization and thus decrease the possibilities modern technologies can offer.

Several surveys were conducted in order to measure the impact of modern technologies in AEC (Woksepp & Olofsson, 2008), (Zeb, et al., 2012), (Şenyapılı & Gökçen Bozdağ, 2012). Although the results indicate a positive impact of IT in the construction industry, we believe that the full potential of modern technology still isn't fully utilized. In order to understand the mechanisms and moderators that affect AEC processes, this paper analyses the flow of information among all segments and all participants in AEC, and with that tries to: (1) provide a general overview of project documentation as used by the Slovenian AEC sector, (2) get an inside view on hardware and software usage, (3) identify phases where difficulties usually occur.

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2. Research Method

The construction IT, focuses on the theoretical analysis and practical implementation of the software aimed to support engineering work. In our case, we were dealing with preliminary theoretical study with which we want to justify the reasonableness of further research. Therefore we have chosen to use surveying as one of the fundamental research methods. The internet is increasingly becoming available as a cost and time efficient way of survey research. However, it is necessary to point out some disadvantages of the online surveys. Wright points out two main problems regarding online surveys: sampling and availability (Wright, 2005). With internet surveying, we may encounter problems with the representativeness of the results (Scheuren, 1980). It may happen that the results do not reflect the actual situation regarding the topic being investigated and that they cannot be generalized out the population. Statistical inference from sample to population - which usually involves a confidence interval as a measure of risk that we're wrong - is based on the fact that the probability of inclusion is known in advance. As the interviewing is not just simply asking questions and finding answers, but seeking the exact answers to very specific questions to a particular group of people in a predefined manner (Pokorny, et al., 2012), we have undertaken a systematic approach. We conducted the survey using the following steps; (1) survey planning, (2) preparing of the questions on the basis of the objectives set, (3) testing of the comprehensibility of the questionnaire on a test sample, (4) actual interviewing, and finally, (5) analysis of the results.

In this case interviewing as one of the methods of scientific research is necessary to determine the target group. A clear identification of the target population is even more important when interviewing through online questionnaires, because when analyzing the results, it is necessary to prove that the data obtained clearly reflects the reality of the entire population. In our research we orientated our focus towards the Slovenian companies which are in some way related to the building environment. We wanted to obtain the answers from owners, architects, engineers, general contractors, subcontractors and supervisors. The research trends in the Slovenian AEC sector indicate that it is very difficult to obtain a sufficient amount of replies (Pazlar, et al., 2004), (Klinc, 2010). In the mentioned studies, two sampling methods were used. Pazlar et. all. used a traditional probability sampling method. Despite intensive promotion via e-mail and advertising in magazines, the response was rather modest. Klinc used a snowball sampling method. As it has proven to be more efficient, we decided to use it as well. The snowballing method, or chain sampling, is a specialized, non – probability type of sampling, which is used in cases where the potential subject studies are hard to locate or hard to reach (Castillo, 2012).

Prior to the survey all respondents were acquainted with some of the terms that appear in the questionnaire. We first clarified the confusion that may occur with the acronym BIM. We use BIM as an acronym for the building information model, which is a product of a process called building information modeling. We presented GDCPP as it was defined by (Aouad, 1998). Formally speaking, the project documentation that is required in Slovenia is defined in the Law on building construction (ZGO, 2008). It should consist of conceptual design, conceptual project, project for the building permit, project for the implementation and the project executed works. In this research project, documentation is used broader than formally defined in ZGO. We use the term project documentation as a set of all documents needed for the construction.

A quantitative approach was chosen to ensure repeatability of the assumptions. The questionnaire was sent to 27 persons on August 29. 2012. They were asked to fill in an online questionnaire and forward it to co-workers, colleagues, acquaintances, friends and all others who work in the construction industry. Overall, 49 replies were received after a two week period. A total of 38 replies were received during the first three days. The next peak response period was detected after a few days, on the third and fourth of September. This response curvature can be related to the snowball effect.

3. Survey results and analysis

In order to ensure the credibility of the survey, problems that come with online surveying need to be addressed. The problems can be merged in principle to the generality of the results. The generality can be guaranteed with general information about the participants. Although the sample size was rather small the authors believe that it accurately reflects the actual situation since responses were obtained from all focus groups: general contractors 18 %, architects 21 %, engineers 18 %, subcontractors 10 %, supervisors 4 %, engineering experts 21 % and owners and others 8 %. The principle of generality can be guaranteed with all age groups being represented and all sizes of companies being represented. Micro companies (1 employee) are represented with a share of 10%, small companies (2 – 9 employees) have a 26% share, medium size companies (10 – 49 employees) have 37% and large companies (more than 50 employees) have a 27% share. It should be noted that the size criteria of companies was adjusted according to current situation in Slovenian construction sector.

3.1 Project documentation

In this set of questions, interviewees were asked to express their opinion about the quality of the project documentation and the impact of modern technologies on it. Figure 1 shows that the majority are satisfied with the current state of project documentation. Cross referencing results about quality of project documentation and respondents' professions show that general contractors are least satisfied with the quality of project documentation. The positive impact of modern technologies is clearly visible from Figure 2. A total of 67 % believe that the quality of project documentation has improved with modern information technologies.

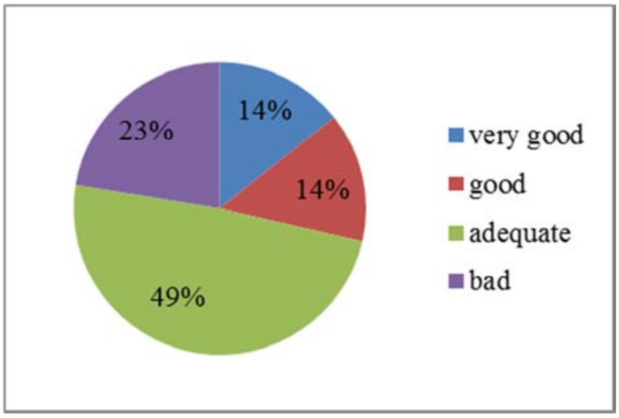

Figure 3. General opinion regarding the quality of project documentation

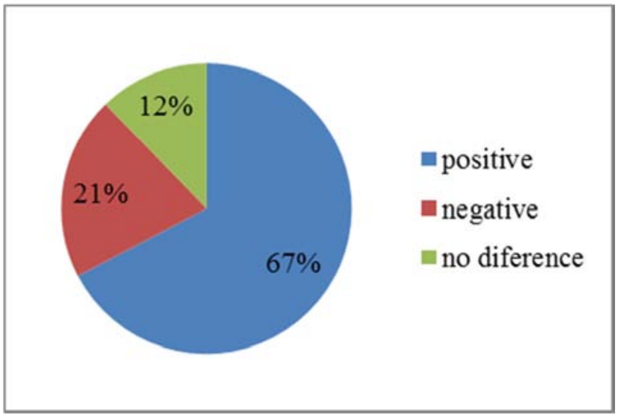

Figure 4. Influence of information technology on project documentation

High quality project documentation is only the first step to success. The next, perhaps even more crucial steps are transition, coordination and eventually interpretation. Interpretation is linked to understanding, which will be discussed later on. Information regarding transition and coordination are represented in Figure 3. It is possible to claim that the transfer of information is still done manually and that plans are still printed out and brought to site in physical form.

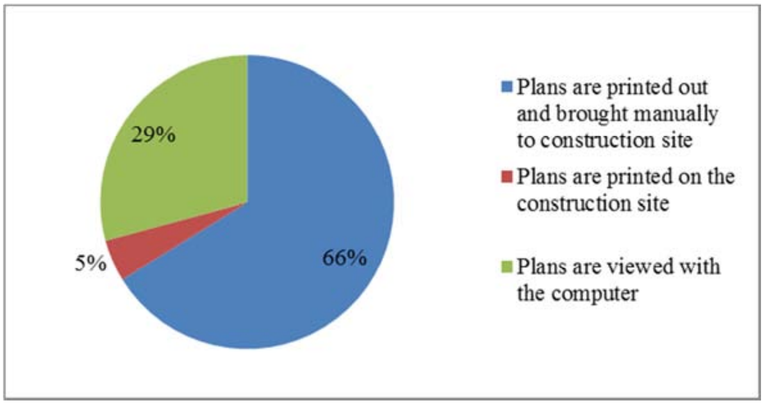

Figure 5. Examination of project documentation

3.2 Understanding of project documentation and risks related to its misinterpretation

The aim of this sub-section is to identify the most frequent risks and their relation as pertaining to various AEC stakeholders. Surveys show that mistakes are most likely to happen because of poor communication. Two of the greatest concerns that can be raised are the problems of non-accessibility of information and poor communication. General contractors and engineering experts were the most concerned with both of those risks. Respondents were also asked to express their opinion about the misunderstanding and abuse of project documentation. Results indicate that 61% of all respondents believe that there is a strong likelihood that project documentation is misunderstood. It is even more worrying that more than 57% of all respondents believe that project documentation is being abused because it can be differently interpreted (Figure 6). Part of survey was aimed at determining the methods of information transfer. Although all of the respondents have access to either a laptop or a PC, access to information still remains a problem. The vast majority of project documentation is still printed and brought to construction sites in physical form. Less than 40% of respondents use a computer for project documentation. Based on this fact, it can be inferred that access to information in digital form is already possible but not jet fully utilized.

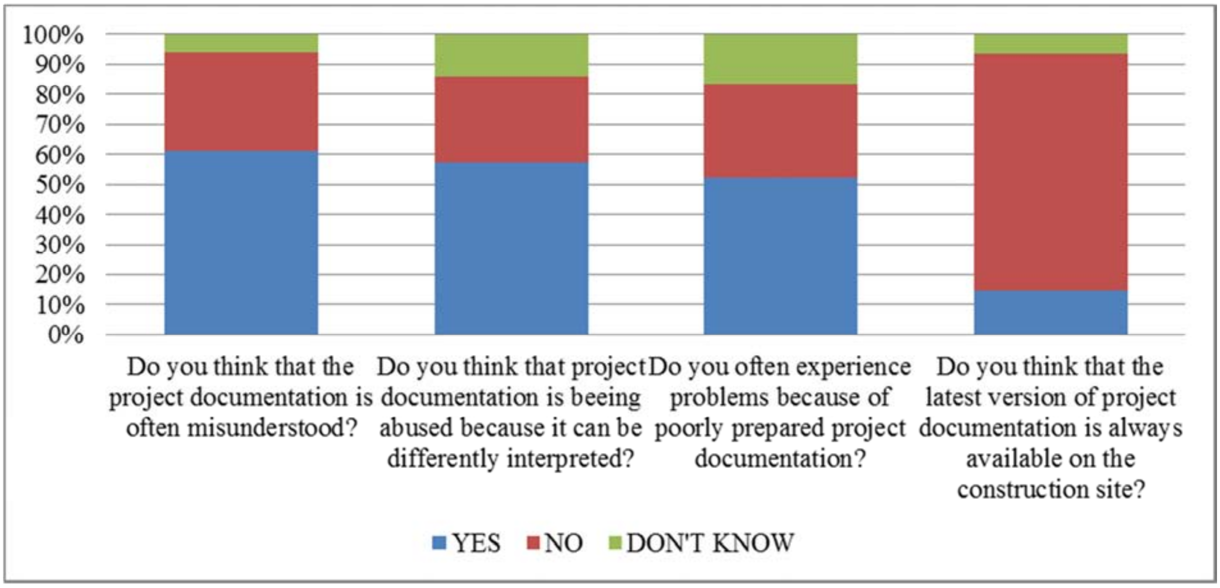

Figure 6. The common problems associated with the project documentation

3.3 Risks related to specific stages of GDCPP

The fourth set of questions deals with the phases of construction in relation to risk factors. Interviewees were asked to rate each phase of GDCPP. Figure 7 summarizes the response rates that are subject to intense risk. For more in-depth understanding of the problem, three of the most critical phases are associated with the participants. Even in this case, it turned out that the most critical groups are general contractors followed by engineering experts. It can be argued that the most critical stages in GDCPP are: coordinated design, procurement & full financial authority, and the production information phase.

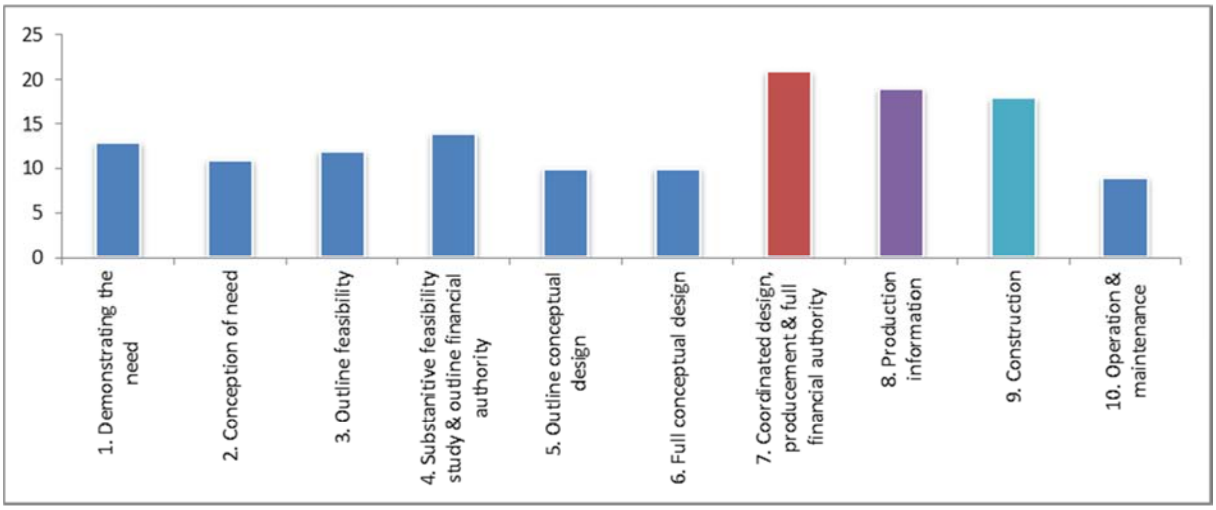

Figure 7. Critical construction stages are phase 7, 8 and 9

4. Conclusions and discussion

The first objective of this paper was to provide a general overview of project documentation in Slovenian AEC in relation to its interpretation. According to the responses, the quality of project documentation is satisfactory and is getting better with increasing usage of modern technology. Misinterpretations may therefore be only partly attributed to the preparation and production of project documentation. Results show that building information modeling is becoming increasingly familiar in Slovenian AEC, but it is necessary to emphasize that although BIM are becoming more and more recognized, they are still primarily used as a 3D presentation method. The fact that building information modeling is primarily used for the production of 3D models did not surprise us, because foreign researches also indicate similar results (Azhar, 2012), (Glennon, 2013), (Huier, et al., 2014).

The authors believe that the engineers and architects will be forced to use BIM in the near future. In some countries, they will be forced through legislation (CIC, 2014) and in others because they would not be competitive. What will happen then? Imagine an idealized scenario: the BIM can be produced, shared, managed and maintained online. This is all well and good, but we are still in phase 7 and 8 of the GDCPP. What about phase 9, the actual construction, where the mapping between real and virtual is still done? Figure 3 indicates that nowadays the majority of plans are printed out and brought to construction sites in physical 2D form. This suggests that it will be necessary to begin thinking about alternative methods of information transfer. Technologies which will help us achieve this goal include: human augmentation, volumetric and holographic displays, automatic content recognition, natural-language question answering, speech-to-speech translation, big data, gamification and augmented reality (Gartner, 2013). The applicability of these should be studied by construction IT researchers. We believe that among these, Augmented Reality should be highlighted. Misunderstandings are connected to the possibility of ambiguous interpretations, but the other hand, there is a poor spatial representation of people who are not directly caught up in AEC. We believe that AR can seriously address this problem, because as a presentation method, AR bridges the gap between the abstract world of project documentation and the real physical world.

The main objective of construction IT research is not to produce the final products, such that can be used commercially; its role is to think outside of the box. It should be setting the guidelines for the research and opening of new horizons. Researchers set the foundations of AR in the 1960s, when the idea of AR was more or less a science fiction. Nowadays in technologically more advanced areas AR is already excising with the technologies such as Google Glass, enforcing the AR in the AEC is slowly follows. Nowadays in technologically more advanced areas AR is already excising with the technologies such as Google Glass (Muensterera, et al., 2014), we believe that enforcing in the AEC will slowly follow (Meža, et al., 2014).

Acknowledgement

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Integration of document- and model-based building information for project management support

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Abstract

In spite of the upcoming BIM based work paradigm and related technologies in the AEC sector traditional semi- and unstructured documents, like formwork or reinforcement drawings, will remain an essential part of the overall project information resources. Such kind of documents are still the basis of the daily work in construction projects and are, in contrast to a BIM, valid as mandatory objects of agreement and integral parts of contracts. Therefore document management will remain a crucial part of the overall project management. Based on the fact that in the frames of practical projects traditional documents will coexist together with model-based building information the existing technological separation between those different worlds of information is counterproductive and out-of-time since it may cause information losses, inconsistent information resources and hinders an adequate and project wide adoption of BIM technologies. The aim of this work is to develop a practical method that allows for the use of IFC building information models within a database-driven project management environment to make model-based building information available for project and document management purposes. The proposed method will establish an integrated overall project information resource constituted by a persistent linkage between elements of the building model and the associated documents.

Keywords: Building information modeling, document management,project management, IFC, data integration.

1. Introduction

Building information is been represented traditionally by semi- or not formalized documents like construction drawings, specifications for building systems and material lists. Due to the upcoming method of Building Information Modeling (BIM) the traditional way of building information representation is shifted to a model-oriented approach where the overall building information is stored in a commonly shared comprehensive building information model that allows for on demand retrieval of information subsets needed by downstream tasks and business processes (Succar 2009). Whereas the model based approach is widely adopted in the early project phases, e.g. for design, clash detection and coordination of disciplines, traditional documents are still the dominant information resource in the later project phases. In terms of practical projects this mostly results in a complementary but technological separated use of document and model based project information. Accordingly, existing BIM software applications and tools already used in practical projects are mostly focused on design phase offering functionality e.g. for building design, modeling and (3D) visualization. Downstream building life cycle phases like construction, operation and maintenance as well as general project management are still weakly supported by appropriate BIM tools. This might be one of the reasons for the slow implementation of the BIM work paradigm in the AEC industry (Kiviniemi 2013, Gu &London 2010), in spite of the well documented benefits especially with regard to the later building life cycle phases (Azhar 2011). This leads to a technological gap within the overall process chain and a setback from new model based working to traditional document based processes which in turn may cause information losses, inconsistent information resources and hinders an adequate and project wide adoption of BIM technologies. From this point of view a complementary linkage between model and document based building information on data level is supposed to re-connect the interrupted overall information process chain by establishing an integrated project information resource (Juli & Scherer 2003).

In practical project environments the use of document management systems (DMS) is common practice in order to cope with the large sets of documents generated during the project lifecycle. Modern DMS provide at least for archival storage of various types of documents, document lifecycle management and document retrieval ensuring reliable access to the set of stored documents. In most practical applications a DMS is integrated into a project management system (PMS). A PMS allows for assignment between a set of documents and related (pre-

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defined) business processes in order to specify and control the workflow and information delivery with respect to the project requirements. However, in almost all cases the inclusion of a document into the DMS database is based on an alphanumerical plan or document key stored in the document file name. The plan key is created manually by the document owner and decrypted by the DMS based on predefined rules. This approach has several drawbacks since it is error-prone and restricted to a very small set of building and document information, consequently limiting the document retrieval and management capabilities offered by the DMS.

An alternative approach to this would be the application of semantic document metadata standards like the Extensible Metadata Platform standard (XMP 2012, ISO 16684-1) available for portable document files (PDF, Fanning 2008). In combination with BIM-CAD tools a significant part of the needed document metadata could be derived directly from the internal building model without the need for manually rework. Such kind of metadata enables a computer interpretable connection between a document and the related content of the corresponding building information model. Furthermore, the capabilities and functions of new BIM data management tools and methods (e.g. model querying, analysis and comparison) will become available for practical document and project management purposes if a reliable connection between the document and the model based information resources exists.

2. Link methodology

The suggested methodology aims to integrate document and model based information resources based on the application of explicit document-object-links which can be generated automatically and stored in a DMS data base. This approach is dedicated to the application in the frames of practical project environments with strong focus on its efficient implementation based on existing PMS infrastructures consequently utilizing the capabilities offered by (open) standard and commonly used technologies like SQL, PDF, Industry Foundation Classes (IFC, ISO 16739) and XMP.

2.1. Link types and semantics

A document-object-link generally implies an explicit relation between a set of documents stored in a DMS and a set of objects contained in the corresponding building model. A link is defined by its type and additional link attributes specifying the link semantics. The type of the link indicates the cardinality of the relation and is basically determined by the documents type and contents. The cardinality specifies the valid number of elements contained in the document and object sets related by a particular link (Figure 8). For example, a single link with cardinality 2:n (subtype of m:n link type) indicating a relationship between exactly two documents and multiple model objects is been described formally as a tupel $\{(d_i, d_j)\ (o_1, o_2, \ldots, o_n)\}$ containing two arrays with $d_i, d_j \in D$ (set of documents) and $o_1, o_2, \ldots, o_n \in O$ (set of objects contained in the corresponding building model). The elements of the document and model object sets are represented by the according element IDs.

