Automated construction schedule creation using project information model

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ABSTRACT: In this paper we will propose a method of using a project information model (PIM) for creating construction schedules. In the paper we will briefly review current available scheduling possibilities, which use combination of BIM and scheduling software. We realized that BIM lacks user specific data that is vital for proper schedule creation and has, on the other hand, too complex structure and software tools for planning personnel to understand. Through the use of simple 3D model viewer, user specific data and BIM, we are proposing a novel approach of schedule estimation in construction, which we call project information model (PIM). PIM is the process that is based on internal logics, that creates the estimated schedule and resource usage. After the PIM process, the automatically created schedule is included in BIM and made available to project managers and other construction stakeholders, to coordinate and carry out activities.

1 INTRODUCTION

The introduction of Building Information Model (BIM) transformed the construction industry. It changed the way people plan, design, build and operate their buildings. But BIM information platform is not yet widely accepted, since many construction companies think that time to design BIM model does not outweigh the advantages gained (Eastman C.M. et al. 2008). BIM is proven to become a standard in construction industry in years to come, when the advantages will be more recognizable and when the construction companies learn how to easily make it and fully use it.

A lot of research has been directed towards recognizing the advantages drawn from BIM for the construction companies, but at present only the minority of construction companies, use it on a day to day basis for their work activity.

Since BIM can carry a lot of information about day to day activities for a certain project, it necessarily has to be integrated into the information systems of companies (in their Enterprise Resource Planning systems – ERP and Customer Relationship Management – CRM solutions), which cooperate on the same project. Partners that work on a specific project, usually work on more than one project at the same time. To manage more projects at the same time, they usually have their own information system in the company (ERP), which is not directly connected to BIM of their common project. In this case the information that is stored in BIM doesn't have much value for the construction company, since it has to be converted to their own information system. Just the opposite is the case, when the construction company does all the construction works (planning, design, building, supply materials, etc.) itself. In this case, the use of BIM can have several advantages if it is integrated in ERP solution of the company.

In this paper we will focus on a construction planning from a cooperation point of view, where the construction works are divided among many construction companies (partners). We will focus on retrieving the relevant information from BIM for each company. We will propose a novel approach called Project Information Model (PIM) for retrieving and saving the relevant information back to BIM by each of the companies that cooperate on the same construction project. Especially we will focus on schedule creation and try to automate it with the PIM approach.

2 4D MODELLING

4D model is a combination of 3D model with added schedule. 3D model is the base of BIM, since it holds all the vital graphical representation of a model. After reviewing the 3D model user can add information about cost, time, resources, technology etc. thus creates the 4D model or even nD model.

Approaches and methods of how to create 4D model can vary from one construction program to another and from one scheduling program to the other, but all current approaches rely on construction planner to assign the duration to work activities. Basically planner links the activities with 3D objects by a separate program, such as 4D Linker. In this case, the planner must have the knowledge of modeling program, as well as knowledge of scheduling program and above all in this case, scheduling process is lengthy process which requires a lot of attention and mental concentration from planner (Hyun Tae et al. 2007).

Researchers expected a lot from 4D model, since it has a lot of potential uses. Apart from construction visualization, it can be used to predict space conflicts (Akinci B. et al. 2002), resource bottlenecks, materials and people resources on a construction field at a certain point of time.

2.1 *Creating a 4D model*

Traditionally a 4D model is created by linking activities of a schedule plan to 3D model elements and then saving all information back to BIM, or to a special file. Some latest CAD software enables semi-automated approach to construction scheduling through the use of methods (so called "recipes"). The result of such approaches is a sequence of activities, but without the estimated timeline (duration) or the necessary resources. The timeline has just linked sequences of activities that are drawn from a 3D model stored in BIM. After the user corrects the duration of activities, the 4D model gets updated and a user is able to save it back to BIM (Zhou et al. 2009).

The problem may arise also from activities that need to be split. 3D model holds elements of construction as parts. When a planner wants to use a construction part in scheduling, he can realize that technology to construct that part is split to at least two activities. In this case, he has to divide part to proper elements and update 3D model and construction sequence. (Tulke J. et al. 2008)

In today's practice, creation of 4D model requires at least two computer programs. One is for viewing a 3D model and the other is scheduling software. Usually the companies have also their own information system (ERP), which holds the information about company's resources, so the planner also has to consult the information system to obtain most current assignments of resources. In this case he can plan the project activities in advance and also see the bottleneck of resources as they are assigned and used among various projects. On the other hand, the planner has to know a great deal about construction sequence, time-space conflict issues (Tantisevi K. 2009), norms and other business process fields, even though this information is usually included in information system of a company (CRM, ERP). In this case, the planning process takes a lot of time, since planner must consult all other relevant employees and break the 3D model apart to get proper predecessor and successor activities for each element. This means, that for scheduling process, BIM only serves planner for visual representation of the activities he planned and solves only the time-space issues if any of the stakeholders simulates the building process (Tanyer M.A. 2005).

