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 (Vukomanovic 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). Accordingly, 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.

ArchiCAD 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 4D models 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 Akinci et 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](image-url)
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](image)

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.

References

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