Additional link attributes can be used to attach semantics to a link describing the indicated relation in more detail. Potential information to be attached to a link may be information about link creation (e.g. link creator, date of creation, parameters used for link creation), technical link specification (e.g. valid document and model object types, document format) or workflow management parameters (e.g. assigned work domain, task, actor or document status). The interpretable link semantics enable extensive link processing in terms of link validation as well as analysis of the integrated model data, e.g. by applying predefined link integrity constraints determining restrictions on the values of link attributes which are valid for a particular link. An example constraint may be the statement “For any building model object of type column, slab or beam with assigned material reinforced concrete a link to two documents, one of type formwork drawing and one of type reinforcement drawing, must exist (at a certain time)”.

Since the links provide for access to the BIM data the link semantics can be derived also by evaluating the object references of the linked model objects. For example, in IFC an object of type wall is related to a space object and each space object is related to the building storey object it belongs to (i.e. spatial zone object) by explicit object references. Due to the transitivity of the document-object-links the IFC object references can be used to represent the relations between documents and model objects in different levels of detail without the need for creating additional links (Figure 8). Furthermore, the document-object-links enable access to a wide range of information stored in the building model like element geometry, quantities, material or topological information.

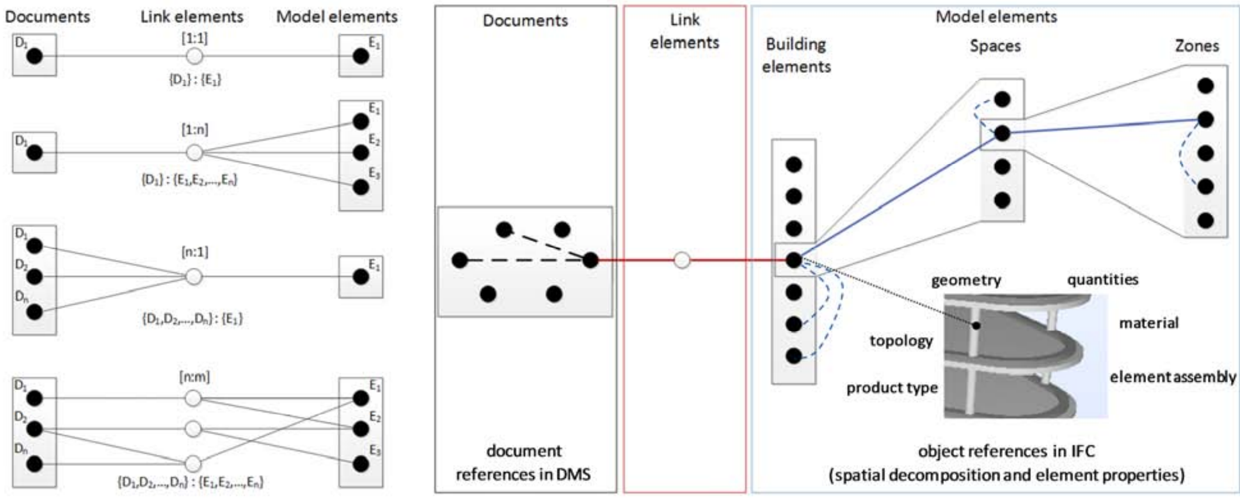

Figure 8. Basic link types (left), transitive relations and additional object properties accessible by document-object-links (right)

2.2. Link representation and storage

In principle there are four different approaches to formally represent and store the information about the document-object-links which differ mainly regarding the amount of storable link information, information access capabilities, effort required for link creation, management and implementation in practical project environments:

- Within the building model (i.e. using IFC): IFC provides for referencing external resources via accordant object type definitions, i.e. instantiated references are part of the particular building model (BuildingSMART 2009).
- Using an external link model according to the multi-model approach: The multi-model concept (Fuchs et al. 2011) is specifically dedicated to the integration of non BIM data provided on the basis of standard or quasi-standard data models with no further expansion of the BIM. Thereby the involved models are linked by the application of a separated generic link model and kept separately manageable (Liebich & Katranuschkov 2010).
- As a genuine part of an ontological model specification: This approach is based on an ontological representation of the integrated data model which explicitly defines the relations between the elements of the involved data models in a more holistic context (Scherer et al. 2012).
- Within the document meta model respectively within the schema of the DMS data base: This approach is similar to the approach using IFC as link container but in contrast to the IFC based approach the links are defined by the DMS data base schema and are stored in the DMS data base accordingly.

The methodology proposed here applies the latter approach for link representation and storage. The according metadata schema is shown in Figure 9. Section A encompasses information about the building model containing the elements which are linked to a certain set of documents and the linked objects itself. This section is an optional part of the document metadata but mandatory for the DMS data base schema. Section B specifies information about the spatial zone related to the contents of the linked document. It allows for document linkage on different levels of detail with respect to the spatial structure of the building and is used to support automated link creation process. It is mandatory for the document metadata schema but is optionally be used since spatial zone is not known in any case. Section C specifies information about the building elements contained in a document. This information is used for automated link creation process and is therefore mandatory for the document metadata schema as well as DMS data base schema. This information has to be exported by the BIM-CAD authoring tool or derived from the building model respectively and stored into the documents metadata. The information content of this section represents the minimum data set needed for consistent assignment between a set of documents and a set of model elements. The actual link is defined by the transitive relationship between *Document* and *ModelObject*. The remaining part of the presented schema specifies further information describing the document itself rather than its content or the document-object-links.

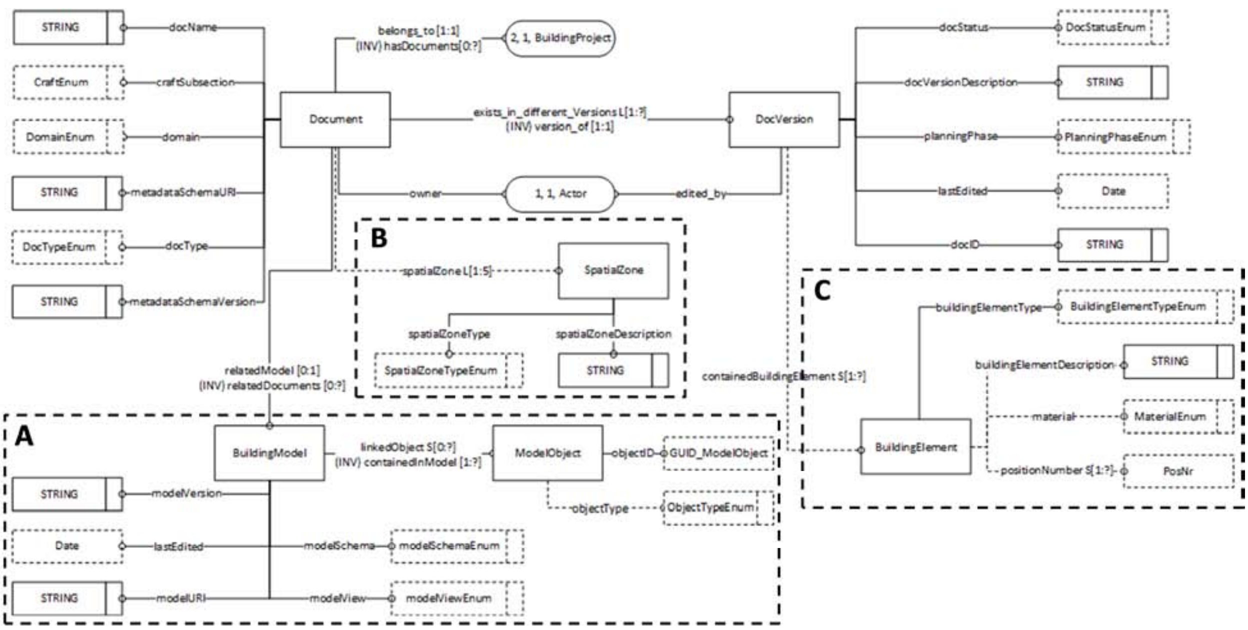

Figure 9. Document metadata schema as part of the DMS data base schema

2.3. Link generation, utilization and management

It is obvious that due to the huge amount of elements contained in a building model as well as the large set of related documents the resulting set of links may become of enormous size. Manual link creation will therefore not be appropriate for practical applications and has to be supported by automated link creation. The automated link creation process is based on a set of mapping rules which can be also configured on demand depending on the particular project requirements. The mapping rules specify the corresponding information subsets of both the document metadata and the IFC model data used for link creation. The information subsets specify a type of checksum which is used to identify a valid document - model object pair if the checksum derived from each the document metadata and the building model data is identical. The minimum information subset would be the Globally Unique ID (GUID) assigned to IFC model objects. A more complex information subset may be the aggregation of building element type, element material and spatial zone containment. The link creation process may also involve the evaluation of existing links, e.g. if the actual document to be linked is a revised version of an existing document.

Once the links are created and stored in the DMS data base they can be used to analyze and query the resulting integrated model data. Model querying requires link evaluation by starting either on the building model or on the document metadata side, e.g. search for elements which are linked to a given document or vice versa. The query execution process evaluates the stored link information based on a mapping between the elements resulting either from a model or a DMS data base query and the related elements contained in the building model or the DMS data base respectively. A query can be also extended by various search conditions utilizing the link semantics, the available document metadata or additional information contained in the building model as well. For example, if the user wants to search for all concrete building elements which have no reinforcement plan assigned.

Since the building model as well as the document metadata is stored separately the link information must be synchronized and dynamically adjusted following different rules for link management. Existing links may be updated (exchange of linked objects), modified (link attributes) or deleted by the DMS according to the link management rules or on demand by the user. For example, if a document is deleted the related link element is deleted too. Changes in the building model initiate a review of the stored link information followed by modification of the affected link elements.

3. Implementation and use case example

The outlined approach has been implemented in a prototypical software application called BIMdox. The Java-based prototype BIMdox is a tool to generate, modify and validate PDF documents with embedded metadata in Extensible Metadata Platform (XMP) standard based on a predefined metadata schema (see section 2.2). The created documents can be added to a connected DMS composed of a relational database and a document repository. BIMdox integrates the filter toolbox BIMfit (Windisch et al. 2012). BIMfit provides several filter functions for querying an IFC-based building model and is used to retrieve the IFC model data needed for link creation by the multi parameter matching process and for link processing as well. BIMdox allows for mapping between the relevant parts of the IFC schema, accessed via BIMfit, and the context dependent matching parameters of the link creation and link processing operations represented by the document metadata schema, queried by standard SQL. The BIMdox graphical user interface integrates a model viewer for 3D visualization of the IFC building model and enables user access to the interlinked information resources (Figure 10).

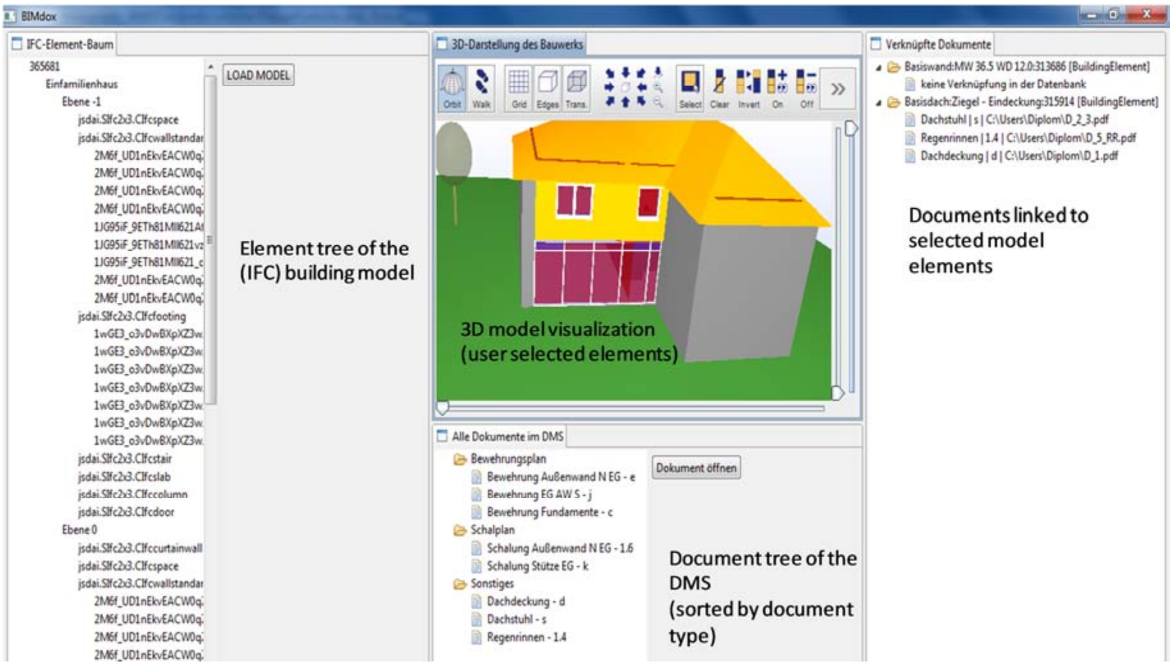

Figure 10. GUI of the BIMdox prototype – document search based on user selected building elements enhanced by a 3D model visualization

3.1. Creating the linked document-building-model

The starting point of a particular use case scenario may be the export of a reinforcement plan (e.g. for a concrete slab of a residential building) in PDF format by using export interface of the used BIM-CAD authoring tool. Simultaneously all relevant metadata which can be derived from the internal data model of the CAD tool is serialized in XML and embedded into the document file according to XMP metadata standard. In a second step the stored metadata is validated by the user and the program (BIMdox) checks if the metadata schema is implemented correctly. After successful validation the document is indexed (document ID is assigned, e.g. Doc_3g45) and stored in the DMS by integrating the document into the document repository and inserting the contained metadata into the DMS database. Step three includes the selection and validation of the IFC BIM model by the user. Afterwards the document can be linked to the related model objects according to its contents described by the document metadata. For the automated link creation process at first the element type and the optional parameter *positionNumber* might be chosen if available since it allows for unique assignment of related building elements (in case GUID is maintained it should be used preferably). Depending on the number of building elements of type slab with the particular position number contained in the building model the resulting link will be of type 1:1 or 1:n. Since the element type and the position number are stored in the DMS database they can be queried by SQL. Accordingly, the IFC building model will be filtered by the related BIMfit functions applying object type and the value of the position number as selection criteria (selection of all objects of type *IfcSlab* and retrieval of the value of the *positionNumber* property for the set of building element objects selected prior). The returned set of values is matched against the SQL result set. If it evaluates to true the GUIDs of the related model objects are requested and inserted into the connected DMS data base (attribute *GUID_ModelObject* in *ModelObject*) by SQL data manipulation operation.

3.2. Querying the integrated model data

If the document-object-links are created they can be used to query the integrated model data using the BIMdox prototype (Figure 10). A typical query may be the search of documents belonging to a particular building element. This type of query can be done easily by direct user selection of a building element either in the building element tree or the 3D model viewer integrated in BIMdox. If a building element is selected, e.g. a wall element of the 2nd floor, it will be highlighted in the model viewer and the GUID of the element will be sent to a SQL query filtering the corresponding documents by evaluating the available link data stored in the connected DMS data base. The resultant set of documents is displayed to the user as a list of document (file) names. The opposite type of query supported by the current version of BIMdox is the search of building elements which are related to a given document. Based on a user selected document the application identifies the IDs of the linked objects by querying the DMS data base. The returned IDs are assigned to a BIMfit model query to filter the related elements by the matching IFC object GUIDs. The search result is displayed to the user by highlighting the filtered building elements in the 3D model viewer.

4. Conclusions

It must be assumed that in the frames of practical projects traditional documents will coexist together with model-based building information. The existing technological separation between those different but strongly related information resources is counterproductive and out-of-time since it may cause information losses, inconsistent information resources and hinders an adequate and project wide adoption of BIM technologies. The presented work aims to develop a practical method that allows for the use of IFC-based building information models within a database-driven project management environment to make model-based building information available for project and document management purposes. The proposed approach is based on explicit document-object-links which are stored in a common DMS data base system. Open standards and common practice technologies (SQL, PDF, IFC, XMP) are used for implementation in order to enable efficient integration into existing PMS infrastructures.

The integration of document and model-based information opens up numerous applications and benefits regarding document and project management. For example, visual support of the document search and retrieval can be enhanced by a 3D representation of the building model including the filtering of the building model according to different multi-model criteria, e.g. for target-performance comparison in project management.

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Creative Construction Conference 2014

An integrated grid based web platform for advanced structural design and analysis

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Abstract

The Building Information Modeling (BIM) approach has revolutionized the way buildings are getting designed and constructed. The BIM design method combined with web services, grid and cloud computing power opens the door for construction engineers to improve the building design through enabling them to run advanced structural analyses for design alternatives quickly with low cost. However, the high hard- and software cost for complex computations like parametric studies are usually reserved for big companies or research facilities. This paper introduces an ongoing research with the to develop a general web-based Structural Engineering platform which allows small and medium enterprises (SMEs) to bundle their already available computing resources for complex simulations. Furthermore it provides data management functions, supports the creation of model variations and offers a collaboration layer to experts of different disciplines in particular an interface to BIM-IFC.

Keywords: grid, structural analysis, structural design, integrated web platform.

1. Introduction

More slender structures, new architectural design paradigms, energy efficient buildings, retrofitting of historical buildings, life-cycle extension of civil engineering structures and an increased demand for safety in our society require broader application of advanced non-linear mechanical modelling and probabilistic safety concepts for structural design. Both demand advanced information management and the automation of the bulk of simulations for design variations and probabilistic evaluation and hence much more computing power. The partial safety factor approach, that is commonly used today, cannot be applied in combination with structural non-linear analysis and has to be replaced by the full probabilistic approach (Alonso et al, 2012). In addition, for non-linear structural analysis the linear superposition principle is not valid, which means that for multitudes of load combinations separate non-linear analyses must be carried out (Caballer et al, 2013: 2-3). With currently available tools this exceeds the labor resources and the computer power of SMEs (Alonso et al, 2012: 1; Caballer et al, 2013: 1). Therefore new methods, preferable integrated on Building Information Modeling, are needed.

Civil engineering companies usually own lots of powerful desktop computers whose capacity isn't entirely used by the employees working at them and hence waste money (Wertel, 2013). The capacity of the single machines isn't sufficient for the computations mentioned above, but bundled together they can provide enough computing power to solve complex tasks. With an appropriate software solution, which combines the single machines to a private grid and helps managing the huge bulk of data, civil engineering SMEs have new simulation possibilities without additional investments in hardware or external services. This paper focuses the population of the web-based engineering platform as a grid-based Structural Analysis web platform, developed in the project *GeoTech Control*[†] and now extended in the project *SE-Lab*[‡].

First we give an overview of the platform architecture and outline a basic workflow. Section 3 will focus on the management of the engineering model and computed data as well as the generation of model instances for parametric studies. The integration of grid-/cloud- computing power into the platform is covered by section 4. Finally section 5 draws conclusions about the presented approach and addresses future work.

2. The Structural Analysis Web Platform

The software system described in this paper is a service-oriented architecture (SOA) and web-based information management platform which provides integrated interfaces with computational kernels for non-

[†] http://www.geotechcontrol.de/
[‡] http://www.selab.eu/

linear and probabilistic structural analyses as a web service and thus enables the porting of computation into a grid/cloud environment. Consequently a huge amount of computation tasks can be carried out simultaneously and hence time-saving and cost-efficient. The platform is developed as an extension component of the Integrated Virtual Engineering Laboratory *(IVEL)* platform, originally developed for thermal energy analysis of buildings (Baumgärtel, Katranuschkov & Scherer, 2011).

Figure 1 schematically shows the architecture of the system. Integrated solver kernels provide algorithms for parallel execution of different tasks. Web-based graphical user interfaces provide basic interaction functions for users such as up-/download of models or start and control of simulation instances. Furthermore the platform is going to offer collaboration possibilities for interdisciplinary project teams of architects, construction engineers, numerical engineers and others through provision of a shared data server and a communication layer. A basic design-analysis workflow could consist of the following steps: (1) the structural engineer prepares the numerical model for the FE analysis using FEA pre-processing software (Atena[§] is applied) and uploads the FEA input file to the platform; (2) desired parameter variations are specified in a XML-based variation model (see section 3.1); (3) on a web GUI the structural engineer specifies further relevant information for the structural analysis and chooses from a set of predefined computation infrastructures (grid, single server, …); (4) the Model Generator creates variants from the numerical model according to the information given in the variation model and passes them to the Computational Service; (6) computation jobs are created and distributed to the available computers in the grid where the solver executes them; (7) computed results are passed to the Data Manager and persisted on the data server to be accessed through the web GUI. The modular and service-oriented design of the platform also allows the dynamic adding and removal of functionality through plugins such as post processing modules, e.g. a toolbox for the generation of different model views such as introduced in Windisch, Scherer & Katranuschkov (2012), or, like Saitta, Raphael & Smith (2005) propose, tools for the filtering of candidates which fulfill some specific criteria from the bulk of results to increase the reliability of a system identification task.