Basically what planner uses from BIM is just a 3D model and technology if that at all is included in BIM.

2.2 *Scheduling methods*

For a planner to work successfully it is vitally important that he is familiar with traditionally used scheduling methods. A lot of them have gained the researchers attention through passed time and solved various problems, but everyone agree that none of them is generally effective. Today construction actors mostly use Critical Path Method - CPM, Programme Evaluation and Review Technique - PERT and Line Of Balance - LOB scheduling methods and diagrams (Devi C.A. et al. 2007).

For the purposed PIM method we will use CPM as scheduling method. Our goal is to automate schedule creation not solve space-time conflicts or workload on a construction field, so our focus is oriented into time issues and we think that this method is most appropriate.

2.3 *Scheduling through BIM fields, stages, lens*

Information which is contained in BIM is usually aggregated. If we need specific information, we have to select it and conceptually divide it based on fields and stages and also through the point of view, which is called through lens. Depending on how much information is included in BIM, fields and stages can be sub-divided according to the meaning of the information (Succar B. 2009).

This division suggests that BIM information can be presented in various ways, depending on the requirements of the specific user. The problem arises when there is too little information in BIM, especially in 3D geometry model, or the information is too much aggregated (Jeong Y.S. et al. 2009). Then the scheduling process has to separate some elements to basic materials and correct the 3D model and the activity workflow. In this case the scheduling process is prolonged since it doesn't deal with its primary activity, but solves the issues that should have been solved in previous activities.

Scheduling process is included in each field and in each stage of a construction project, no matter how we look through the lens. If we look at the construction project through the lens of an investor, we

can see that only quality, time and cost of construction is relevant, where on the other hand for builder only resources, time and expenses are important. We could go on explaining various roles in construction project so we could see that there is always time in question. So we can assume that scheduling is of vital importance for any actor in construction process.

Since scheduling can be found in any stage and field of BIM, we will try to define how to automate it and connect it with information system (ERP) of particular construction company. To achieve this we will try to solve the standardization problem (Long L.D. 2009) and define norms in a way to be usable for every process and resource in construction.

3 PROJECT INFORMATION MODEL – PIM

Project information model method consists of user specific data such as norms, resources, technology, personnel, costs and connection to BIM and ERP on the other side. The user data is stored in databases and can be linked to the 3D model automatically through the use of interoperability data structures and files based on keys and ontology. With this method the user can assign specific technology, resources, costs and personnel to a 3D model element and get the estimated schedule as a result. The user also doesn't need to worry about supporting activities, since the technology provides all the necessary data. At the end, the user can fine tune the schedule, resource allocation, personnel and costs manually and afterwards save all the necessary data back to BIM.

The PIM process is shown in figure 1.We can see that the BIM holds all the necessary data and is intended for information sharing among various construction actors. Each actor can retrieve the information about process technology from BIM which means that creator of 3D model must supply only the information about which process technology should a construction actor use, when working on a construction project.

When a user pulls the information of technology from BIM, he can import it in his own information system (ERP), which has information about resources (transportation capabilities, logistics, equipment, tools, human resources, etc.) and PIM, or can just import it to his PIM.

User's PIM has information about technology, norms, resources, tools, machinery, supporting activities and other relevant objects that are needed in his database. When user's information system (ERP) combines the norms with the resources he has available (according to PIM model), the user's information system can return the estimated time for each task and since activities are connected, the system actually returns estimated schedule.

The PIM also has the knowledge about possible predecessor and successor activities for each activity. This means that when user pulls process technology from BIM, PIM separates the 3D elements according to process and adds additional tasks as needed (for example: if we have a 3D element façade, then based on the process, PIM is able to divide it to activities – build the construction scaffold, do the facade, pull down the scaffold).