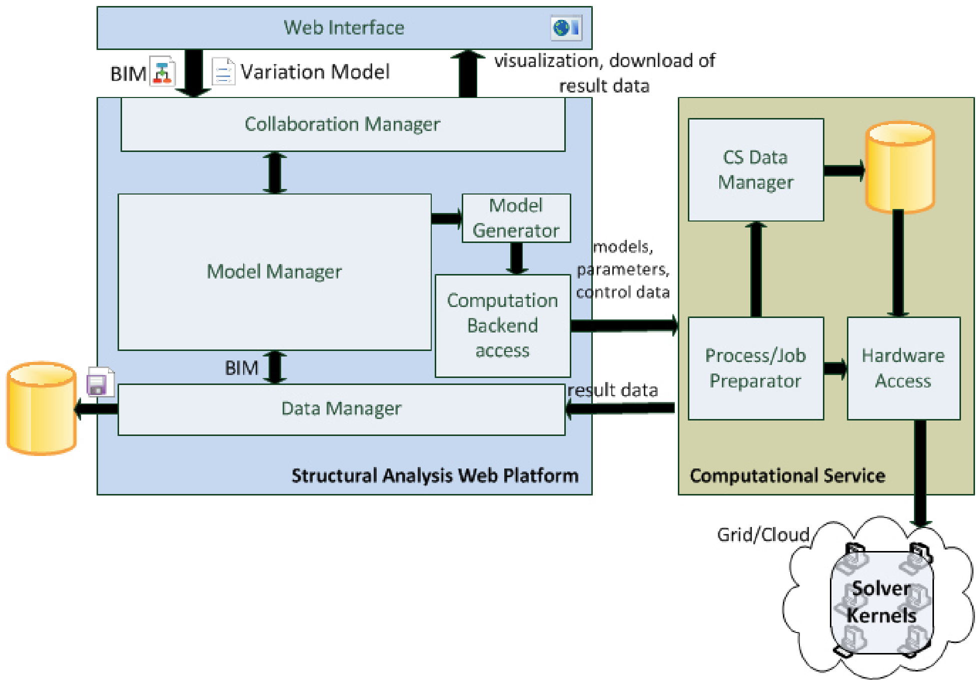

Figure 1. Top-level architecture of the Structural Analysis web platform

[§] http://www.cervenka.cz/products/atena/

3. Model generation and integration

This section covers the creation of simulation model variations and the management of the input- as well as the potential huge amount of result data for collaboration purposes.

3.1 Model Generation

Parametric studies like system identification for the determination of an optimal parameter set for a building model require a huge number of model instances because of the non-deterministic variation possibilities for design/material parameters or a huge number of different supposable load cases. Already the manual creation of so many models is very time consuming and from the economical point of view impractical.
Therefore our approach offers support for model generation techniques. The basic idea is to define the parameter variations in a generic variation model which can be combined with an engineering model in order to provide the basis for the generation of concrete model instances for structural analyses. The advantage of this approach is that there is no need to change the original model. Figure 2 shows the general scheme of a variation model. The approach assumes that every variation point in the engineering model is uniquely addressable by an identifier which is used to assign it to variation elements in the variation model. The engineer now has the possibility to define exact values for an element in a comma separated list. The second possibility is to define an algorithm which generates the parameter values. Specific values not covered by the algorithm can be included explicitly or, the other way round, excluded for some reason if covered by the algorithm.

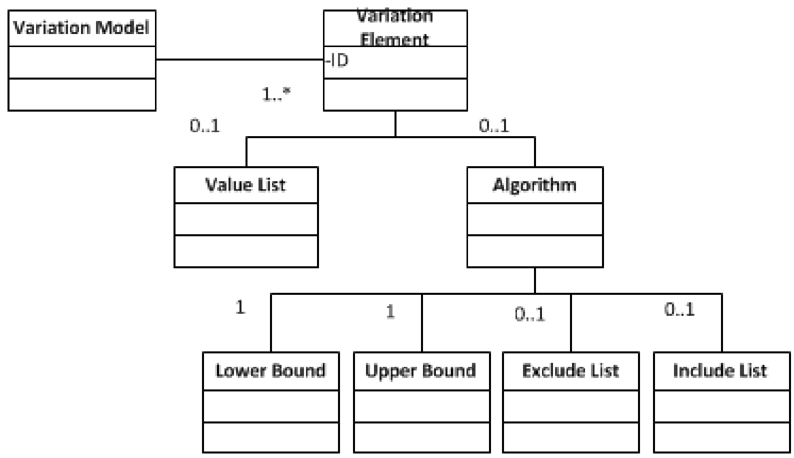

Figure 2. Schematic structure of a variation model

Internal the building models are managed as SPF (STEP Physical File Format) files according to ISO 10303-21 (2002). Hence all building elements and parameter definitions own a STEP line id of the form #xxx (x={0,…,9}) which can be used to identify the element / parameter uniquely. One application in case of BIM design model would be the iteration over alternative load cases or standardized dimensions of a specific building element to determine an optimal design variant. Figure 3 shows an example extracted from an IFC compliant model and a possible variation model based on XML. The left SPF file model extract shows a solid element (e.g. a wall) and a material layer definition. As shown in the figure, the depth of the solid area, which is the only variable parameter in this line, is varied five times. The thickness of the material layer is increased in steps by 10 mm between the values 300 and 400 mm.

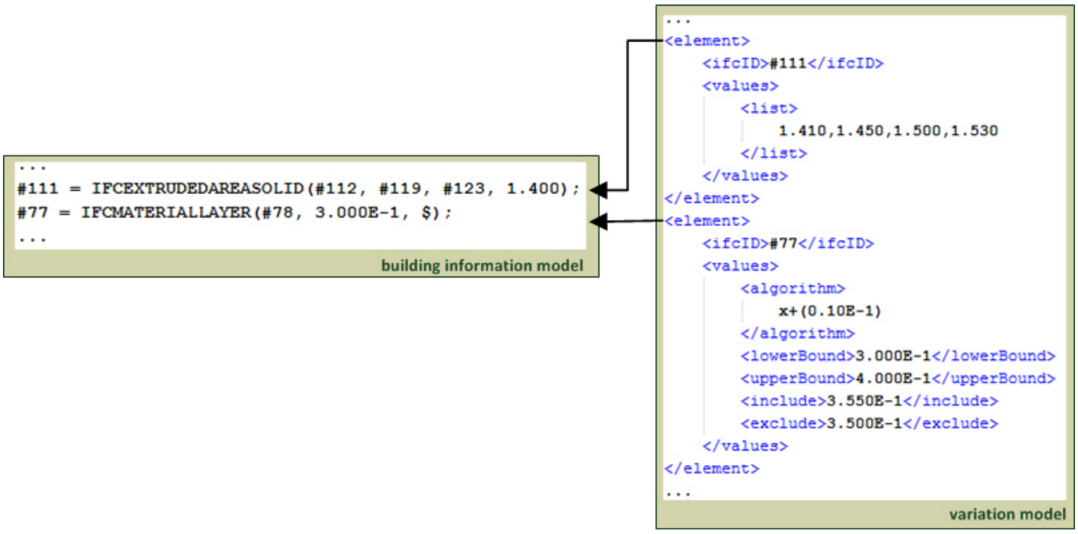

Figure 3. Definition of parameter variations in a variation model

3.2 Data integration

The generation and computation of a huge number of model and load variations require an efficient data management. Experiences from a previous project show that computed FE models for one analytic problem can easily reach a size up to 5 gigabytes (Hollmann, Faschingbauer & Scherer, 2012: 7). Consequently, there is a need for data reduction techniques to reduce the amount of data which has to be transferred over the network or persisted on the data server. The strategy of our approach allows the marking of relevant parameters in the initial engineering model before the model instance generation starts. In addition, the engineer can specify a set of key results, for example the displacement of selected nodes or the maximum load for pushover analysis. In a post processing step the system extracts the computed values for the marked parameters from the result model and transmits solely these values over the network. Hence the required bandwidth and disk space for the storing of result data can be reduced significantly.

4. Grid integration

As mentioned in section 3 there is a need for parallelization of computations and advanced data management as well as provision of high performance computing power through grid or cloud access. Dependent on the engineer's task the architecture of the platform allows the dynamic selection of the computational infrastructure, e.g.:

- A HPC server owned by the engineering company for sequential computation of huge models
- A private grid consisting of the employee's local machines for parallel computation of a huge number of small-medium sized models (sensitivity and probabilistic analysis)
- Access to a public HPC cloud if the company's resources are not sufficient

To date the prototype supports grid- and single server-based structural analyses e.g. with the ATENA solver (Cervenka, 2013) and uses the UNICORE[**] middleware as access framework to the grid resources. A special component called *Job Preparator* (see figure 1) processes the task description, model instances and further input and generates computation jobs according to the chosen infrastructure. In case of grid-based computation it creates UNICORE jobs in form of batch files which are transferred to the different grid nodes where they trigger the solver. When finished, the results are sent back to the platform and stored in a shared data server. Figure 4 schematically shows the usage of the company's computing resources bundled in a private grid.

[**] http://www.unicore.eu/

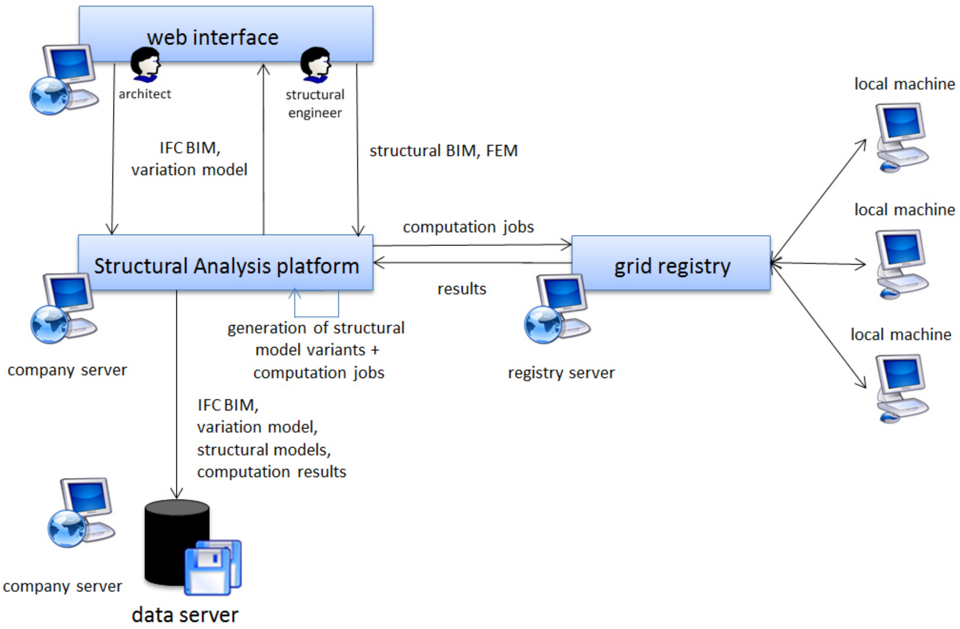

Figure 4. Grid-based computation infrastructure

5. Conclusions and future work

This paper has introduced a work in progress to integrate grid and cloud technologies within a web platform for structural analysis. The platform enables SMEs to run complex simulations in an acceptable amount of time on their already available IT infrastructure.

Furthermore the system provides support for the generation of model multitudes for parametric studies. Therefore the variation model approach allows the definition of parameter variations distinct from the original engineering model. An integrated model generator combines the initial engineering- and variation model and creates model instances. The grid middleware distributes the jobs to the PC nodes registered in the grid and collects the computed results.

Finally a data management component handles the storing and retrieval of the uploaded/computed data and supports web-based collaboration.

The granularity of the approach allows the extension to any engineering analysis, which is under development in a current EU research project. For the future we plan the integration of further solvers into the platform to use the grid infrastructure for the execution of tasks besides structural analyses like energy simulations. The objective is to generalize the platform for any kind of engineering problems and to control the engineering computations from one common BIM model.

Another key aspect will be the investigation of advanced data storage technologies to improve the data management. The objective there is to store all computed data and to do result analysis on demand and at any time also repeatedly applying data analysis, data mining, fuzzy and statistical methods. This means that methods are to be investigated which allow identification of sets of models through meta information and the subsequent tracing of the model results to extract desired parameters from the bulk of simulated data. The catalog of requirements is continuously updated through focus group interviews (FGIs) and discussions with industry partners.

The generation of model variants shall be extended to suspend needless parameter variations a priori and hence to reduce the amount of computations to be executed. More effective parametrization methods are under research and will be developed by means of thorough literature review.

Performance and usability of developed prototypes will be tested using test cases from real projects.

Acknowledgement

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BIM implementation – global initiatives & creative approaches

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Abstract

This paper examines the issues related to the implementation of Building Information Modeling (BIM) in the construction industry and the various initiatives and approaches that are being used in various countries around the world to promote effective BIM implementation in their construction industries.
Objectives of Study
The effective implementation and use of BIM remains a major issue for the construction industry. Whilst the technology underpinning BIM has been around for well over a decade BIM implementation and take-up has been relatively slow in the construction industry compared to industries such as manufacturing and engineering. The purpose of this study is to investigate the initiatives and approaches that are being used by countries that are leading the way in the field.
Methods
The methodology for this paper is based on a literature review of the key global trends in relation to BIM implementation and then a detailed investigation of implementation strategies that have been developed in a range of countries and regions such as North America, Scandinavia, the United Kingdom, Singapore, China, Hong Kong and Australia.
Results
The research reveals that there BIM implementation has gained considerable momentum over the past few years. A number of countries are developing successful implementation strategies with North America, the United Kingdom and the Scandinavian region generally leading the way. A key finding was the importance of coordinated government support and leadership as a critical driver for BIM implementation. Other important strategies were found to be the development of national and global BIM standards, legal protocols to address liability issues, BIM certification, education and training and articulating the business case for BIM implementation.
Conclusions
The paper concludes with a range of strategies and recommendations that flow from the research findings.

Keywords: BIM, BIM Implementation, Digital Technologies.

1. Introduction

Building Information Modeling (BIM) presents both enormous opportunities and challenges for the construction industry. As BIM evolves and construction processes increasingly become automated the roles of construction professionals will need to adapt accordingly to provide more sophisticated services that incorporate 3D, 4D time, 5D cost modelling and 6D facilities management and sharing cost information/data with the project team as part of the BIM integrated project delivery approach. The implementation of BIM on construction projects is gaining momentum around many parts of the globe. Whilst the technology underpinning BIM has been around for well over a decade BIM implementation and take-up has been relatively slow in the construction industry compared to industries such as manufacturing and engineering. This is starting to change as building clients and government entities increasingly become a driving force for the adoption of BIM by mandating its use on their projects and the technology and implementation issues continue to improve.

This paper will commence with a review of current global BIM implementation trends in the construction industry and will then focus on the implementation strategies that are being successfully used by countries leading the field. The latter will be based on the research findings of an investigation of best practices and strategies from around the world**.**

2. Literature Review – BIM Implementation Trends

2.1. BIM Development Generally

The concepts of BIM can be traced back to the earliest days of computing in the 1960s and solid modeling programs began to emerge in the 1970s and 1980s. The development of the ArchiCAD software program in 1982 in Hungary is viewed by many as the real beginning of BIM and the development of the Revit software program in 2000 saw a real shift toward effective BIM implementation (Bergin 2010). Whilst the technology underpinning BIM has been around for over two decades BIM implementation and take-up has been relatively slow in the construction industry compared to industries such as manufacturing and engineering. However, there has been a significant shift in momentum over the past five years as technology and implementation issues improve and the industry realizes the significant advantages to be gained from the use of this technology (RICS 2013).

A range of research is also emerging to address implementation issues for the industry (Brydea et al. 2013, Ahmad et al. 2013, Sacks & Pikas et al. 2013) and to communicate the benefits of effective implementation to key industry players (Cook 2014, Love et. Al 2013). McGraw Hill (2014) has been tracking the evolution and implementation of BIM in the global construction industry since 2007 through extensive global surveys. They have found significant change over that period and quite dramatic implementation increases over the past few years in particular. In North America their survey results showed that BIM adoption by contractors escalated from 28% in 2007 to 71% in 2012.

Their latest survey in 2013 comprised responses from 727 contractors from ten of the largest national construction markets in the world - Australia, Brazil, Canada, France, Germany, Japan, New Zealand, South Korea, the United Kingdom and the United States. They also undertook qualitative analysis of the markets in China and India to determine BIM trends in two countries that represent approximately one-third of the world's population. They found significant acceleration in implementation. *"Change is sweeping the globe. Project teams are benefitting from faster communications, smaller, more powerful and mobile computers, robust digital modeling tools and a transformative shift toward integrated delivery processes, all of which are generating positive outcomes, efficiencies and benefits unimaginable just a few years ago"* (McGraw Hill 2014, p. 1)

They also found that whilst BIM implementation has been led by countries such as the United States, the United Kingdom, Germany, Canada and France relatively new adopters in countries such as Australia, Brazil, Japan, Korea and New Zealand are rapidly building momentum and even outperforming the more established countries in certain areas. *"BIM usage is accelerating powerfully, driven by major private and government owners who want to institutionalize its benefits of faster, more certain project delivery and more reliable quality and cost. BIM mandates by US, UK and other government entities demonstrate how enlightened owners can set specific targets and empower design and construction companies to leverage BIM technologies to meet and exceed those goals, also driving BIM into the broader project ecosystem in the process"* (McGraw Hill 2014, p. 4)

AECOM (2013) predict that this will continue to escalate with the BIM market expected to grow from $1.8 billion in 2012 to $6.5 billion by 2020. They also predict market transformation in the near future. *"A sharp increase in the number of BIM projects is anticipated over the next 18 months, constituting a significant market transformation well beyond achievements to date*" (AECOM 2013, p. 76).

A major recent development was the recent decision in January 2014 by the European Parliament to modernize European public procurement rules by recommending the use of electronic tools like BIM. *"The adoption of the directive, officially called the European Union Public Procurement Directive (EUPPD) means that all the 28 European Member States may encourage, specify or mandate the use of BIM for publicly funded construction and building projects in the European Union by 2016. The UK, Netherlands, Denmark, Finland and Norway already require the use of BIM for publicly funded building projects."* (Autodesk 2014, p.1). This clearly has potentially significant ramifications for BIM implementation in the region.

2.2. United States

The United States have long been a global leader in BIM development and implementation in the construction industry (Wong et al. 2009). In the United States the US General Services Administration (GSA) has pioneered the implementation of BIM on public projects. The GSA is responsible for the construction and operation of all federal facilities in the US. In 2003 they established a national 3D-4D-BIM program through its Public Buildings Service (PBS) Office. In 2007 they mandated the use of BIM for spatial program validation on all of its projects (Khemlani 2012). They have also developed a range of guidelines and standards that includes a National BIM Standard that is internationally recognized. The GSA are clear leaders in promoting BIM adoption initiatives (CIBER 2012). As a major public sector client with approximately 8700 buildings and over 300 million feet of space across the United States this program has had a tremendous influence on BIM adoption thus demonstrating the importance of major client and government leadership for the industry (Building Smart Australasia 2012).

BuildingSmart Australasia (2012, p. 53) comment that the "*GSA is committed to a strategic and incremental adoption of 3D, 4D, and BIM technologies. The next stage for GSA in BIM implementation is exploring the use of BIM technology throughout a project's lifecycle in the following areas: spatial program validation, 4D phasing, laser scanning, energy and sustainability, circulation and security validation, and building elements"*.

CIBER (2012) also note that the US Government is moving to require BIM on all of their building projects. The US Army Corps of Engineers, Air Force and Coast Guard have all moved down the BIM path.

2.3. United Kingdom

In the United Kingdom the government has introduced a BIM implementation strategy for the UK construction industry that is considered by many to be the most ambitious and advanced centrally driven BIM implementation program in the world (HM Government 2012). The objective is to transform the UK industry into a global BIM leader in a relatively short space of time (Withers 2012). The UK Government Construction Strategy was instigated in 2011 with the intention to require BIM on all of government projects by 2016 through a 5 year staged implementation plan. BIM is seen as central to the government's objective in achieving a 20% saving in procurement costs (Cabinet Office 2011). This strategy has had a dramatic impact on the UK construction industry as firms face the reality of developing the necessary technological capabilities to meet these requirements. The UK government has established a BIM Task Group to assist both the public sector clients and the private sector supply chain in reengineering their work practices to facilitate BIM delivery (McGraw Hill 2014).

2.4. Scandinavian Region

The Scandinavian region is also a global leader in BIM adoption and implementation. Norway, Denmark and Finland embraced the ArchiCAD software early and were amongst the first countries to adopt model-based design and advocate for interoperability and open standards and have been integral to the development of Industry Foundation Classes (IFCs) and another interoperability initiatives. Khemlani (2012) contends that prefabrication is an important element of construction in this region and that the model based BIM technology is ideally suited for this construction methodology. The various governments in this region also provide considerable support and incentives for the development and implementation of BIM technology. The Finnish Government have invested heavily in IT research in the construction industry since the 1970s (Granholm 2011). They recently released a Universal BIM Guide for the industry which is being heavily supported. The Finnish public sector is the key driver in BIM adoption with Senate Properties, a major government entity responsible for managing the country's property assets, leading the way and requiring BIM modeling that is IFC compliant since 2007 (BuildingSmart Australasia 2012).

The Danish government is a strong supporter of BIM and invests heavily in research and development (Granholm 2011). Danish government clients such as the Palaces & Properties Agency, the Danish University Property Agency and the Defence Construction Service all require the use of BIM on their projects (BCA 2012). Denmark is also leading the development of a new BIM classification standard by Cuneco, a centre for productivity in construction. The objective is to establish this standard for not only Denmark but for the European Union region (and potentially for global use). This new BIM classification standard is very important for the European Union and there has been worldwide interest in its development (PR Web 2013). In Norway BIM implementation is led by Statsbygg – a firm responsible for construction, management and development of government facilities. The have used BIM for their projects since 2007 and have required IFC compliant BIM since 2010 (BuildingSmart Australasia 2012).

2.5. Brazil

Brazil is the largest country and has the largest economy in Latin America and therefore has a major influence on the South American region. Brazilian construction market activity is escalating and being assisted by the hosting of major events such as the FIFA World Cup in 2014 and the Olympic Games in 2016. There are a lot of international firms working in Brazil that are influencing the BIM scene and lifting the level of BIM implementation by the local market. The McGraw Hill (2014) international survey of contractors found that whilst the Brazilian industry was relatively new to using BIM there is building momentum in the country. However the industry is lacking leadership and a coordinated approach from government.

2.6. Singapore

The Singapore Building and Construction Authority (BCA) have developed a strategy to have BIM widely implemented on public projects by 2015 (Granholm 2011). The government has also established a Construction Productivity and Capability Fund (CPCF) of S$250 million with BIM a key target. In 2000 the Construction and Real Estate Network (CORENET) program was established as a strategic initiative to drive transformation in the industry through the use of information technology. CORENET provides the infrastructure for the exchange of information amongst all project participants. The CORENET e-Plan Check system for development applications is a further initiative to encourage the industry to use BIM. The system enables architects and engineers to check their BIM designed buildings for regulatory compliance through an online 'gateway'. Singapore has adopted the Industry Foundation Classes (IFC) as the standard for BIM implementation (BuildingSmart Australasia 2012).

2.7. Australia

In Australia BIM use in the construction industry is not currently widespread and there has not been any government mandates to use BIM on projects of any note. But the past five years has since interest in BIM adoption intensifying as a result of a number of initiatives to engage and inform project stakeholders about the potential productivity gains and gaining competitive advantage (CIBER 2012). These initiatives include the development of Australasian BIM guides such as the 'National BIM Guide' by the National Specification (NATSPEC), 'National Guidelines for Digital Modelling' by the Corporate Research Centre for Construction Innovation (CRC-CI), the 'Australian and New Zealand Revit Standards' (ANZRS) and the BIM-MEPAUS guidelines and models. The 'buildingSmart' organisation (previously called the International Alliance for Interoperability) continues to play a major leading role in BIM development and implementation in Australia that includes establishing an 'Open BIM Alliance of Australia' that involves an alliance with a number of software vendors to promote the concept of 'Open BIM' (CIBER 2012).

2.8. China

The Chinese industry is in the early stages of BIM adoption. A survey undertaken by the China Construction Industry Association in 2012 found that less than 15% of 388 surveyed Chinese construction companies used BIM (McGraw Hill 2014). McGraw Hill also undertook industry interviews with leading professionals to gain an insight into BIM implementation in China. They found that contractors were adopting the technology at a faster rate than design professionals. BIM was considered by designers as merely being 'additional work' within a fixed fee and so lacked incentives. They also found that the Chinese industry had structural barriers such as difficulties with changing traditional methods and that on many projects the Chinese law requires the design and construction stages to be separated with contractors not involved in the design stage. This inhibits the use of collaborative BIM approaches.

Nevertheless, a China BIM Union was formed in 2013 as part of the China Industry Technology Innovation Strategic Alliance by the Ministry of Science and Technology. The development of BIM standards is occurring and a draft of the Chinese National Standard 'Unified Standard for BIM Application' has been completed and issued for comment (Natspec 2014).

3. Research Methodology

The literature review revealed that many countries are leading the way with BIM implementation. Accordingly the research methodology adopted for the next phase of this study was to undertake an analysis of the key factors in these countries that facilitate successful BIM implementation. The purpose of the investigation was to determine best practice and innovative approaches being used around the globe that can be used by all. The following provides an overview of the main findings of this research**.**

4. Research Results – Best Practice & Innovative Approaches to BIM implementation.

4.1. Government & Industry Leadership

The research revealed that the most critical factor for successful BIM implementation is national leadership and coordination to maximize efficiencies and avoid the many problems created by piecemeal and disjointed approaches. This leadership should primarily be driven by government entities but needs the support of and collaboration with major industry players such as major private sector clients, contractors and industry/professional associations. Given the global nature of construction activity there is also the need for global leadership to facilitate the transportability of BIM implementation across the world. The recent European Union Public Procurement Directive (EUPPD) by the European Parliament for the 28 European Union member countries to encourage, specify or mandate the use of BIM for their publicly funded projects is a prime example of this high level leadership (Autodesk 2014). Autodesk also contends that this will boost the European Union construction industry's global competitiveness in securing international construction contracts. These global initiatives also need to be supported by international BIM standards and protocols that are ‘borderless’ and can be applied in all countries as applicable. There is much duplication of effort in BIM development across the world and there is much to be gained by global leadership in coordinating this and bringing it all together for mutual benefit.

BIM has the most chance of success if it is owner driven (McGraw Hill 2014, CIBER 2012). Government mandates appear to be the most effective. BIM mandates such as those imposed by major government entities in the United States, United Kingdom and Singapore have been highly successful in providing the catalyst for moving the industry down the BIM path. Firms are essentially faced with the proposition that if they don’t become BIM capable they won’t secure future work with these entities – a major influencing factor. Industry organisations and professional associations also have an important role. Their roles need to be collaborative so that multi-disciplinary approaches are adopted. Leadership is also required by major contracting and consultancy organisations to encourage their supply chain to fit in with their BIM requirements. This support is crucial particularly for smaller firms who arguably need the most assistance.

4.2. The Business Case and Competitive Advantage

Competitive advantage also provides a significant trigger for BIM implementation. The construction industry is characterized by firms who adopt a ‘wait and see’ approach and are averse to investing in leading the way with new practices. However, as firms increasingly see their competitors gaining competitive advantage through their BIM expertise the greater the incentive to jump on board. This doesn’t apply to just national considerations. It is clear that firms will increasingly struggle to secure work on international projects if they don’t have BIM capabilities. This competitive advantage has global implications. Firms need to be globally competitive even if they don’t work on international works as they will increasingly be competing against international firms with these capabilities on their domestic projects.

The business case for all players in the construction industry needs to be a key consideration. If the business value and the return on investment (RIO) of BIM implementation cannot be adequately communicated then this will create a barrier. This is the bottom line for business. Currently BIM implementation is still inhibited by firms that have cynical and negative views on the value of investing in the necessary BIM technology and training largely due to the difficulties in articulating the business case for these firms. The McGraw Hill (2014) report on the business value of BIM in the major global construction markets is a good example of what is needed to communicate the benefits to firms. Their major survey of contracting organisations in North America, Brazil, Europe and the Asia Pacific found that 75% of firms had a positive return on investment in their BIM program with reduced errors and omissions, less rework and lower construction costs cited as the key benefits. The firms also predicted that the percentage of their work that involves BIM will increase by 50% over the next 2 years giving a clear indication that investment in BIM is essential for firms – otherwise they will be left behind with potentially disastrous business consequences.

Articulating the business case for industry clients is probably even more important as they will be the primary drivers of BIM implementation. A common reason for not investing in BIM cited by firms is that their clients do not require them to use BIM. Evidence is building from a number of national and international studies that BIM adoption generates considerable value for clients through improved information sharing, reduced design errors, improved design quality, increase productivity and lower construction times and costs (CIBER 2012, NIBS 2013, McGraw Hill 2014).

4.3. National & Global Standards

Consistent national and global standards are necessary to achieve the efficiencies envisioned by this technology. It is nonsensical for there to be a large range of different systems and piecemeal approaches to BIM development. Global leadership can help to ensure that collaboration occurs on a national and global scale. Clearly, if BIM is to be the future of international projects, then common standards need to be adopted. Key to this will be the use of Industry Foundation Classes (IFCs), the vendor neutral format which allows models to be worked on independently of specific software. There continues to be much confusion about this technology (NBS 2013).

The NBS (2013, p.2) describe the following as essential for these Standards. “*BIM Guidelines – to move the industry to the use of world best practice BIM protocols in support of collaborative design practice (BIM can assist the industry to move to integrated, whole of life cycle property solutions and away from the current silo mentality). Product Data and Libraries – access to BIM-compatible product information in an open format that is properly specified, fit for purpose and can be correctly integrated into the project model. Process and Data Exchange – need for business process changes to facilitate integration of the briefing, design, construction,* *manufacturing and maintenance supply chain throughout the entire life of a built facility, achieved through effective exchange of BIM-based data and information. Regulatory Framework – the development of automated building design performance assessment and compliance checking based on the object-based information models that are developed through BIM processes. In order to achieve maximum benefit, BIM needs to be extended in to the geospatial domain, so that models can be tested within a virtual urban and regulatory context".*

4.4. BIM Protocols & Legal Contracts

Legal and contractual issues with the use of BIM models are another critical consideration. The uncertainty of legal liability is due to the large number of project participants contributing to the BIM model and/or relying on the accuracy and quality of the information in the model. A range of initiatives are being developed in various countries to address this issue but there is still a long way to go. The American Institute of Architects (AIA) 9 has developed a BIM protocol document (Conditions of Contract) to engage with BIM that is widely cited as a good legal model. This protocol establishes a binding relationship between the parties for agreement on the key issues: protocols, level of model development and model elements (CIBER 2012). The US National Institute of Building Sciences (NIBS) have investigated the establishment of project based liability insurance cover to reduce the risks associated with an integrated approach to design and construction. Issues relating to Intellectual Property (IP) rights and data ownership also need to be more effectively addressed. Many firms are loathe to share their databases and information that they view as their own intellectual property that provides them with competitive advantage. An example is the cost data bases of project cost management consultants. There is also a need for appropriate audit and risk management control mechanisms.

4.5. Quality of the Model

These legal issues directly relate to the quality and accuracy of the BIM model. BIM models require the input of vast amounts of complex information from a wide range of project participants. The quality, comprehensiveness and accuracy of this information are crucial to the successful use of the model. Research has shown that one of the major concerns with BIM models is the quality of the model (Smith 2013) – if parties don't trust the information in the model then it has obvious consequences. For example Smith (2013) found that quantity surveyors/cost planners commonly use traditional quantification methods rather than the automated quantities capabilities of BIM models due to concerns over the accuracy of the information in the model. BIM model quality requires clients to be prepared to invest in the necessary resources to achieve the required quality levels but this can be difficult with clients who focus on saving 'up front' costs in the design development stages.

4.6. BIM Maturity Models & BIM Engagement Index

BIM expertise correlates directly with experience and BIM Implementation (McGraw Hill 2014). BIM maturity models and engagement indexes are now being used to assess BIM capabilities. Kassem et al. (2013) contend that most models are focused on the individual organization but that there is a need for country-wide maturity/engagement scales and models. BIM adoption surveys can form the starting point for country-wide measures of BIM maturity. Kassem et al. cited BIM adoption surveys carried out in Australia, the United Kingdom and the United States as examples of metrics that can be utilised in country BIM maturity models. BIM Think Space (2013, p.1) describe the benefits of determining whether a country is BIM-mature, BIM-maturing or BIM-infant. *"If done properly, a country's BIM maturity highlights what has been achieved, what is still lacking, and what can be learned from others"*. McGraw Hill (2014) describe the benefits of a BIM engagement index as the more engaged firms are with BIM the greater their ability to reap the benefits. They have used a consistent global engagement index since 2009 with BIM usage levels categorized as Light (less than 15% of projects), Medium (15-29% of projects), Heavy (30-59% of projects) and Very Heavy (60% of projects plus). In their 2013 global survey described earlier in this paper they found that the majority (60%) of contractors operated at a light or medium level but there were expectations for more than two thirds of firms to be heavy or very heavy BIM implementers within two years.

4.7. BIM Education, Training & Research

BIM education, training and research are essential to drive not only implementation but also the evolution of the industry. BIM education is required at tertiary level so that graduates entering the industry have the necessary BIM knowledgeable and capabilities. Natspec (2013, p.1) contend that *"an industry reluctance to change, a* *'wait and see' approach and a shortage of experienced/educated BIM practitioners/technicians/educators is slowing the inevitable uptake of BIM in the AEC industry. It is clear that tertiary education institutions, with the support of government and industry, need to fully incorporate BIM education into their curricula, to provide the AEC industry with the 'BIM-ready' graduates required for the collaborative BIM working environments to which they will be part of in the future"*. They undertook an international study of tertiary BIM education and found that current BIM education tends to focus on the use of particular BIM software but that there is a pressing need for education in open BIM concepts, BIM management and working in collaborative BIM environments.

5. Conclusion

International trends have shown a marked increase in BIM implementation in key markets in the construction industry over the past few years and that this is set to accelerate sharply over the next few years. This is being driven by government mandates in key industry markets such as the United States and the United Kingdom and major private sector clients and contractors who realize the benefits to be obtained from this technology. These developments and initiatives are encouraging implementation on a wider scale as other countries realize that there markets will be left behind if they don't keep pace with countries leading the BIM field. It is clear that the sooner firms invest in BIM capabilities the better position they will be in to take advantage of various initiatives and capabilities that will continue to evolve. However, this does require investment in the future and one of the big issues here is that many firms in the industry are under-capitalised and operate on very low profit margins which inhibit their ability to invest in this technology for longer term benefits. This is arguably one of the biggest implementation issues but, conversely, could act as quality control mechanism by gradually forcing less capable firms out of the market. Ultimately, it is clear that the inertia over the past decade is now giving way to rapid BIM adoption rates as firms realize that they are going to be left behind if they don't embrace and evolve with the BIM revolution.

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Alignment of costing and budgeting with Building Information Modeling

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Abstract

Building Information Modelling generates not only a digital project model but provides a variety of secondary parameters such as time, cost, space and others. It is the so-called multidimensional modelling. One of the main benefits of this type of modelling is 5D category (processing of elements and their cost). This category can be beneficial during the entire lifetime of a construction project. In both, the pre-investment as well as the execution phases, a strong emphasis must be given to establishing reliable construction budgets and cost estimates which have significant impact on the quality of project execution. The operation cost of a new building has also to be considered. It can be reduced by maintaining high standards of craftsmanship, as well as by a stringent compliance with the standard operating procedures during the construction phase. The implementation of BIM system has also a significant positive impact. It requires higher standards during the project preparation phase, though.
In order to minimize capital investment while achieving optimal operational cost alignment of costing software with Building Information Modelling is necessary. One of the most important drivers of a robust budget is the quality of entered data (the bill of quantities and unit prices). This will allow responding to all dynamics in prices, savings or budget overruns in a timely manner.

Keywords: building information modelling, multidimensional modelling, the life cycle of buildings, costing software.

1. Introduction

Construction contracting belongs to those areas of business which are financially demanding and where changes in the operating phase abound. The importance of creating a construction budget lies in accounting for all the possible costs that may arise during construction. Construction budget needs to be a transparent and efficient means of communication between the contractor and the client. Therefore it is essential for the budget to follow a clear structure. That structure is nowadays represented by the costing system. Following construction data and costing principles is of utmost importance, as is project documentation processing and maintaining the standards of craftsmanship, making a contract for work, and many other concerns. However, construction product assortment displays extreme variety. As a result, any of the categories of goods stated in a construction contract may change considerably over the period of investment phase, not only material-wise, but also in costs. Such situations are possible and likely because construction projects are being carried out in long production cycles.

2. BIM in price estimates and costing

BIM model brings a vast amount of partial benefits, from advance visualization methods, to simplified construction management or lowering the operational costs of finished construction. In construction project, there usually is high risk level in the fist stages of the project. Such risk level is caused by the need of large financial expenditures which have to proceed gradually. If these expenditures are not managed carefully, they may cause failure in overall project management.

Correct input data is necessary in order to create a realistic price estimate. Input data may also be viewed as potential risks influencing expenditures in the investment and operating phases. The risks in the project life cycle may therefore be divided in risks caused by human, technical, and political factors. The influence of these risks on the project life cycle is not in effect during the entire project life cycle. These individual risk factors are more likely to affect various phases of the project, each one of them in their own particular time.

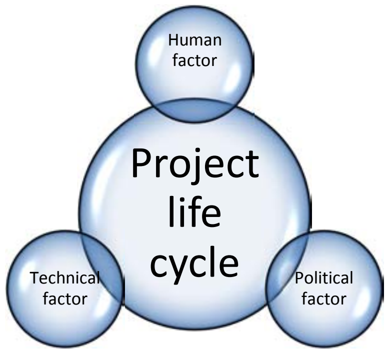

Figure 1. Pattern of risk factors influencing a construction project life cycle (source: author)

3. BIM use in costing

Should we talk about costing or construction costs, the term as such means a structured sum of expenses which arise on the basis of a specific human activity. Sooner or later, any member of the building proceedings is confronted with a financial estimate or costing. Although each member of the proceedings considers the costing from his viewpoint, the goal of all members is the same – to find out how much a construction, or any given activity included in the construction, will cost (Matějka, P., Hromada, E., Anisimova, N., Dobiáš, J., Kovář, P., & Kozáková, I., 2012). The essential prerequisite for costing therefore is the output of BIM software applications, such as:

- Bentley Architecture
- Nemetschek Allplan Architecture
- Graphisoft ArchiCAD
- Autodesk Revit Architecture

While designing a construction project, collisions of operations have to be taken into account, as they would lead to inadequate costing. In other words these collisions would cause double pricing of the same kind of work.

In the Czech Republic, following software programmes are the ones most often used for the purposes of costing:

- BUILDpower
- KROS plus
- euroCALC

If we want to process data correctly, the items, measurements and bills of applications used to design projects need to match the items or aggregated items of costing applications. Furthermore it is important that costing applications state predominantly usual prices of goods, not only prices arising from continual indexing. Structure of item (or aggregated) prices requires a format that allows for frequent updates over short periods of time. This would enable the software to mirror current market prices. Consecutively the applications would simplify reacting to price changes, possible savings or impending budget overruns. Frequent updates of the costing applications and linking aforementioned applications to BIM would lead to major savings of both time and money not only in the planning and investment phases, but also in operating costs of the building.

4. Risks connected to BIM in price estimates and costing

4.1 Risks caused by the human factor

- Project documentation
  - Quality of materials in relation to lower operating costs (repairs, replacements, etc.)

    In the planning phase, decisions are made that influence the project's safety, durability, layout, and technical equipment. If the construction is to be in accord with building standards, project documentation should state material demands, technology specifications, and quality of craftsmanship in execution of the project. Building standards are a key issue in both designing and executing a construction project. Unfortunately, the client (developper) often does not take into account further aspects, such as operating costs, which are closely connected with the durability and quality of materials used in construction. BIM brings important assets to such situations because it links all phases of the project, from project documentation to facility management. This attribute of BIM thus brings into the picture also the owners, future owners, or facility managers of the building. For these individuals the output is important because the quality of building project and execution result in monthly operating costs (pre-payments, etc.).

- Bills of quantities
  - Collision of building constructions within one area (the project stated constructions as overlaying each other). When doing bills of quantities, it is immensely important that one construction should not overlay the next. Which means that there should not be double insertion of a ceiling board in the same height or several walls in the same spot.
  - Inaccurate bills of quantities
    Building Information Modeling will assure accuracy of counting in the phase of adding up individual items. BIM will be operated by human factor but lower the high risks of mistake.

4.2 Risks caused by technical factors

- Project documentation
  Building Information Modeling enables analysis of solar and light models while creating a construction project. These analyses simulate the incidence of sunlight on the projected building. This helps analyse the shadows of neighbouring buildings or find the optimal architectonic layout. It also allows the architect to simulate the daytime cycle and design lighting on the grounds of the building's location. These analyses may lead not only to better technical and technological parameters of the project, but also for ensuing analyses and simulations of the operating phase, and support solutions that lead to energy savings (Arlati, E., Roberti, L., Tarantino, S., 2009).
  The problematics of maintenance and reconstructions is a major part of the sustainability debate. In this respect, BIM tools can be used for detailed analysis of particular project specifications. This should result in optimal usage of given space without unnecessary wasting of water or energy sources. Furthermore, the application should make it simpler to plan construction so that maintenence and potential reconstructions are as unproblematic as can be. It calls for use of easily repairable items that do not require much maintenance, and for a project of a building that will take into account its sustainability in the operating phase.
- Bills of quantities
  - Calculation of unidentifiable items (air, etc.)
    Building Information Modeling enables smarter work, more efficient production, better output. BIM is a tool to be controlled and adapted, but there is a large number of individual problems that have to be solved. Many of them are already accounted for, some need further correction. An example of these is the automated creation of bills of quantities. It is easy enough to make a list of the model's individual items. However, the list has to be checked for missing construction parts, corrections have to be made, errors removed. One of the current errors is counting areas and volumes of air as if they were construction units.
- Realization budget
  - Updating prices in costing software
    Human sources are not absolutely reliable, and neither are technical sources or data. The range of construction products and materials is vast. Frequent updates of current prices and uploads of new items into BIM are therefore very important, as they can influence the price of project execution.