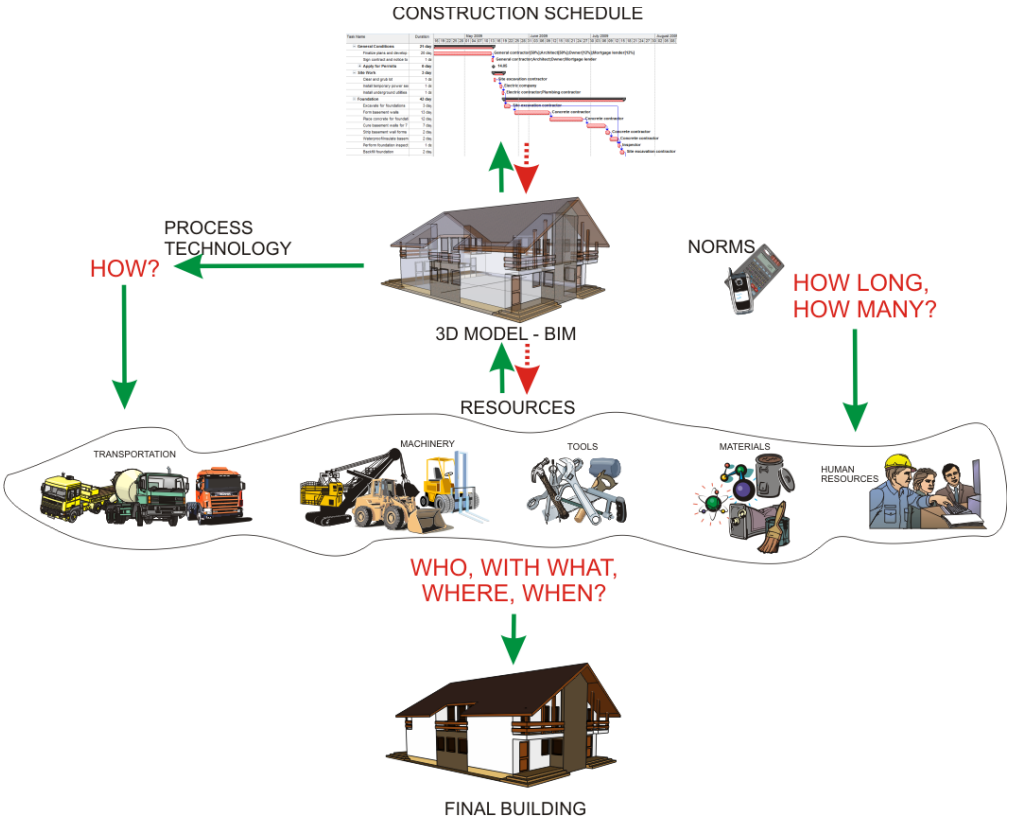

Figure 1: Project Information Model (PIM)

Since all the activities need resources, the PIM supplies information about them as well. According to norms (norms are applied to each resource, tool, machinery and transportation) for each activity, the PIM can return how many human resources, which tools, what machinery and how long it will be needed. If the PIM is connected to user's information system (ERP), planner can easily see which resources are available when and for how long. In this scenario the planner can also see if there will be any lack of resources, if many projects are constructed concurrently, so the company can plan in advance resources it needs.

3.1 *Elements of PIM*

If we consult Figure 1 we can see that the PIM model consists of resources, process technology, norms, construction elements and activities.

Main element of PIM is the process technology. Process technology holds data about how various elements of construction are constructed. The process technology also provides information about predecessor and successor for the activities. For example: if we want to pour the concrete foundation, first we need to construct the paneling or dig hole (predecessor activity), only then we can start with mixing the concrete, sand and water and pouring it into prepared structure. It is important to note, that predecessor, except for the process technology Start (which marks starting activity), has to be defined, successor is always available as an option.

Each process technology element is then connected with the norm. Norms are elements that supply the information of how long does the process take to complete. Each norm is defined in a measurable and objective unit rounded down to its basic unit. Norms are written in nominal (basic) value. Norms also have additions that correct the norm basic value. This is the case when a norm that is specified can't be achieved because of objective conditions or perhaps can be corrected because of tools that are used during the construction process. Those additions can also have negative values thus making norms nominal values lower.

Process technology elements and norms are then connected to resources. Resources are elements that are then further divided to machinery, tools, materials, transportation and human resources. Each resource has a norm which specifies its limitation and acceptable time to complete a task. The process technology that is connected to the resource specifies how an activity has to be carried out. This means, that the process technology also connects various resources together. Although the human resources are stated separately, they are connected to each resource.

3.2 *PIM realization*

All PIM elements are stored in relational database. The process technology and resources are stored in separate tables and are connected with each other based on relations. Each process technology has connections to tables of various resources and also carries an index of predecessor element. Norms are connected to each of resources and also to process technology. This is useful because the construction company can assign a process to subcontractor and get just the time estimate for its planning purposes.