4.3 Risks caused by political factors

Political factor will impact any price estimates even without BIM. The individual risks (such as inflation rates, changes in construction law, state commissions law, price law, etc.) cannot therefore be blamed on the introduction of BIM.

4.4 Conclusion

The aforementioned data (risks) lead to the conclusion that Building Information Modeling does not replace human sources. Rather than that, it helps optimize the phases of pre-investment planning, designing a project, its execution, and operation. But all of these can only be accomplished by the human factor. Close connection of the human and technical factor are very important, and can lead to good results.

5. BIM implementation risks

Building Information Modeling implementation brings both economical and personal impacts. Firstly, software has to be bought by companies, which provide for activities connected with both building, and operation of buildings. It might be necessary for some of these companies to buy new computers, capable of operating these demanding software programmes, which would raise the companies' operating costs. Thelength of the period of higher operating costs and lower productivity during implementation will depend on the capacities, knowledge, and understanding of the staff who will need to learn to operate the software and use it in the future. For the successful use of BIM, it is necessary that subcontractors also embrace the options of the programme with optimism, because subcontractors make up for a large part of the activities of investment phase (Matějka, P., Hromada, E., Anisimova, N., Dobiáš, J., Kovář, P., & Kozáková, I., 2012).

The beneficial motivation for a company to implement BIM may be that cooperation with the academic environment and feedback on their actions would make them the leading company of the market. Feedback carried on in the form of data collection and their ensuing evaluation will strengthen the company and increase the productivity level of their employees.

Higher operating costs and lower productivity over the implementation period in the leading company or market challenger will be rewarded by organizing educational courses not only for the company, but also for other companies, nation-wide and further. Nevertheless, the leader of the market may not forget that competition is tough in construction and innovations. Therefore the company will still need to support customer loyalty and ensure added value for the customer in order to keep up their position, not to drop to the second place and become merely a market challenger.

BIM implementation will also influence investors, as the cost of purchase will be projected into investment costs of the project/building (Perez, FGL., Vanegas, SIC., Lopez, DM., Paaez, ECC., 2011). The investor needs to be aware, though, that these investment costs will be appreciated in the long-term perspective because they lead to lowering of operating costs.

Last but not least, BIM implementation will influence the owner of the object. The lowering of operating costs will project itself in the figure of advance payments.

The list of risks follows in the ensuing table, for the sake of clarity.

Table 1. Scheme of risks concerning project participants in the implementation phase of BIM (source: author)

Project participant	Risks
Contractor	Unwillingness to communicate with other participants
	Recovery of investment into BIM implementation
	Educating own employees
	Technical knowledge of the problematics
	Lax attitude of subcontractors towards BIM
Investor	Low appreciation of the benefits of BIM (investor does not take into account the sum of investment in the first phase, and operational costs in the following phase, and only focuses on the high investment cost)
Owner/ Facility manager	Technical knowledge of the problematics
	Knowledge of software using BIM

6. Benefits of using BIM

Nowadays, most architects use BIM without necessarily being aware of it. BIM is based on 3D geometrical models, such as is the output of almost any construction design these days. By using BIM, the designers could solve the problem of collisions, which usually arises in construction execution. They could also define the properties of materials used, define the producer, price, and many other factors. That would simplify ensuing documentation processing. Estimator would not need to make a bills of quantities, as it would be easy enough to check the current one in BIM, correct errors, or fill in missing information, because errors are still made in BIM.

The main benefit concerning the investor would be the option to continually check project status (Zheng, HK., Cao, JW, 2013). Data of the project are formatted and structured as a point of reference, with regard to the option of creating control analyses. Input data are very precise, therefore it is not necessary to recreate an analytical model every time. Additional benefit for the investor is reduced fixed costs by elimination of extensive amounts spent on operating and maintaining the asset. (Láska, PED., Simpson, I., Hill, Snading, C., 2013).

Public Administration as an investor operates a large number of buildings. These usually comprise the city council, offices of various administrative departments, nursing homes, establishments for the handicapped, senior homes, nursery schools, primary and secondary schools. Centralized information is of essence when such a large number of facilities is to be managed properly.

By using BIM in Public Administration, anyone can demand information on a given building in the inventory, and also find out whether such information had been processed already. These actions would eliminate a number of very similar activities of the public administration (such as energetic audit, energetic license, ecological audit, internal audit, etc.) within different departments. This would further result in better management of financial means (Volk, R., Stengel, J., Schultmann, F., 2014).

As can be seen from the aforementioned example, there are good reasons for BIM implementation, and ensuing usage in costing and financial management, in the government sector as well as in the private sector. The state as a client/investor with a large number of public projects is truly the leading investor in the market. Therefore it would be worth consideration whether it should not be up to the state to require all projects to be created in BIM. This would also simplify keeping up with EU's increasing standards (Porwal, A., Hewage, KN., 2013).

Facility management's activities include actual facility management, utilization of these facilities, energy management, maintenance, janitorial services, etc. It is immensely important for facility management to process strategic and tactical plans for ensuring these supportive activities of FM in their entire range. Usage of BIM in the operating phase would make up for the shortcomings which facility managers have to face as soon as in the planning phase of a construction project. It would result in:

- Lower energy consumption
- Savings in facility management
- Efficient use of spatial properties of the object
- Easier planning of furniture and equipment changes

The list of benefits follows in the ensuing table, for the sake of clarity.

Table 2. Scheme of benefits for project participants using BIM (source: author)

Project participant	Benefits
Contractor	Linking practical completion stage to architectonic design
	Linking practical completion stage to operating projects and simulations
	Simulations of energy consumption
Investor	Being in control of all project phases
	Processing changes and object demands (extrawork)
	Low operating costs
	Repairs and maintenance of construction items in short time segments
	Linking the frequency of repairs and maintenance to further investments
Owner/ Facility manager	Low operating costs
	Low frequency of repairs and maintenance resulting from the investment phase
	Information on maintenance of construction items
	Simplified bills of construction units, areas, and bills of quantities

7. Conclusion

It has been shown that linking costing programmes to BIM would streamline the creation of construction budgets, financial estimates, estimated dates of completion. It would summarize all information on suppliers of construction items, and make supervision easier. Current information and feedback fits the needs of both private and public sector. It is not yet possible to establish the economical benefits of BIM implementation with its higher financial demands for project designing, but lower costs of extrawork, which is the usual reason of budget overruns. The reference literature indicates the total cost of asset life cycle and covers the implementation of BIM but there is no reference to linking the cost in budgeting tools with eventual linking to BIM.

BIM is a useful tool not only for the planning, and investment phases, but also in the operational phase. It is an invaluable and beneficial tool for the future owners and managers of a given building.

Acknowledgement

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BIM and QR-code. A synergic application in construction site management

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Abstract

Construction phase still presents many difficulties and contingencies related to the project documents information management between the actors involved. Different studies investigated methods and models to optimize the operational management of the construction phase. Concerning workers' health and safety protection most of them focused on the development of on-site and in real-time control systems. Therefore, the authors identified the exigency of a prevention information system based on workers' involvement. To reach the aim three objectives have been identified: (1) the check of workers' training, (2) the definition of works operational procedures and (3) the schematization of the assembly/disassembly/use of site equipment and temporary structures. The developed system is characterized by a synergic application of BIM model and QR-code and it has been applied on a case study. At the same time a questionnaire has been developed and proposed to different subjects of the construction sector in order to evaluate the potential use of BIM model and QR-code. The field test has allowed to demonstrate the practical use of the tool, enhancing communication between the Client technical structure, the General contractor and sub-contractors, improving workers' integration and participation and allowing a better availability of on-site health and safety information and documents.

Keywords: BIM, health & safety, information management, operational management, QR-code

1. Introduction

The purpose of the research presented in this paper is to improve, using Information Technology (IT), design and management of construction processes, with a particular attention to the construction site phase. IT instruments used are the Building Information Modeling (BIM) and the Quick Response Code (QR-Code) applied both to improve and speed up various aspects of the construction process. It has already been demonstrated the possibility and the consequent benefits of using IT methods, in particular BIM, for a better integration within different disciplines of the building process [Feng & Ho, 2013; Zhenzhong, Jianping, & Ziyin, 2008] and that BIM technology can be used as a starting point for safety planning and communication [Sulankivi, Kähkönen, Mäkelä & Kiviniemi, 2010]. With the QR-code applications we have optimized the information flow between different actors involved, especially during the construction phases. The BIM and QR-code have been applied in a synergic way to a study case in order to analyze the effectiveness and the limitations of the system. The potentiality of the system has been evaluated also through a questionnaire proposed to different subjects of the construction sector.

The use of BIM technology for the representation of the construction site design, site planning and management have had, in recent years, some developments [Sulankivi, Kähkönen, Mäkelä & Kiviniemi, 2010; Babic, Podbreznik, & Rebolj, 2010; Harty, Throssell, Jeffrey, & Stagg, 2010]. Concerning BIM technology applied to the execution phase management, some previous studies have been carried out [Trani, Bossi & Cassano, 2013]. These investigations have revealed that construction site BIM design during the planning phases allows to identify, with greater precision, the possible criticalities related to operational procedures. Thus, it is possible to increase the level of workers' safety, improving works production quality and avoiding improvised decisions in working progress. In the execution phase, the same BIM model can also be exploited by construction companies for a better site organization, in particular for a detailed development of the specific operational procedures. It is of paramount importance that the information related to design and operational management, collected in the BIM model, are available for all the figures involved in the construction process.

QR-code is a type of matrix barcode, also called two-dimensional barcode [Liu, Yang, & Liu, 2008.] with a great capacity to store data and equipped with a "self-correcting" function, that allows the reading of the code

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even if it is partially damaged, and a very simple structure. The most common method of database decoding consists of tablet/smartphone's apps dedicated to read the QR-code and quickly convert it in a URL. The widespread use of QR-codes was made possible thanks to all of these intrinsic qualities and to the presence of applications available for tablet or smartphone users. Thus, QR-code has been identified, together with BIM technology, as the instrument for the practical development of the proposed system.

2. QR-code and BIM in construction site

The prevention information system is characterized by a synergic application of BIM model and QR-code. To have a better design and management of the construction process three objectives have been identified: (1) the check of workers' training, (2) the definition of works operational procedures and (3) the schematization of the assembly/disassembly/use of site equipment and temporary structures. Below a summary of the three applications referred to the case study is presented with some examples. The case study consists in a restoration site of a building tower located in the center of Milan. The tower is characterized by 28 floors above ground and 2 underground floors. Main works are concrete pillars reinforcement and metal carpentry assembly.

2.1. Check of workers' training

One of the main criticalities is related to the data availability about workers' training. To achieve the object, we have developed several data sheets that summarize the significant worker information in order to not waste time looking for them in the paper archives of the construction company. For each of the summary sheets, a QR-code is created and the code is placed on the tag of the corresponding worker or on the respective hard hat. So, thanks to a scan of the code with a smartphone or tablet, that links to the database URL, it is possible, for example, to control the authorization to a specific equipment or processing, easily and with a great rapidity. On the same online page containing summary sheets, links that lead to the original training certificates are available. Below an example of application of the system to the case study is presented. Figure 1 represents the worker tag with the application of QR-code , while figure 2 represents the data sheet that summarizes worker information. Data sheet, as indicated, is organized in different parts in order to have a structured information system that simplify the verification of workers' data and allows a faster comprehension from the inspection body.

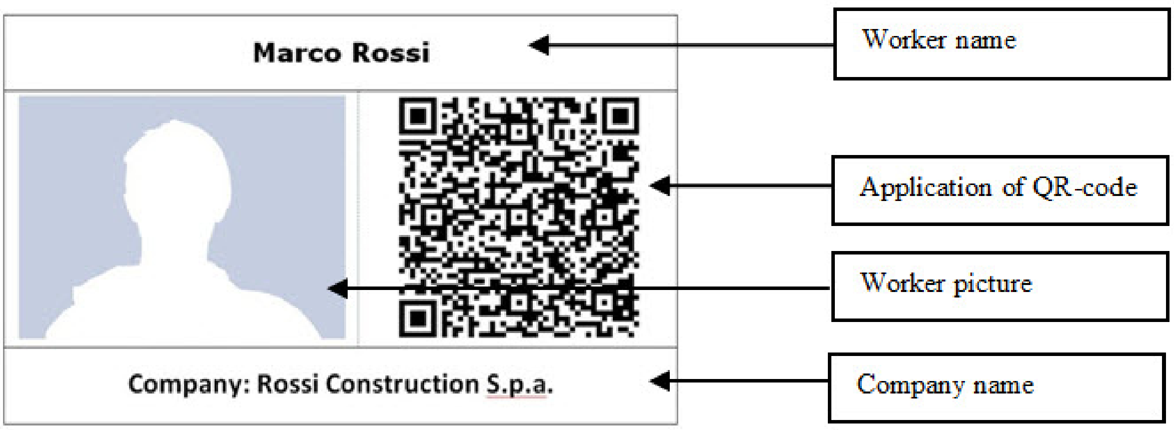
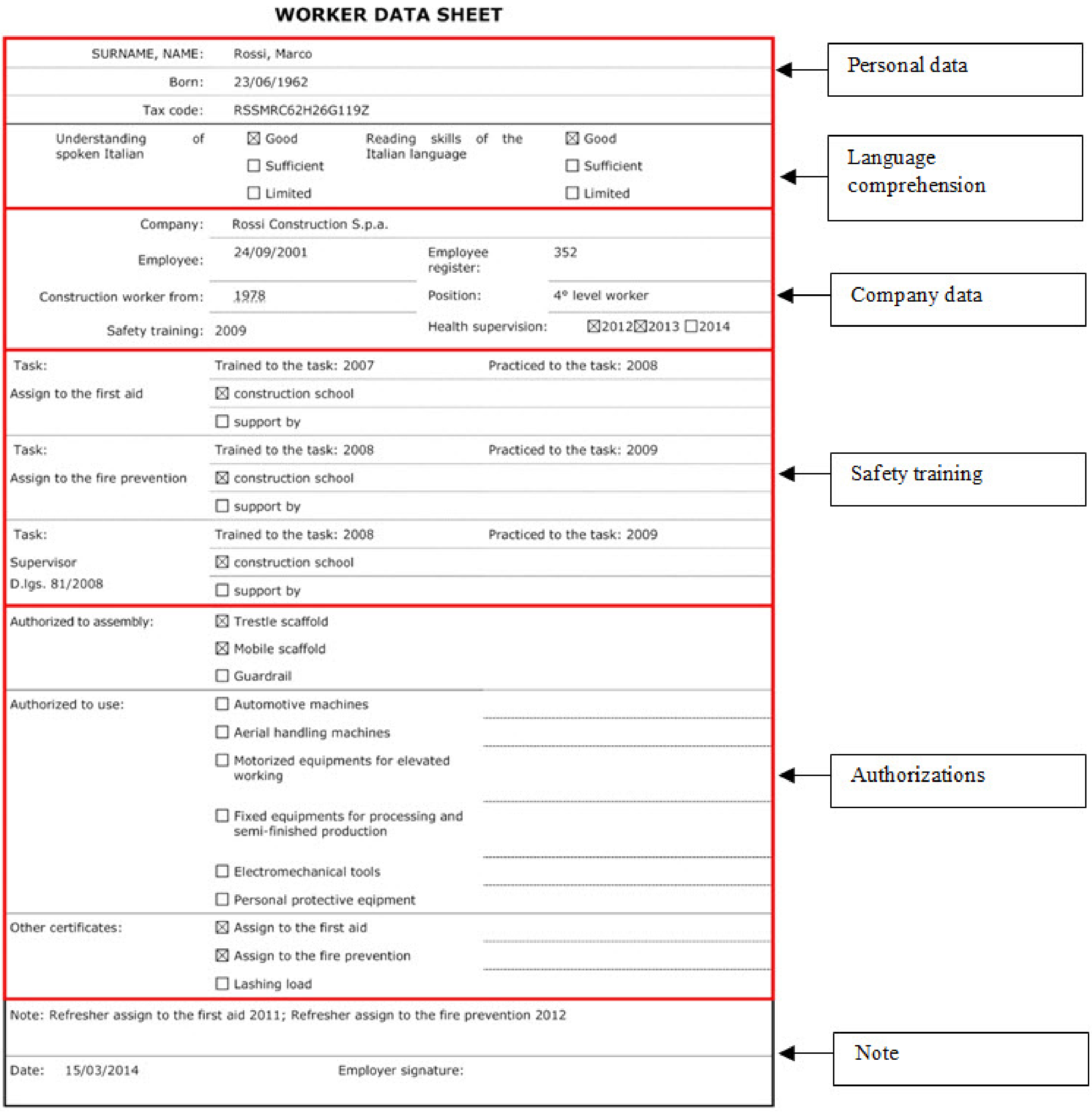


Figure 11. Worker tag with the application of QR-code


WORKER DATA SHEET

SURNAME, NAME:	Rossi, Marco		
Born:	23/06/1962		
Tax code:	RSSMRC62H26G119Z		
Understanding of spoken Italian	☒ Good ☐ Sufficient ☐ Limited	Reading skills of the Italian language	☒ Good ☐ Sufficient ☐ Limited
Company:	Rossi Construction S.p.a.		
Employee:	24/09/2001	Employee register:	352
Construction worker from:	1978	Position:	4° level worker
Safety training:	2009	Health supervision:	☒2012☒2013 ☐2014
Task: Assign to the first aid	Trained to the task: 2007 ☒ construction school ☐ support by	Practiced to the task: 2008	
Task: Assign to the fire prevention	Trained to the task: 2008 ☒ construction school ☐ support by	Practiced to the task: 2009	
Task: Supervisor D.lgs. 81/2008	Trained to the task: 2008 ☒ construction school ☐ support by	Practiced to the task: 2009	
Authorized to assembly:	☒ Trestle scaffold ☒ Mobile scaffold ☐ Guardrail		
Authorized to use:	☐ Automotive machines ☐ Aerial handling machines ☐ Motorized equipments for elevated working ☐ Fixed equipments for processing and semi-finished production ☐ Electromechanical tools ☐ Personal protective eqipment		
Other certificates:	☒ Assign to the first aid ☒ Assign to the fire prevention ☐ Lashing load		
Note: Refresher assign to the first aid 2011; Refresher assign to the fire prevention 2012			
Date: 15/03/2014		Employer signature:	

Figure 12. Data sheet that summarize the worker information

2.2. Definition of works operational procedures

The next analyzed aspect is related to the definition of schematic operational procedures in order to easily transfer them to workers. Generally, construction companies documents, in which operational procedures are contained (*i.e.* Operational Safety Plans), have a lexicon not always understandable for workers. Thus, these documents are not suitable for a practical use on construction site. Therefore, it has been developed a "form" as a means of communication with workers, characterized by simplicity, linear logic and clarity. A specific group of forms constitutes a complementary and operational procedure that should be included in the Operational Safety Plan. In the forms are attached some three-dimensional images (see figure 3), extracted from the construction site BIM model, that represent workstations and activities in order to allow workers' immediate comprehension of the correct operating sequence. The information contained in the forms are structured in a systematic way that allows the construction site manager, or otherwise the employees of a specific company, to gain a practice for data acquisition. The forms are included in the company online database, hence a QR-code is associated to each form. By affixing a tag with the QR-code to the technical element, object of processing or adjacent to it, any subject can display on its smartphone or tablet all the information contained in the forms. In the case study, for example, a tag has been fixed on a concrete pillar and near the metal carpentry. Next figure represents one sheet of the group that gives the operational procedures for the pillar reinforcement. As in the previous sheet, the document is organized in different parts, as indicated, in order to have a structured information system that simplify the comprehension from workers.

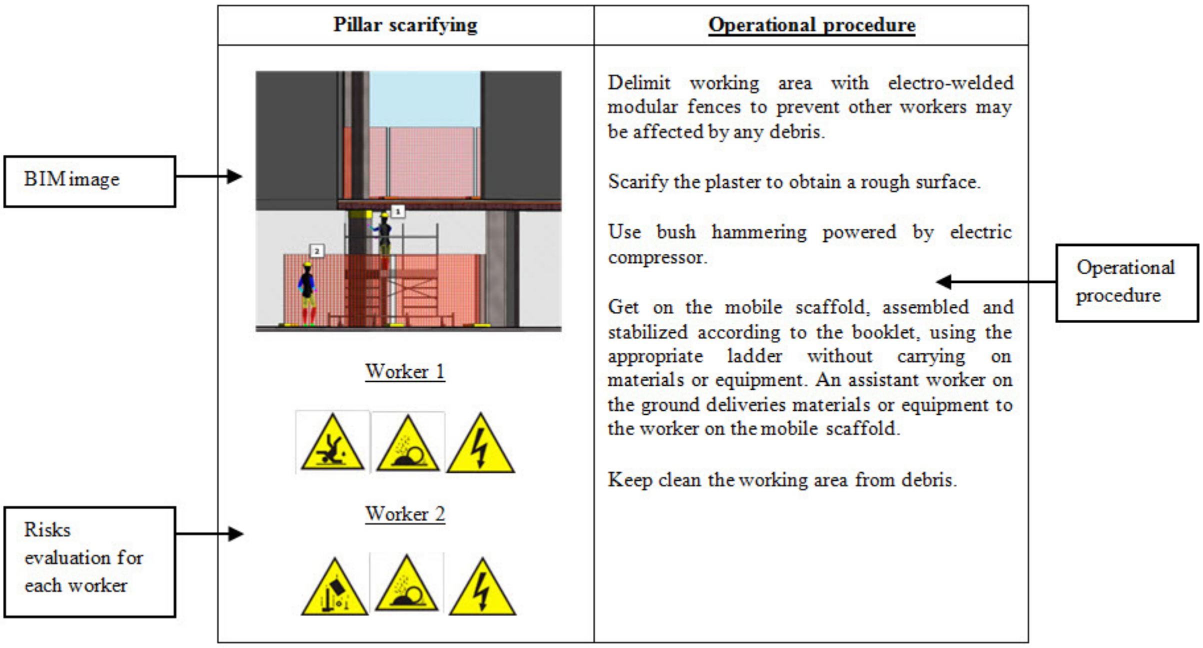


Figure 13. Pillar scarifying operational procedure

2.3. Schematization of the assembly/disassembly/use of site equipment and temporary structures

In order to schematize the assembly/disassembly/use of site equipment and temporary structure, another application of QR-code in constructions site has been its placing directly on the object that have to be used. This management process provides that not only equipment/temporary structures handbooks are available in the site offices, but also each equipment/temporary structure is accompanied by the respective handbook in the specific workplace. In this way, two significant problems have been solved: handbooks deterioration and their consultation in real time. As an example, a developed form has been the one for a mobile scaffold (see figure 4), in which all the information necessary for the proper installation, use and dismantling are summarized and being accessible thanks to the technology of the QR-code. The form structure has been developed starting from the typical information contain in temporary structures handbook, but summarized in order simplify the information transmission and optimize the usability of the structure on site.

3. Information system users feedback

What has been described and applied in the specific case study shows how the adoption of QR-code, together with BIM technology, has been absolutely achievable and easily enjoyed. However, in order to analyze the wider development of this system and evaluate its potential use, it has been decided to contact several professional figures -users-, from both the companies' world and the freelancers' world, and interview them through a questionnaire. Regarding construction companies, employers, managers and supervisors have been interviewed, while concerning freelancers the research has involved in particular safety coordinators, construction supervisor, project managers and project supervisors. By analyzing and comparing the different answers, it has been possible to evaluate the strength and weakness of the proposed system in order to improve and further develop it.

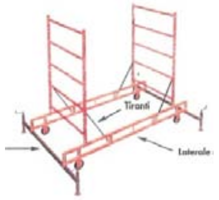
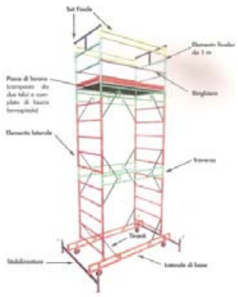
MOBILE SCAFFOLD	
Assembly instructions	
Check the integrity and the perfect functionality of all mobile scaffold components before use them. The mobile scaffold must be assembly by two people at least and always using PPE provided. <u>PPE to be used</u>: Hard hat, Gloves, High visibility clothing	
	**<u>Assembly base section</u>** To connect two base side elements and insert a pair of orthogonal elements in the slots. To connect in the upper part two opposite elements with a pair of cross elements (tie rods facing inward). To attach the tie rods to the elements and lock it by the screw. To install the stabilizer bars at side of the base and stabilize the structure by the leveling screw. To lock the wheels by appropriate wedges or brakes.
	
Use instructions	
To move the mobile scaffold must lift the removable part of the stabilizer bar and to must reduce the height to a maximum of two bays. The movements can be done only in longitudinal and cross direction of plant. During the movement, on the mobile scaffold must not be any people or things. Before each use (and also after each movement) should verify the correct assembly of the mobile scaffold and that is in a vertical position.	
Disassembly instructions	
The disassembly of the mobile scaffold must be performed in reverse sequence of that of the assembly.	

Figure 14. Mobile scaffold assembly/disassembly/use

The questionnaire is composed by 12 questions, accompanied by some examples of system application, that have been structured in the following way:

- The first three questions are related to the usefulness of the system from the point of view of figures belonging to construction companies and related to management roles, such as construction site managers or foremen. For each question it is required a score association to the system benefits.
- The next four questions are addressed to evaluate the system utility form the point of view of figures belonging to construction companies, which have a role of control on construction site, such as health and safety managers, workers health and safety representatives or sometimes the same employers.
- The following three questions identify three ranges of work amounts related to the applicability of the system. In particular, works have been divided under € 500,000, between € 500,000 and € 5,000,000 and over € 5 million.
- Finally, the last two questions are related to the practical applicability of the system. In fact, it needs tools, such as tablets or smartphones, that are common between business men or professionals but not among construction site workers. Is then requested an opinion about the likelihood that construction site managers or foremen will be equipped by the aforementioned instruments respectively from now until the next 2/4 years.

For each question, a spectrum of responses has been provided by assigning a score from 1 to 4, where 1 means little useful/probable and 4 means very useful/probable. Thus, it has been possible to analyze the different respondents opinions, without forcing them to give a clear yes or no but giving the opportunity to show the different shades of their reasoning. At the end, a number of 52 respondents questionnaires have been collected. From the different answers, summarized in the graphic above (see figure 5), we can conclude that the majority of respondents have considered very useful the overall presented system, differentiating however its applicability depending on the different types of construction site. Indeed, in the questions about the usefulness of the system for small sites (question 8), the responses have been very different from those regarding big sites. Most of all the respondents has felt that the system would be beneficial if the initial investment is quickly recovered from the speeding up of operations on-site, otherwise they have felt the investment required by the system unaffordable for small sites. Furthermore, with the increasing amount of works the percentage of positive responses increases until it reaches the 78% of responses with the highest available rating. Finally, with regard to the provision of tools, such as smartphones and tablets, in the next two years, the respondents have indicate that it is unpredictable, especially considering the economic crisis that is sweeping the country, while they are more optimistic for the dissemination of these tools in the next 4 years.

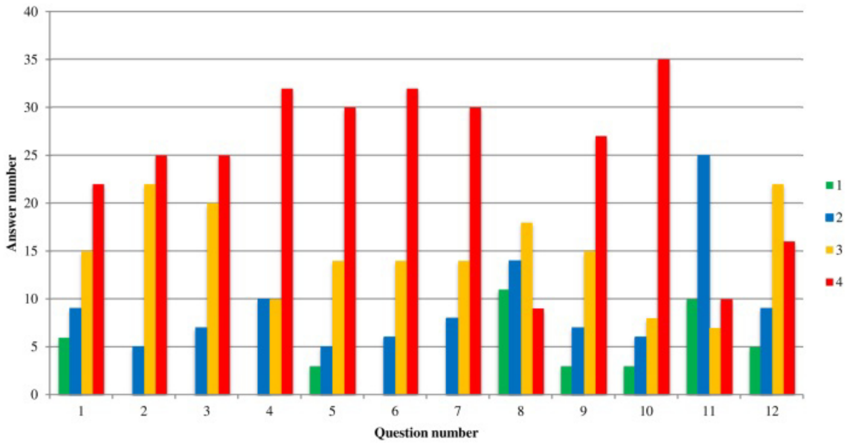


Figure 15. Questionnaire answers

4. Conclusions

Referring to the questionnaire, the system is generally evaluated positively, with some limitations that make it more useful and applicable in big construction sites under the organization of structured construction companies, more difficult to apply in small construction sites. Professionals interviewed, even if with some difference, have appreciated the proposed system and they have considered it gradually implemented. Indeed, the system presents the advantage that, once developed, it has to be only easily updated, and it will be even more simply to implement according to the IT knowledge progression. Moreover, in the case study the company, that has tested the system, has been positively collaborated, showing appreciation for it. Thus, the case study illustrates the practical use of the developed prevention information system, characterized by a synergic application of IT instruments, QR-code and BIM technology. It has been demonstrated that the system, based on workers' involvement, aim at reaching the three identified objectives: (1) the check of workers' training, (2) the definition of works operational procedures and (3) the schematization of the assembly/disassembly/use of site equipment and temporary structures. In conclusion, the system is developed and structured in order to have a better design and management of the construction process during the execution phase, enhancing communication between the Client technical structure, the General contractor and sub-contractors, allowing a better availability of on-site health and safety information and documents.

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An automatic three dimensional modelling system for bridge inspection

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Abstract

Taiwan Bridge Management System (TBMS) is an internet-based system used by all the bridge management agencies in Taiwan. Currently, TBMS has an inventory of 28,000 bridges with more than ten years of visual inspection data and maintenance records. The visual inspection data are firstly recorded at bridge site on inspection forms and then input manually into TBMS later in the office. Photos of deterioration of bridge components are also manually picked from the photos inside the used camera and uploaded to TBMS when inputting the inspection data. Such operations are inefficient and create errors frequently. Thus, this research aims at establishing an automatic three dimensional (3D) modelling system on a portable device to facilitate the bridge inspection processes and to avoid such input errors.
The 3D modelling system is written in 3ds Max by Autodesk, packed as a 3D bridge inspection application software (App) running on a portable tablet, iPad mini 3G (Wi-Fi plus Cellular) by Apple. Before inspection, basic data of the bridge are downloaded from TBMS via Wi-Fi or 3G. The system also allows choosing among the bridges displayed on an electronic map centered by the location of the inspector. Once the basic data of the bridge, such as width, length, number of spans, type of abutment, type of girder, type of pier, type of pier foundation, etc., are downloaded, the App automatically generates a 3D model for this bridge. The modelling is performed by generating various types of bridge components in different colors and composing them based on their geometrical locations in the bridge. The generated 3D bridge model can be enlarged, shrunk, and rotated so that each component can be pinpointed, selected, and inspected.
The innovative, automatic 3D bridge inspection App is being used by agencies and engineering firms in Taiwan.

Keywords: bridge inspection; 3D modelling; portable device; bridge management.

1. Introduction

Taiwan Bridge Management System (TBMS) was online in year 2000 and has an inventory of 28,000 bridges with more than ten years of visual inspection data and maintenance records. According to regulations set by the Ministry of Transportation and Communications, bridge management agencies in Taiwan are required to perform visual inspection on every bridge once every two years and all bridge inspection results should be input into TBMS. The visual inspection follows a DER&U evaluation methodology and in many cases was performed by engineering firms if not by engineers of the agencies. Usually, inspection results are firstly recorded at bridge site on inspection forms and then input manually into TBMS later in the office. Photos of deterioration of bridge components are also manually picked from the photos inside the used camera and uploaded to TBMS when inputting the inspection data. Such operations are inefficient and create errors frequently.

To improve inspection efficiency and avoid inputting errors, this research developed an automatic three dimensional (3D) modeling system for bridge inspection on a tablet. The mobile device, iPad mini 3G (Wi-Fi plus Cellular) by Apple Co., was chosen as the implementation platform due to its technological advantages; it is easy to carry and has fast operation capabilities; it is equipped with a touch screen, internet connectivity, and a long last battery, very suitable for bridge inspection needs; and it has a relatively stable operation system (iOS 7.0). In addition, by wearing a protection shell and kept in a transparent plastic bag, the iPad mini 3G is free from damages caused by unintentionally dropped downs or light rains during inspection at the bridge site. The

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system has been packed as application software (App), called 3D bridge inspection App, and can be downloaded into the tablet by any authorized user who has access to TBMS.

2. Literature review

Network level BMSs are used by many countries around the world. One of the early developed BMS was PONTIS (now called AASHTOWare) established in 1992 by Federal Highway Administration; its current version has seven functional modules but 3D modelling capabilities are not included. CBMS2012, established by Ministry of Transport of The People's Republic of China is the only network level BMS known to have 3D modelling capabilities for bridges. It differentiates bridges at various levels of conditions by coloring modelled 3D bridges.

Some project level BMSs have 3D capabilities to model a bridge, such as Yongxin Hu (2005) and Bien (2011). However, they are developed only for modelling a specific bridge and are not automated in the 3D modelling process; they run on desktop or laptop computers, not on tablet devices.

Bentley (2014) developed InspectTech Collector Mobile App on iPad for bridge inspection without 3D modelling of bridges. Currently, on tablet devices, there is no bridge inspection App has 3D modelling capabilities, not to mention generating 3D models of bridges in an automatic manner.

3. Functional modules of the 3D bridge inspection App

Figure 1 shows architecture of the 3D bridge inspection App. In addition to a user interface, the App consists of five functional modules: (1) Data downloading module, (2) 3D bridge modelling module, (3) Bridge inspection module, (4) Auxiliary evaluation module, and (5) Data uploading module. These five modules are described below.

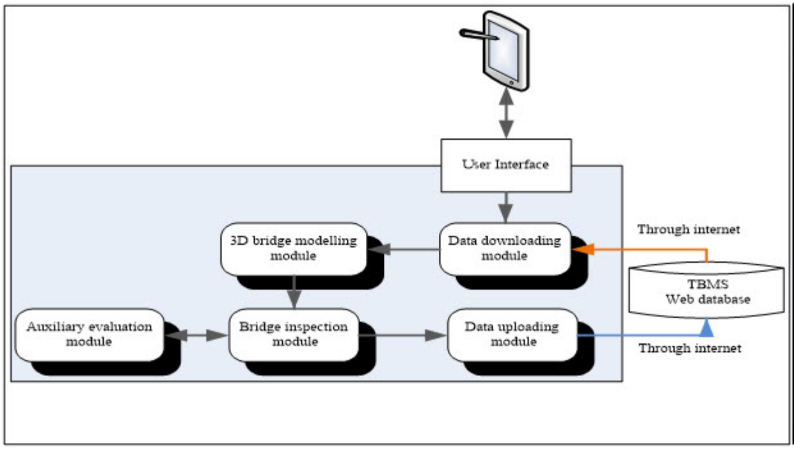

Figure 1. System architecture of the 3D bridge inspection App.

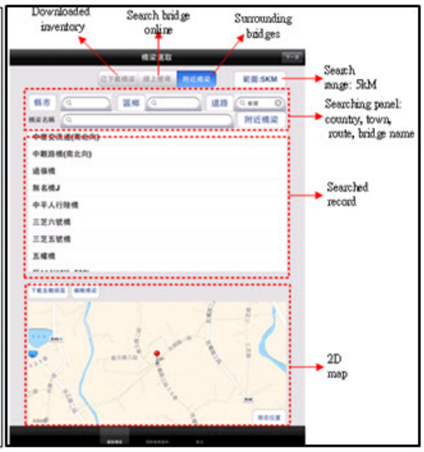

Figure 2. The App searches bridges before downloading bridge data.

3.1. Data downloading module

This module allows the user to search bridges nearby, or search specific bridges according the input conditions, and then displays the searched results in the middle of the tablet, as shown in Figure 2. Notably, the user must have an account in TBMS to login into the App before activating this module; otherwise, the login will fail. The bridge to be inspected is then selected by touching the bridge name shown on the screen. Accordingly, this module will download appropriate bridge data from TBMS through available internet connections such as Wi-Fi or 3G.

In TBMS, the bridge inventory has six types of information stored in more than 80 fields for each bridge; they are (1) management data, (2) hydrological information, (3) geometry data, (4) structural data, (5) special structural data, and (6) design parameters. This module downloads through internet the geometry, structural, and special structural data of the designate bridge via a web service provided by TBMS.

3.2. 3D bridge modelling module

In TBMS, a bridge is decomposed into 20 components and each of these components should be examined during bridge inspection. Since bridges could be very different in size and shape, modelling of all kinds of bridges is very difficult to achieve at this moment. In this research, the main purpose of 3D bridge modelling is to facilitate bridge inspection processes; therefore, representations of major bridge components are clearly displayed while certain components are simplified. I.e., representations of 3D bridge components are only illustrative and are not up to physical scale. Running on iOS operation system, 3ds Max by Autodesk is chosen and incorporated in this research to automatically modelling the 3D bridge components based on download bridge data.

To clearly model these bridge components in 3D for inspection purposes, a few principles, described below, were determined before implementation. Currently, this research focuses only on modelling of reinforce-concrete and pre-stressed concrete bridges. For long bridges, the default number of displayed spans is set to five, as shown in Figure 3; otherwise, the bridge will become a long line which is very difficult to use after modelling. Components of the other five-span of the bridge should also be displayed if the user requests. Numbering of piers, which is necessary for identification purpose during inspection, is illustrated by 3D numbers attached to each pier, also shown in Figure 3. Direction of mileage-increasing of the bridge is demonstrated by 3D solid arrows in every span, as shown in Figure 4.

In the 3D bridge inspection App, not only for illustrative purposes but also fulfilling inspection needs, 3D modelling of these 20 components is categorized into three types, as depicted in Table 1.

(a) Single-type component: there are 10 kinds of bridge components in this category that are modelled by one typical component regardless the size or type of the component specified in TBMS. For example, expansion joints are modelled by black, long and thin rectangular bars, and located between spans at the slab level, as shown in Figure 3. Details of the expansion joints are not shown. Being small compared to the size of the bridge, these expansion joints still can be enlarged and pinpointed during inspection.

Table 1. Types of bridge components in the 3D bridge inspection App.

(a) Single-type component	(b) Multiple-type component	(c) Tabulated component (not modelled in 3D)
(1) approaching embankment	(1) abutment foundations	(1) superstructure drainages
(2) approaching guardrail	(2) pavements	(2) sidewalks
(3) protection works for approaching embankment	(3) piers (4) pier foundations	(3) bearings (4) earthquake brakes
(4) abutments	(5) longitudinal girders	(5) transversal beams
(5) retaining walls		
(6) guardrails		
(7) scouring protection for piers		
(8) expansion joints		
(9) decks & slabs		
(10) waterway		

(b) Multiple-type component: there are 5 kinds of bridge components in this category that are modelled by the exact number and type of the components. They are major components of a bridge. In Figure 4, piers of the bridge are single-pier type in round shape with a protection cover, and have pile-type foundations below them. Other types of piers that can be modelled are multiple-pier and wall-pier. Available pier foundations are direct-foundation and caisson in addition to the pile foundation. For longitudinal girders, both the exact number of girders and their actual types, such as plate-girder, I-beam girder, and box-girder, are properly modelled, as shown in figures 5 and 6.

(c) Tabulated component: the rest of the 20 bridge components are in this category. Since these components are either relatively trivial; such as sidewalks, or too small to display; such as bearings, they are not modelled in 3D and are tabulated in a pull-down menu which allows the user to choose from during bridge inspection.

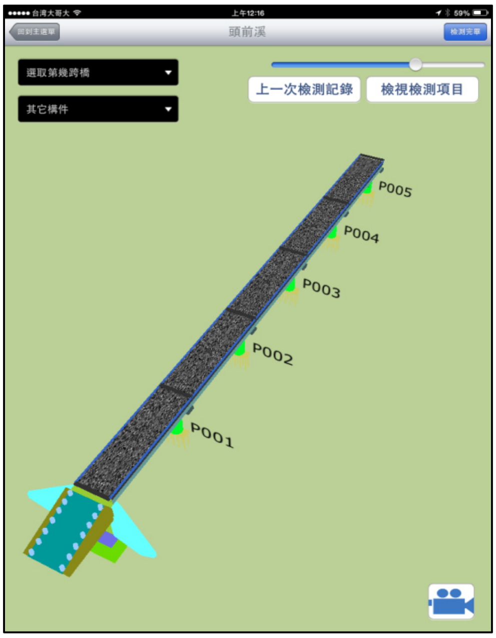

Figure 3. 3D modelling of a bridge by iPad mini.

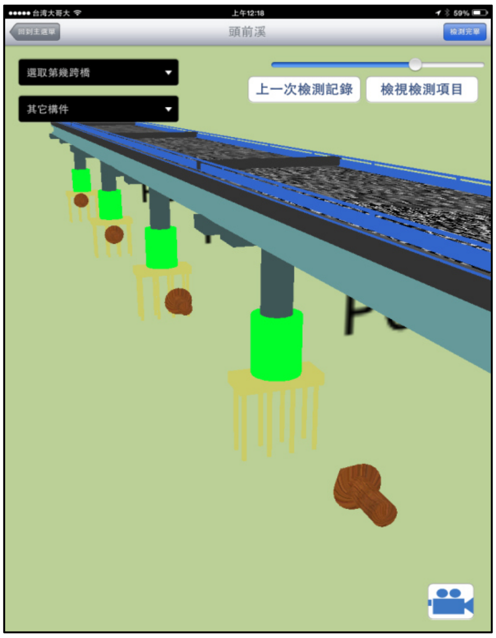

Figure 4. Bridge components in the 3D model.

3.3. Bridge inspection module

The methodology of bridge inspection and evaluation incorporated by TBMS is called DER&U, which was initiated by a joined effort of two consulting companies, CSIR and Join Engineering in 1990's. In the DER&U methodology, "D" stands for degree of deterioration; "E" represents extent of the deterioration; "R" implies relevancy to safety of the deterioration; and "U" depicts urgency for repairing of the deterioration. All of these indices are numerically rated on an integer scale from 0 to 4. While rating the deterioration conditions, the inspector can also input his/her personal comments if deemed necessary.