The process of creating PIM is different for each construction company. The first step is to define activities that are usually carried out by employees of a company. Next step is to identify how do this activities fit into construction process technologies and based on this the construction company has to fill in the records to table of processes. When the table of process technologies is set up, the construction company has to define norms for each process. This means that it has to set up the criteria of duration of the process (how long), what resources are necessary for the process (how many) and how is the process carried out (how), as it is shown in Figure 1. Evaluating this step, in the next step company has to define all the resources necessary to successfully carry out process. With this procedure, the necessary resources are also entered into a relational dataset. When the resources table is filled, the company must also define norms for each resource. Norms can vary from company to company, since only a company knows what kind of machinery, human resources and tools it uses.

The one last thing the company has to fill, is the table which connects process technology to elements of the BIM model, especially 3D geometry model. This table is known as ontology table. Based on the ontology, PIM elements are connected to BIM elements. This means that company has to create PIM only once and then reuse it with any BIM in the future. PIM model can also be connected to the company's information system. In this case, the resources tables are cross-linked, allowing planner to get recent information of the resources available from ERP system of the company.

In other words, PIM model is static and is construction company dependent, while BIM is construction company independent. This means that only relevant information that are vital for construction process stakeholders and lifecycle of a building are shared through BIM. Other company dependent information is safely stored in PIM model.

Process of exchanging information from BIM to PIM and vice versa is through the use of Industry Foundation Classes (IFC). Based on IFC elements that are included in BIM, the ontology table and connections to PIM process technologies are created. The connection to company's information sys-

tem can be either through the use of IFC or through other plug-ins that modern ERP systems provide.

3.3 *Scheduling process according to PIM*

In the constructions companies where PIM is realized, construction planner uses PIM as scheduling method. First step he has to do is to import BIM into PIM. In this step the 3D model geometry is transferred to PIM temporary database. PIM evaluates 3D model and extracts the process technology. If a technology is unknown, it notifies the planner. The planner must then supply all the necessary information according to procedures that were described in chapter 3.2. When all conflicts are resolved, the process may continue.

The planner starts the process of scheduling in PIM model. This pulls the information about resources needed to construct the process, according to process technology which is now stored in PIM database. When automated scheduling is finished, the planner gets a view of the construction sequence and activities. Each activity has resources attached to it. Since all the resources are also connected to norms, the timeline of the activities is properly defined and expressed in basic duration (normative duration).

Next step for the planner is to connect the PIM model with ERP system of the company. When the information from ERP is pulled and included in PIM, the planner can see resource assignments by name of the resource. In case the specific resource if assigned to multiple activities in the same period of time, the planner is notified.

After reviewing the construction schedule, planner can reassign resources to different activities, or also change the purposed construction process. He can also change the duration of the activities in a way, that he assigns more resources to specific activity. Since the CPM scheduling method is used, the planner can immediately see which activities need more attention. When construction planner has finished fine tuning the schedule, he has the option to save schedule back to BIM and the option to save the resource assignments back to ERP system of the company.

When all the information is saved back to BIM, other construction actors can see the schedule and resources for specific construction activity. Based on BIM lens and level of detail the planner saved to BIM, other construction actors can see different information that concern them.

The information about resource assignments is also saved back to ERP as well. In this scenario, the company management and project leader can immediately see what kind of resources are available within the company and what resources have to be outsourced.

4 CONCLUSION

We have shown the possibility to create a new construction planning method which we call PIM. With the suggested method we are able to shorten the scheduling process, make it comparable from project to project and allow user to gain time and effort which is reflected in profit margin of the company. This is done through the standardization of activities and use of norms. We use IFC to push and pull information from BIM model and ERP system of the construction company.

In purposed method the construction planner doesn't link activities to 3D elements by hand, instead he links the process technology from BIM to PIM process technology or just defines process technology for 3D geometry element. A lot of linking is done automatically through the use of ontology, so the planner has to manually link only the process technology that the specific construction company hasn't done yet. Since processes are reused from PIM, the construction schedules are comparable from project to project and can also serve as a knowledge base for the construction company.

The PIM model is also connected to construction company information system (ERP) which enables the managers and project leaders to immediately see the assignment of the resources to various projects and also the resource requirements. Consequently the cost estimate can be drawn from the ERP system in there are cost for specific resources defined. In this case the company's management can take appropriate action in time, which results in profit gain of the construction company.

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