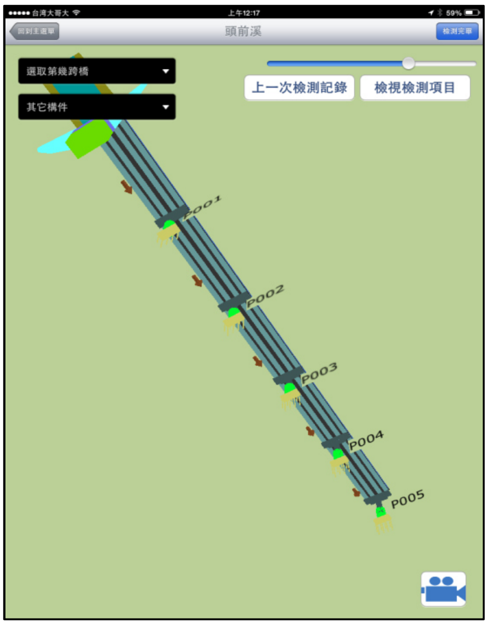

Figure 5. Bottom view of the 3D bridge model.

Figure 6. Four box-girders of a span under inspection.

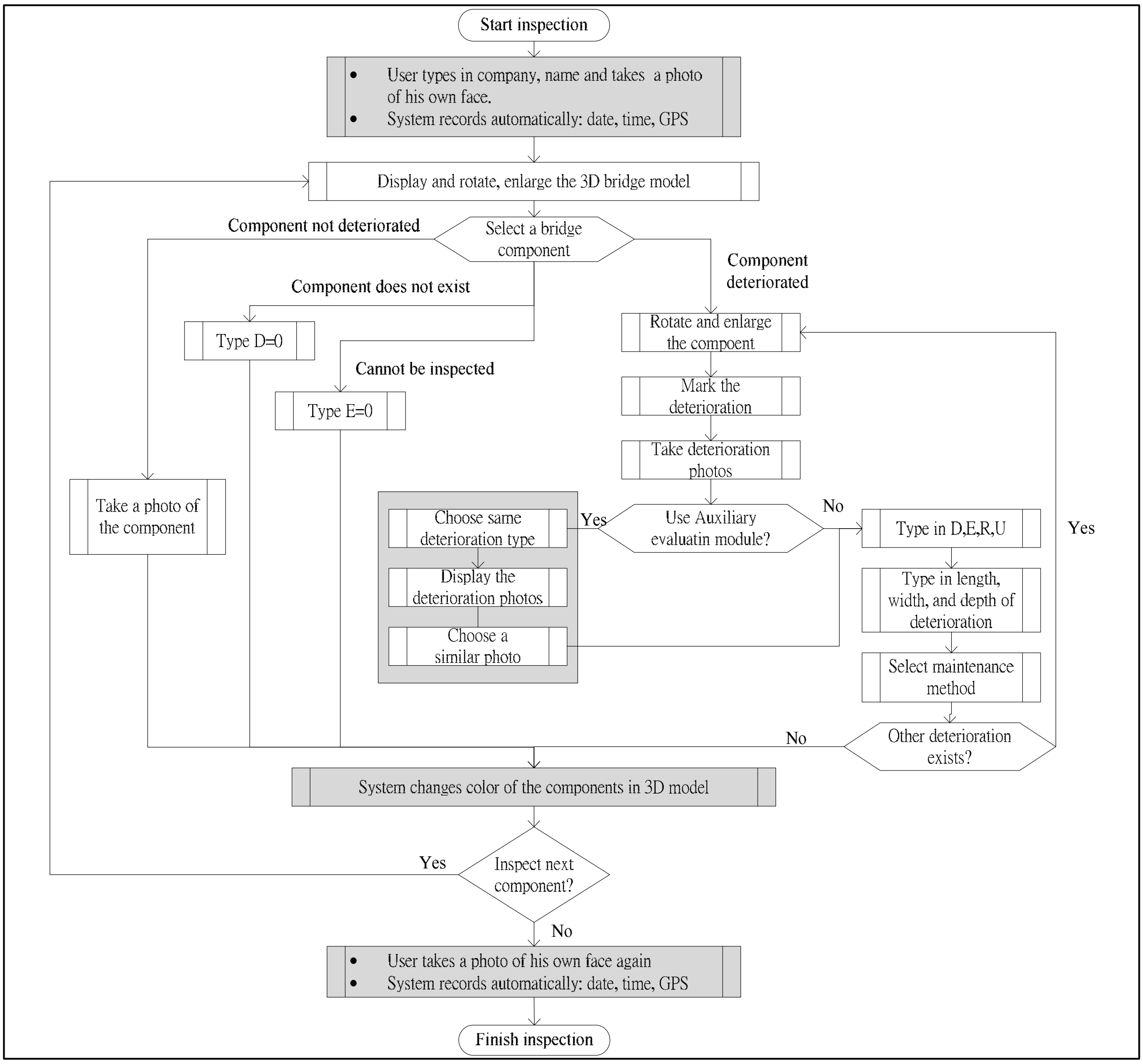

Figure 7. Inspection processes of the 3D bridge inspection App.

Figure 7 shows the inspection processes when using the 3D bridge inspection App. After the bridge to be inspected is selected and its inventory data are downloaded, the App automatically generates a 3D bridge model for inspection. The App requires the inspector to take a pho of his own face before manipulating with the 3D bridge model. Arguments of privacy were raised during implementation of the App. However, decisions were made to take the inspector's photo before and after inspection for based on responsibility concerns.

To inspect a component, the user can enlarge, shrink, or rotate the 3D bridge model to pinpoint the desired component which is then extracted from the bridge model and shown alone in 3D. If the bridge component is not deteriorated, then a photo of such component should be taken and saved; if the bridge component is deteriorated, then the user can enlarge and rotate using fingers on the touch screen in order to mark the deterioration on the component. Typical deteriorations for the various 20 bridge components are built inside the App, in the format of icons as shown at the top of Figure 6, so that the user can select an appropriate deterioration icon and put it onto its corresponding position on the component. The component with the deteriorated icon is then saved as a 2D picture along with an actual deterioration photo taken by the user. To evaluate the deteriorated condition of the component, DER and U values are determined and input by the user by touching the appropriate numbers (between 0 and 4) on the screen. Detail deterioration dimensions should also be input by the user. Finally, an appropriate maintenance method for such deterioration should be determined by the user from a scrolling menu in which default maintenance methods are displayed. Once a component is examined, color of the component will be changed to grey for identification purpose. However, if a component has a more serious deterioration, its color will become yellow or red, depending on the D value of the deterioration. Once a component is inspected, the user can choose to continue to the next component or stop the inspection.

Notably, a useful recording function is also implemented into the 3D bridge inspection App that allows the user to record necessary information such as surrounding views of the bridge and verbal comments of the user.

3.4. Auxiliary Evaluation module

Using of the DER&U methodology requires certain training so as to produce correct inspection results. However, if the user cannot determine a degree of deterioration (D value) for certain bridge component, a set of component deterioration photos taken from real bridges that are provided in this Auxiliary evaluation module, can be used for reference. There are 243 deterioration photos for 109 types of deteriorations and each photo has a D value embedded plus an explanation of its deterioration. More deterioration photos are been collected by the authors.

3.5. Data uploading module

There are three ways to upload the bridge inspection results to TBMS from the 3D bridge inspection App: (1) upload only the inspection data, (2) upload only the deteriorating photos, and (3) upload both the inspection data and the deteriorating photos. Such design provides flexibility for uploading if access to internet is limited.

Since there are long bridges with a large number of spans, inspection of such long bridges may take a few days and could be performed by multiple crews, thus, TBMS accepts multiple uploading of inspection results of the same bridge from various tablets and combines all the uploaded inspection results, which were uploaded within one month, into one single inspection record for the bridge.

4. Conclusion

This research developed an automatic 3D bridge modelling system for bridge inspection. The system is packed as a 3D bridge inspection App which can be downloaded into a portable device, iPad Mini 3G running iOS 7.0. The 3D modelling of bridge, written in 3ds Max by Autodesk, is automatically performed based on download bridge data. The vivid and manipulable 3D bridge model, in which each 3D component can be selected, displayed, and put on appropriate deterioration information, facilitates bridge inspection processes and reduces inspection errors. The developed 3D bridge inspection App is now being used by several agencies and engineering firms. Feedbacks from them are expected in the near future. In addition, improvements of the current version are also been made to incorporate more types of bridges such as steel bridges and cable-stayed bridges.

Acknowledgement

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Creative Construction Conference 2014

Examination of construction redlines procedure against good practice configuration management

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Abstract

Building Information Modelling (BIM) is becoming more widely used in construction. Revisiting change control becomes important as construction-phase change control mechanisms could become embedded within project-wide IT systems. Research on change control in construction examines change causes, effects and propagation; and proposes models for improving change control systems. There has been less research attention to the practical challenges of using digital change control processes within the construction phase of projects; or to the connections with related work on configuration management in manufacturing. This paper examines current and proposed construction-based change control processes within Crossrail, a large-scale civil infrastructure programme underway in the UK, through an in-depth study using semi-structured interviews, meeting notes, technical and management documents and other related material. With a focus on the redlines procedure, the preliminary findings show that current approaches to construction change control are insufficient in: firstly, enabling requirements-led conformity of product configuration; secondly, featuring appropriate controls; and, thirdly, considering change impacts prior to their implementation. The paper discusses the related need for a more proactive approach and highlights how configuration management principles inform proposed work on construction-phase change control in Crossrail. Further research is suggested in developing a network analysis prototype to aid the identification and assessment of change impacts prior to approval of requests.

Keywords: Change control; change process; configuration management; construction project; network analysis; product data

1. Introduction and background

Revisiting change control becomes important as Building Information Modelling (BIM) becomes more widely used in construction. This increasing use of BIM – a managed approach to whole-life asset information – is shown by recent market reports and surveys (e.g. NBS 2013). Its uptake is often through project-wide IT systems that use digital product data repositories. Here, new opportunities arise for construction-phase change control mechanism to become embedded within these systems.

Efficient control of change is a fundamental component, indeed a pre-requisite, of limited scope creep within an ever-evolving configurable system, such as one resulting from a construction project (Williams 2009). Given the consistent occurrence and inherently risk-prone nature of change, managers are advised to confront, embrace, adapt and use changes to the construction project's best interest (Ibbs 1997). To this effect, many researchers have been exploring the problematic issues relating to change within the construction context.

There is substantial research on change causes and effects (Hanna, Russell et al. 1999; Love, Mandal et al. 1999; Ibbs, Wong et al. 2001; Manavazhi and Xunzhi 2001; Josephson, Larsson et al. 2002; Ibbs, Nguyen et al. 2007; Sun and Meng 2009). Some researchers go even further, by providing construction change management toolkits in order to aid deployment of systemic and stable 'good practice' (Ibbs, Wong et al. 2001; Charoenngam, Coquinco et al. 2003; Motawa 2005; Arain 2008; Isaac and Navon 2009). Overall, the toolkits build on contractual requirements, experience from previous projects, and principles of effective control and/or project expertise, whilst there is a notable contrast between models that are process-oriented and object-oriented (Stasis, Whyte et al. 2013).

While the existing literature examines change causes, effects and propagation, as well as proposes models for improving change control systems, less research attention has been given to the practical challenges of using digital change control processes within the construction phase of projects; or to the connections with related work on configuration management in manufacturing. This paper presents a qualitative understanding of the evolving change control practices in Crossrail drawing on in-depth empirical research. Section 2 expands on the existing discussion of construction-based change control. The research methods for this study, which uses a qualitative mapping approach, are described in section 3. Preliminary findings, in section 4, compare the redlining process with the template configuration management process. Section 5 discusses the need for a more proactive, rather than reactive approach to change control, offers conclusions and outlines directions for further research.

2. Construction-based change control

Engineering change is a modification made to parts, drawings or software that have already been released during the product design process and life cycle, regardless of scale or type (Jarratt, Eckert et al. 2011). This may encompass any modification to the form, fit and/or function of the product as a whole or in part; moreover, it may lead to a variation in interactions and dependencies of the constituent elements of the product (Jarratt, Eckert et al. 2011). In manufacturing, there has been considerable work to develop standards for best practice in change control as part of a wider 'configuration management' process, through which important items are tracked.

In construction projects, change refers to an adjustment of the design, building work, project program or other project aspects caused by variations to pre-existing conditions, expectations or requirements (Sun and Meng 2009). It characterises an event that results in an alteration of the project's original scope, execution time, cost, and/or quality of work (Ibbs, Nguyen et al. 2007). This may affect the product and/or related documentation. Changes may be categorized by time (anticipated or emergent, proactive or reactive, pre-fixity or post-fixity); need (elective or required, discretionary or non-discretionary, preferential or regulatory) or effect (beneficial, neutral or disruptive) (Motawa, Anumba et al. 2007, p.368).

These literatures on engineering changes in manufacturing and construction are not well connected. To provide relevant background to this research, both are considered below. Relevant research has been outlined regarding: firstly, the causes, effects and propagation of construction change; secondly, the toolkits for modelling change management systems; and, thirdly, the configuration management definitions and core activities.

2.1. Causes, effects and propagation of construction change

It is reasonable to expect change occurrences within projects, and this is a consistent research finding (Sun and Meng 2009). Incomplete information of project variables during the early project phases leads to inadequate knowledge of future project states (Motawa 2005). Contractors' conditions, resource availability, environmental conditions, and contractual structures and relations may alter during the project (Arain and Pheng 2005). The lack of future knowledge necessarily leads to current plans with at least some degree of incompleteness and unrealistic forecasts (Motawa 2005). Such information deficiency is coupled with the fact that construction projects are typically undertaken in ever-fluctuating natural and business environments, often within a fragmented industry, using a disparate supply chain, and with long-term schedules prone to multifaceted risks (Ibbs, Nguyen et al. 2007).

Changes are frequently associated with serious implications and disruptions to the project's objectives, scheduling and costing (Ibbs, Wong et al. 2001), potentially leading to 'scope creep': the accumulation of seemingly minor changes over time to modify a project's scope into something larger, costlier, and significantly different than originally intended (Williams 2009). Detailed effects include, amongst others, the following: rework or revision of work (Love, Mandal et al. 1999; Josephson, Larsson et al. 2002); costing increases of up to 10-15% of a contract's value (Sun and Meng 2009); additional work and time loss (Bower 2000); design revisions (Manavazhi and Xunzhi 2001); and indirect effects, such as disputes, claims and other litigation issues, productivity loss, lower workforce morale, resource misallocation, float loss, cash flow alterations, and increased risk of coordination failures and errors (Hanna, Russell et al. 1999).

The available literature suggests that, left uncontrolled, the detrimental effects of changes propagate and multiply throughout the interconnected elements of a project. Issues of configurability between affected parts of the project tend to arise in parallel, and as a result, of stand-alone changes (Williams 2009). According to Sun and Meng (2009, p. 560):

"*A construction program, or project plan, consists of a series of inter-related and sometimes inter-dependent activities or processes. Each process requires a set of inputs and produces a set of outputs. Outputs from one process may be inputs to another process. Project planning or project scheduling is the task of defining all the activities/processes and their inter-relationship. It is done at the start of a project when many input parameters are uncertain and assumptions have to be made. Variations in any of the assumptions during execution will lead to changes from the baseline project plan.*"

It is well understood that the potential for harmful effects of uncontrolled, poorly controlled, unwanted or unexpected changes increases in magnitude and severity as the project unfolds. This follows the fact that the availability for responsive manoeuvrability and adjustment dwindles with the passage of project time and, thus, project flexibility decreases (e.g.: Isaac and Navon 2009; Sun and Meng 2009; Williams 2009; Isaac and Navon 2011; Isaac and Navon 2013). The phenomenon has additionally been observed in engineering product development in general (e.g.: Jarratt, Eckert et al. 2006). Much related to this, Williams (2009) argues that the potential for uncontrolled or poorly controlled change is directly analogous and causal to the potential extent of overall scope creep.

2.2. Toolkits for modelling change management systems

The construction literature documents designs for change management systems, which are variously built on contractual requirements, experience from previous projects, and principles of effective control and/or project expertise. There is a notable contrast between models that are process-oriented and object-oriented. Amongst others, the literature contains the following change toolkits:

- A step-based normative process model that builds on contract requirements (Charoenngam, Coquinco et al. 2003);
- A generic process-oriented system that is based on five 'good practice' principles (Ibbs, Wong et al. 2001);
- A change-process model that is supported by a database and flows through four major principles (Motawa 2005);
- A three-phased process model that follows six principles of effectiveness in managing IT systems, and which builds on a knowledge-based decision support tool able to learn continuously (Arain 2008);
- A systems dynamics model that allows for change prediction and dynamic planning (Motawa, Anumba et al. 2007); and
- An object-oriented, graph-based model for pro-active change impact identification (Isaac and Navon 2009).

2.3. Configuration management definitions and core activities

Configuration management is defined as the coordinated activities that direct and control the interrelated functional and physical characteristics, also known as configuration, of a product (British Standards Institute 2003). These characteristics are defined through the product configuration information, which describes the requirements for product design, realisation, verification, operation and support. The complete practice of configuration management commonly focuses on providing through-life direction to those technical, organizational and administrative activities that establish and maintain control of a product, its configuration information, and the configuration items comprising it. It provides identification and traceability, the status of achievement of its physical and functional requirements, and access to accurate information in all phases of the lifecycle. The degree and method of implementing configuration management varies according to the size of the organization, as well as to the complexity and nature of the product (British Standards Institute 2003).

A **product** can be of varied nature, degree of complexity, and purpose; it can manifest at various locations; and it can be comprised by one or more sub-products (Hass 2003). The 'Configuration Management Standard' (ANSI and TechAmerica 2011) treats a product as the result of a process. A large number of generic product categories exist; they can act as stand-alone assemblies of a single product (or sub-product, depending on the scope employed), or can be combined into systems (Hass 2003; ANSI and TechAmerica 2011).

In the context of construction, the product is the outcome of the construction project: the collection of constructed and delivered facilities (Williams 2009). Similarly, in the context of a large-scale infrastructure programme such as Crossrail, the product is the complete assembly of artefacts, systems and/or facilities that is to be delivered for operations and that is, indeed, the outcome of the combination of all processes undertaken until handover (physical and digital). For a construction project, a **configuration** can be defined as the functional and physical characteristics of the project as set forth in technical documentation (plans and specifications), and ultimately achieved as the completed construction (U.S. Department of Defense 2001). In other words, the configuration is what is required to be built, what information is there about that which is to be built, and the actual build. Given that plans and specifications define that which is to be built, any change to these documents – such as a change order – constitutes a change to the configuration. In complex construction projects, this configuration is being continuously modified throughout the product's entire lifecycle (Williams 2009).

Configuration items are defined as an "aggregation of work products that is designated for configuration management and treated as a single entity in the configuration management process"; further, these "may vary widely in complexity, size and type, ranging from an entire system including all hardware, software and documentation, to a single module or a minor hardware component" (IEEE Standards Association 2012, p.2).

These configuration items become subject to overall coordination of operations, whilst collectively articulating the delivered product of any given project.

Table 1. Core activities of configuration management; from Hass (2003).

Identification	A crucial activity that seeks to determine the metadata for a configuration item, therefore uniquely identifying it and specifying its relations to both the outside world and other configuration items. As the number of configuration items increases, the cost of not carrying out identification – should one want to manage product definition – grows exponentially.
Change Control	Changes are almost inevitable after the initial definition of a product. Mistakes, requests by customer, altered surrounding and enabling environments, new knowledge and problem-solving methods, and modified perspectives on solutions, are only a few of the reasons for this near inevitability. The purpose of this activity area is to be in full and unambiguous control of all change requests for a product and of all implemented changes. At the level of a configuration item, one should be able to identify any changes relative to its predecessor, enabling backwards traceability to the item where the change was implemented. Change requests are initiated by events and have owners.
Controlled Storage	Ultimately referring to a tangible, physical medium, the purpose of storage is to ensure that a configuration item: will not disappear or be damaged; is safely stored at a specific, physical place (often called a library or a repository); is readily and constantly available; is to found at the condition it was left; and that it has access records (as to who viewed, copied or modified it) attached. It is important to note that recent cloud technologies mean that libraries built on them are located at multiple sites.
Audit	Ensures that the product, which is understood as the configuration item released for use, both fulfils its requirements and is complete as delivered. The assurance includes configuration management information; consequently everything required is completely delivered in the expected versions. The information further ensures that the history of each item can be thoroughly accounted for.
Report/Status Reporting/Status Accounting	This activity area is concerned with enabling the useful and timely availability of that information which is necessary to effectively manage a product's development and maintenance. Other activity areas deliver the data foundation for status reporting – in the form of metadata and change control data. Status reporting entails extraction, arrangement, and formation of that data in accordance with what is demanded of them.

Controlling change throughout a programme’s lifecycle is of particular weight to its relative success or failure; and configuration management seems to be a robust way of doing so. Williams (2009, p.178) notes that configuration management is a “*technique [...] being increasingly used in the construction industry to manage the change that occurs in complex projects to help keep projects from experiencing scope creep, large cost overruns, and major schedule slippages*”. Configuration management allows the controller to check the consequences of a change before it is made, and to provide traceability of product data so as to understand where problems occur, thus diagnosing and contributing to recovery (Burgess, Byrne et al. 2003). An authorization approach is used to control change and there are different hierarchy levels depending on the use of configuration items (Billingham 2008). The processes, procedures and users of the configuration management system play an integral role in keeping data integrity throughout the lifecycle by controlling changes to a data system. If users do not follow the process, errors can occur which can cause problems in the product, its production, and/or related information dissemination (Hameri 1997; Hameri and Nitter 2002).

3. Methods

The paper is based on data collected through ongoing research with Crossrail to assess the evolution of change control mechanisms within the programme. The work maps, compares and contrasts an existing change control procedure to the template change control procedure – which is compatible with configuration management principles. This research is intended to support the later development of a network analysis prototype to aid the change impact identification and assessment function within the change control process.

3.1. Data collection

The empirical evidence collected includes: semi-structured interviews with involved managers, consultants and other personnel; notes from meetings and observations; technical and management documents available in-house, such as processes and procedures guidance and flowcharts, and review sheets; and other related material, including important communication items, presentations and drawings. Table 2 outlines the main sources of data that has been used in the preliminary analysis.

Table 2. Main sources of the data used in the preliminary analysis.

Subject Matter of Data Collected	Crossrail	Contractor/Partner
Semi-Structured Interviews	***5***	***2***
Meetings, Notes of	***23***	***3***
Asset Information and Configuration Manager	14	0
Information Applications Manager	4	0
Red Lines Business Case Development Team	1	0
Technical Information Department	3	0
Management Consultants	1	3
Technical and Management Documents	***11***	***3***
Best Practice Guidance	4	0
Processes and Procedures Flowcharts	5	0
Processes and Procedures Specifications and Descriptions	1	1
Contracts/Tenders	0	1
Technical Review Sheets	1	1
Other Related Material	***8***	***1***
Communication Items	2	0
Presentation Material	4	0
1st Tier Contractor Briefings, Notes of	0	1
Drawings	2	0

3.2. Preliminary data analysis

The dataset has been used to conduct a qualitative analysis of change control within Crossrail, focusing on: understanding the overall change control process; identifying existing, planned and template change control procedures; documenting key steps and involved roles in two elected procedures; articulating how the two procedures compare and contrast from the perspective of configuration management principles; and acknowledging expert information regarding issues of construction-phase change control. In aiding the analysis, particularly in order to understand the principles, process-flows, and differences between the two procedures, a business process software package was used for their qualitative mapping and representation. The analysis combines the qualitative mapping with qualitative information from configuration management guidance on change control for nuclear plants, as well as of the in-house guidance, to highlight three problem areas of traditionally-practice construction-phase change control: requirements-led conformity relationships; adequate controls; and change impact identification and assessment. The emerging interpretations and analyses have been checked with key members of the project, which are in agreement and anticipate further development.

4. Preliminary findings

4.1. Change control overview in Crossrail

The change control process is not a unified business item; rather, being a programme of numerous projects, locations and involved contractors, Crossrail features an array of change control procedures. Enabled by both enterprise and non-enterprise mechanisms, these procedures span the entire lifecycle phases of the programme. As such, they address various concerns and are necessarily handled by a wide variety of personnel within the organization responsible for delivering the infrastructure. Ample documentation of management and technical nature has been found to account for these procedures; nonetheless, it is understood that inconsistencies across them exist. The research has identified a few of the core procedures prevalent at the design and construction phase, and their interface, as summarized in the following table.

Table 3. Change control procedures: existing, planned and template.

Existing Procedures	Planned Procedures	Template Procedures
High-Level Change Process	Chief Engineer's Communications Process	Template/Enterprise Change Control Procedure
Programme Baseline Change	Works Information 2B Change Control Process	(abides to configuration management principles)
Design Management Process		
Management of Redlines Procedure		
Management of As-Builts Procedure		

Advocates of configuration management, along with other personnel involved in the management and execution of these procedures, have expressed concern for the effectiveness of the entire change control suite. From the perspective of configuration management, the concerns relate to insufficiencies in: requirements-led conformity relationships; appropriate controls; and change impact identification and assessments. From the perspective of other personnel, the concerns involve: inadequate consideration of: conflicts and interfaces between procedures; each procedure from involved parties; and ample room for systemic improvements.

The preliminary findings address the three concerns relating to the redlines procedure from the perspective of configuration management. The findings are presented by comparing and contrasting existing to template change control – the latter of which has been developed in-house by advocates of configuration management. External configuration management guidance on change control is used to strengthen the analysis and advance the findings.

4.2. The redlines procedure

A traditional and repetitive procedure during the construction phase of any project is that of annotating changes to drawings after they have been released for construction. This annotation is known across the sector as ***redlining***, due to the mere fact that it is historically performed by marking corrections on design-approved paper drawings in red ink. The task, which is conducted by the site contractor, is intended to highlight approved, post-design deviations from the original drawings, as reflected by an inspector of the built asset. The annotated drawings are then transferred to the authority controlling the whole programme, i.e. Crossrail, so that records of these changes are held internally. Customarily, these records are used later to update the as-built drawings – itself being a change control process – prior to data handover to the operator. The official description of the procedure is as follows:

> "[…] *The CRL Management of Redlines Procedure describes how IFC Drawings provided to the Contractor, via the Issue of Design Documentation for Construction Procedure, are to be annotated to indicate any approved deviations with the installed condition. This procedure then describes how those deviations from the IFC Drawings are to be incorporated into the CAD Models and CAD Drawings to produce the final As-Built CAD Models and As-Built CAD Drawings.* […]"

Up to the end of 2012, Crossrail had been controlling this procedure through an electronic route that was not incorporated with the project-wide IT systems, namely the obsolete ***project technical requests*** database tool. More recently, the incorporation has been made, yet the steps and controls have been left largely unaltered. The procedure makes use of ***register and issues records***, produced along with the finalization and distribution of as-built drawings – a, usually hyper-linked, excel file of information exchanges between a single contractor and the organisation. It also makes use of ***field change documents***, in word document format, which is the control document for change proposals initiated from the contractor or the field engineering team.

4.2.1. The insufficiency of requirements-led conformity relationships in the redlines procedure

One of the foremost concerns in Crossrail is employing consistent product configuration control, throughout the programme's entire lifecycle, for the purpose of abiding to its stated requirements. It is to this effect, along with mitigating the risk of scope creep, that the organization has adopted configuration management. The following is an extract from Crossrail's configuration management plan, demonstrating the importance of establishing and maintaining requirements-led configuration integrity of the system:

> "[…] The purpose of CM is ultimately to ensure conformance to Requirements. A large, complex and highly integrated rail system presents many challenges and risks in terms of establishing and maintaining the integrity of the system configuration throughout the design, build, test and commissioning, and operation. These risks manifest themselves as configuration incidents. Configuration incidents result due to incompatibility in system components, normally at the interface, and can have different levels of severity which the following broadly demonstrates: minor – at the design stage, resulting in design rework; medium – at the build or test stage, resulting in major design and build rework; severe – during operation, resulting in service affecting failures or potential safety incidents or disaster recovery which requires configuration data to be quickly replicated to minimise service disruption. CM is the means of mitigating and managing these risks by establishing and maintaining system integrity at all stages throughout the lifecycle and ensuring products conform to their requirements […]"

The requirements-led conformity relationships, as outlined above, can be alternatively understood as follows: physical configurations (also known as assets) must conform to configuration information (also known as designs, design information, or product information), which in turn must conform to requirements (also known as product/system/design requirements, or requirements information). These three elements are collectively known as the product configuration, and their equilibrium throughout the product's lifecycle is necessary when abiding to configuration management principles (IAEA 2003). As such, Crossrail's configuration management plan is consistent with important guidance for, amongst others, the nuclear plant industry. The following extract from the IAEA (2003, p.3-4), is demonstrative of this compatibility:

"[…] Configuration management programs ensure that the construction, operation, maintenance, and testing of the physical facility are in accordance with the design requirements as expressed in the design documentation, and to maintain this consistency throughout the operational lifecycle phase, particularly as changes are being made. […] The physical configuration should conform to the facility configuration information,* which is based on the design requirements. The facility configuration information, which includes as-built drawings and operating (including maintenance) procedures, should accurately reflect both the physical configuration and the design requirements. Changes to design requirements should be reflected in both the physical configuration and the facility configuration information. Changes to either the facility physical configuration or facility configuration information should be supported by, and be consistent with, the design requirements. […]"

Despite the aforementioned guidelines, both from external and internal sources, Crossrail's redlines procedure follows the traditional construction industry practice of incorporating post-design changes to the approved information only after construction has been completed. Specifically, any changes approved past the release of issued-for-construction drawings are not used to construct new drawings within the product data repository. Instead, input on deviations from issued-for-construction drawings – as observed from inspecting the assets – are used to produce as-built drawings. As seen in Figure 1 below, such a practice results in conformity relationships being led by assets rather than requirements.

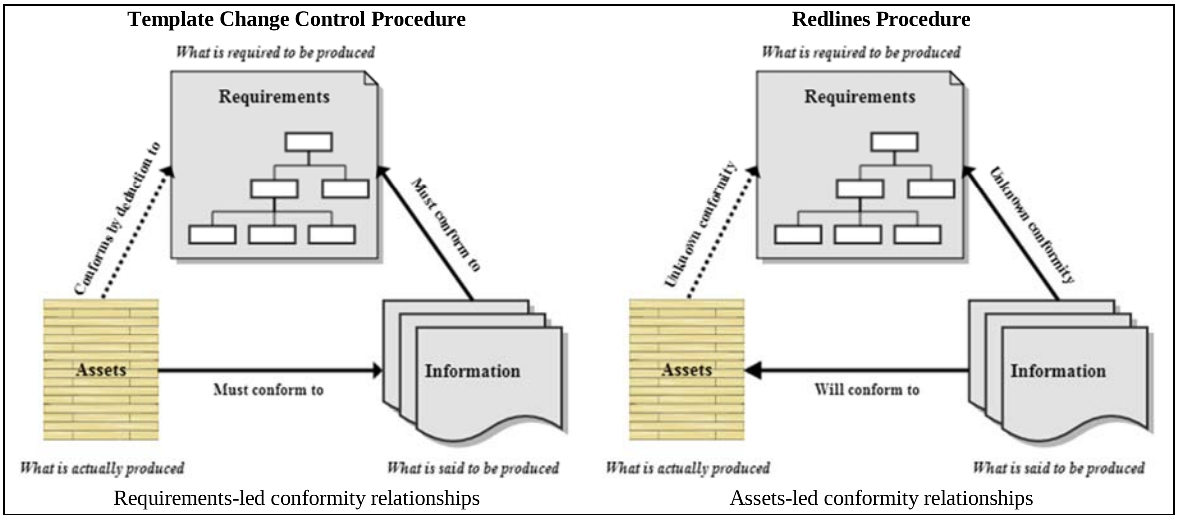

Figure 1. Conformity relationships comparison between template change control procedure and redlines procedure.

By allowing the redlines procedure to operate inconsistently with requirements-led conformity relationships, as prescribed by configuration management guidance on change control, a number of important issues arise. Firstly, uncertainty is raised as to whether or not any number of the observed deviations had been indeed approved to begin with. Moreover, the practice allows for time-periods throughout the construction phase where the information is not properly updated. Given that mismatch between information and assets might exist at any time during construction, the reliability of any current information baseline during that time-period is questioned. Lastly, the procedure permits uncertainties relating to whether or not conformity relationships hold true, even post-incorporation of information updates based on the asset inspections performed once construction is complete.

The apparent disconnect between requirements and assets is particularly problematic in terms of configuration management. It increases the risk of medium configuration incidents during construction and testing, or even severe configuration incidents during operations, should product configuration inconsistencies affected from earlier practices surface at a latter phase. These incidents, described earlier as resulting from incompatibility in system components, can be associated with severe disruptions, costs, reworks and safety-critical failures; or, more generally, what Williams (2009) defines as scope creep.

4.2.2. The insufficiency of appropriate controls in the redlines procedure

The importance of controls in product configuration is highlighted by the IAEA (2003, p.6):

"[…] The objective [of information control] is to identify and manage facility configuration information (including document and electronic information* control) related to the physical configuration and the design requirements. […] The objective of change control is to maintain consistency among the design requirements, the physical configuration, and the facility configuration information as changes are made. It is the most important element of effective configuration management, and warrants extra attention. A graded approach* to individual change control activities should be considered. The degree of assurance required for a particular change should be proportional to the safety significance, complexity and economic impact of potential configuration errors. […]"

By comparing the redlines procedure to the template change control procedure, as seen in Figure 2 below, the former's insufficiency in appropriate controls that are necessary for configuration management can be identified. Specifically, the redlines procedure:

- Lacks cross-functional review of change impact assessments;
- Lacks an independent decision-making authority to approve or disapprove requested changes; and
- Lacks the ability to verify, through a digital product data repository, that change requests (in the form of annotated drawings) are indeed reflective of, and limited to, approved deviations.

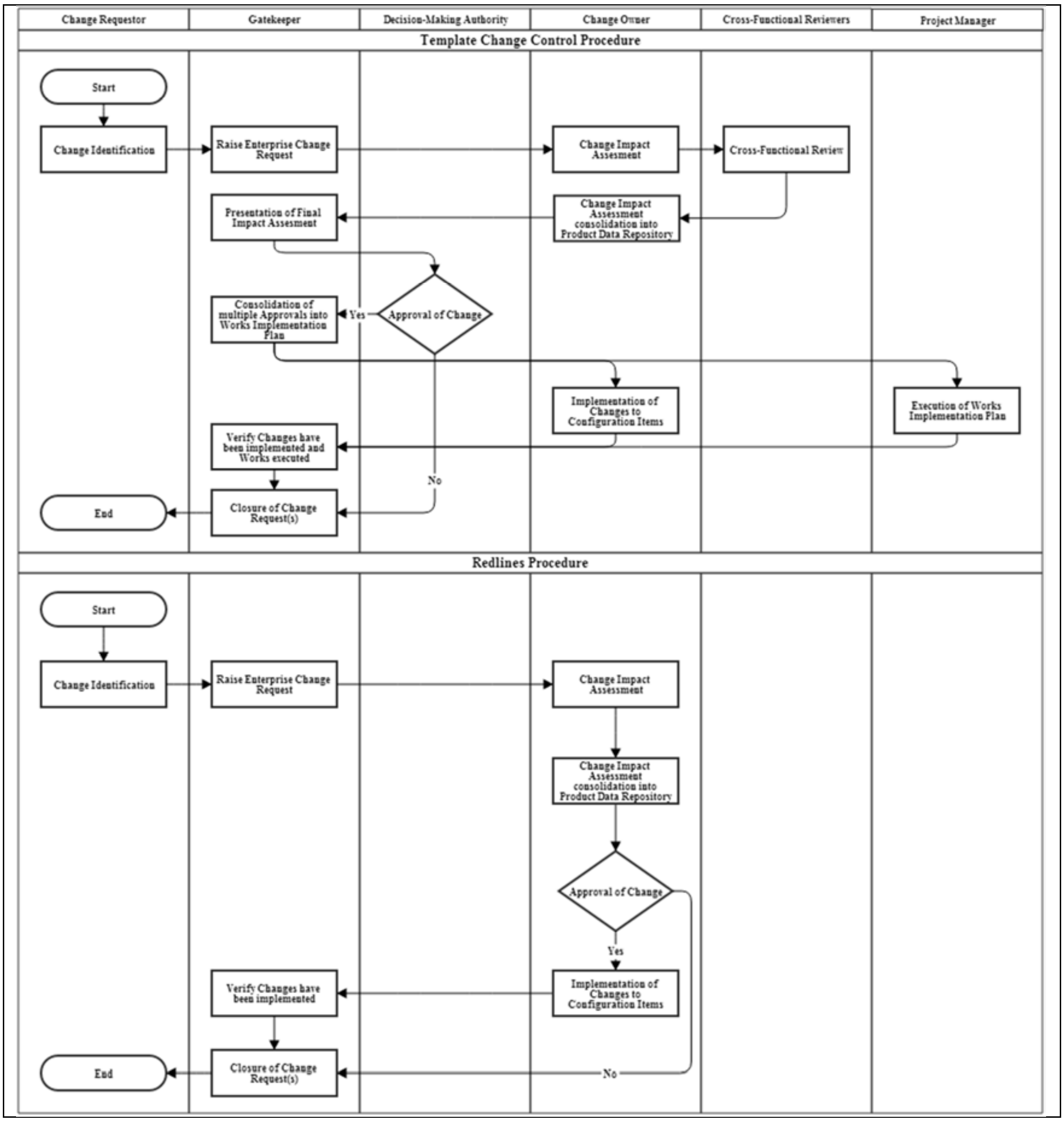

Figure 2. Swim-lanes process flowchart comparison between template change control procedure and redlines procedure.

This insufficiency in appropriate controls is particularly problematic when considering the quality and effectiveness of the redlines procedure. By lacking cross-functional review, change impact assessments are not shared with relevant personnel that could provide useful insight into other project components that might be affected by the change request, or even improve the existing assessments: they are based solely on the judgment of one person. Given that the lack of this particular control eliminates the function of external approval as well, the author of the assessment assumes the responsibility of approving their own work. As such, it cannot be ensured that change impact assessments are performed to an acceptable standard, or indeed performed at all.

The conflict of interest extends by further entrusting the same person with the authority of approving changes, responsibility of consolidating impact assessments into the product data repository, and task of implementing changes to affected configuration items. Following this practice, the function of approving changes becomes much less important: the person who is responsible for both identifying impacts and performing the relevant changes in the product information has no considerable incentive to disapprove of his or her own judgment. Indeed, the existing procedure cannot ensure that the change owner does not consolidate all involved steps, or even skip some. This gives rise to a considerable uncertainty as to whether or not quality standards are kept high, or even if the whole procedure is sufficiently effective.

4.2.3. The insufficiency of change impact assessments in the redlines procedure

As mentioned earlier, the existing redlines procedure cannot ensure that sufficient, if any, change impact assessments are performed. The evidence collected to date suggest that minimal change impact assessments are performed, but are of lesser quality than what configuration management guidelines would require. Such a practice raises questions as to whether propagations of changes are adequately understood, known, controlled and documented. The importance of change impact assessment is provided by the IAEA (2003, p.6):

> "[…] The objective of assessments is to help define facility CM needs and to measure how effectively the basic relationships between design requirements, physical configuration and facility configuration information are being established and maintained. Assessments should be conducted during all stages of the facility life cycle and generally should emphasize examination of end products rather than program. […]"

5. Discussion and conclusions

The findings indicate that the redlines procedure, an example of traditional change control during construction, features a number of problematic areas. Firstly, it is insufficient in addressing requirements-led conformity relationships, thus leading to an increased risk of inconsistencies in the product configuration, as well as in associated scope creep. Secondly, it does not sufficiently incorporate appropriate controls, leading to questions regarding the procedure's ability to ensure quality and effectiveness. Thirdly, it features inadequate change impact assessment, thus questioning whether change propagations are being appropriately accounted for. Despite being traditionally practiced and successful in its execution, the implicit assumption that deviations have been approved – which lays the basis for structuring the whole process – seems to be overturned when examined from the perspective of configuration management.

Given that changes have, according to the procedure, been already approved, there seems to be no concrete reason for relevant product information to remain outdated until implicated assets have been constructed. If indeed constructed assets reflect nothing beyond the sum of issued-for-construction drawings and their approved alterations, an appropriate procedure would be limited to on-site verification of already updated drawings; in such a case, the existing procedure would need to be re-structured accordingly. If, on the other hand, constructed assets are not limited to changes that have been already approved, the mere addition of a step validating whether or not this is the case for any part of the documented deviations observed on site would neglect the more pertinent issue. As the product configuration must conform throughout the lifecycle, the latter situation would require one or more of the following actions: information-led reworks; assets-led variations to approved information; or alterations to requirements led by assets and/or information. In any case, the risk of scope creep would be increased, especially as the programme unfolds and change propagations take place (Williams 2009). It should not be overlooked that any potential benefits assumed to be realized at the site level in the short-term do not mean that accumulated detriments to the whole programme are mitigated in the long-term.

The acknowledged deficiencies associated with the redlines procedure highlight the need for more proactive construction-phase change control, drawing on template procedures that abide to configuration management principles. Firstly, in order to address insufficiencies in controls such as lack of cross-functional reviews, the procedure could: incorporate the necessary functions that are absent; re-assign those that are currently inconsequential to additional personnel; and align roles and responsibilities to incentives. These steps would ensure that the quality of configuration management does not significantly deteriorate over time. Secondly, a restructuring of the whole process is suggested, even beyond this procedure, to account for the urgency of ensuring requirements-led conformity relationships. The process would therefore necessitate the use of approved information, perhaps acknowledging them in terms of as-developing drawings, and place a primary role in them when verifying completions on-site.

Regardless of change control process structuring, the impact on ensuring proactive product configuration conformity would not be as prevalent in the absence of a satisfactory mechanism for pre-approval change impact identification and assessment; consequently, the authors address the third problem area by suggesting the use of network analysis for the aforementioned function. The next steps will expand the existing dataset to incorporate: interviews with change control experts in both the organisation and a site managed by a contractor; management and technical information on specific and traceable change requests; and meta-data on configuration items involved with, and affected by, these change requests. Drawing from recent research on construction-based network analysis (e.g. Isaac and Navon 2009; Isaac and Navon 2013), the methods will expand on the current qualitative approach to feature iterative development of a software tool. The analysis will seek to: firstly, aid the construction of a prototype using network analysis software; and, secondly, compare and contrast simulated results of change propagation to expert opinion and, where possible, observed results. The researchers anticipate this development to aid the application of configuration management during construction-phase change control.

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