BIM-based Takt-Time Planning and Takt Control: Requirements for Digital Construction Process Management

J. Melzner[a]

[a]W. Markgraf GmbH & Co KG, Germany
E-mail: juergen.melzner@gmx.de

Abstract –

Continuous and robust process planning is contrary to the different goals of project participants in the construction business. The aim of holistic building process management must be to optimize the overall process by streamlining individual processes. Lean management methods are increasingly being used to harmonize building processes. For this purpose, especially the method of takt time planning and takt control is appropriate. Building information modeling (BIM) is another promising way to promote a collaborative planning and construction process. BIM is generally understood as a virtual 3D model of a project with additional information. In order to be able to use the synergies of the two methods, the requirements, framework conditions, and goals of the two methods must be coordinated so that the added value of information for process planning can be used. The parallel application of lean construction methods and BIM can create added value that leads to productivity gains. In established BIM applications, the product (e.g., building) is planned as optimally as possible. However, the production process is not sufficiently considered. This is where lean construction methods are used to optimize the process. This article describes synergies through the combination of both methods and defines the requirements for a new BIM use case, "takt time planning and takt control." The presented concept is prototypically tested on a hotel tower project and the benefits and requirements are discussed.

Keywords –

Lean Construction; Process planning; Construction Management; Building Information Modeling

1 Introduction

A paper of the ISARC 1993 starts with the paragraph "The chronic problems of construction are well-known: low productivity, poor safety, inferior working conditions, and insufficient quality" [1]. Although this statement from more than 25 years ago could describe many of today's construction projects, little seems to have changed since then. Low productivity is one of the biggest challenges facing the construction industry nowadays.

Many studies show that the productivity of the construction industry has not increased in recent years compared to that of other industries. While other manufacturing industries have increased their productivity by more than 20% in the last 20 years, productivity in the construction industry has increased by only about 4%. These considerations raise the question of whether other industries are better at realizing the opportunities of digitization than the construction industry.

The construction industry is facing a change. Digitization is pervading more and more sectors of the industry. The implementation of digitization projects requires a strong standardization for business processes as well as for products and components.

Building Information Modeling is seen as the driver of digitization in construction. All relevant information in a construction project will be mapped into a consistent data model. Thereby an improvement in the achievement of the project goals in the dimensions dates, costs and quality is to be achieved. However, the industry has not been able to increase productivity to nearly the same level as other manufacturing industries. With the aim of increasing productivity, lean management methods are increasingly being adapted in the construction industry. Lean Construction and Building Information Modelling, at first glance, are two independent methods whose evolution has been shaped by different perspectives.

This paper describes two methods currently most promising in construction management to increase productivity, occupational safety and quality. Lean Construction methods and BIM are internationally used methods in construction. However, the combination of both methods lacks framework conditions to enable a digital exchange of building data especially for the takt-time planning application. Therefore, the minimum requirements will defined in the paper.

2 Problem Description and Objective

Ineffective processes not only lead to a loss of time, but also to wastage of various resources. Not fully used or misdirected resources lead to rising costs during operation, indicating flawed planning and reduced values. Studies in the United States, Great Britain and Scandinavia have shown that wastage in the building construction process is very high:

- 30% of the construction work must be repeated to produce appropriate quality,
- 10% of material assets get lost due to wastage and disorder, and
- only 40–60% of the performance is efficiently used in construction activities [2].

The complex process of construction project planning depends on many parameters and the quality of construction schedules is highly related to the engineers´ knowledge. The initial schedule includes, in most cases, only the basic information about the planned construction. The pieces of basic information are the approximate start and end dates of the different trades. Detailed schedules with linked activities to represent the dependencies between activities are in most cases missing [3].

Software applications relieve users from routine tasks. However, the shortcomings of present software tools, which are currently used for construction process management, include the separate generation of the building information model and the construction process model.

The successful implementation of projects requires a structured and effective communication between all stakeholders. The increasing development of BIM tools has to be evaluated concerning their situational suitability of information exchange in construction projects. Construction projects are generally characterized by a large number of stakeholders such as construction companies, architects, planners, and representatives of regulatory bodies.

In order to gather the relevant information in a BIM process, information pertaining to who, when, how, and which has to be identified and provided. The buildingSMART propagated a method to define such exchange requirements is the Information Delivery Manual (IDM) (ISO 29481). The objectives of IDM are meant to standardize the information needed for specific-use cases in the BIM process. This manual defines the requirements for data exchange for all participants, including software providers.

An IDM targets both BIM users and solution providers and consists of three main parts- process map, exchange requirements, and functional parts. The process map describes the flow of activities for a specific process e.g., cost estimation. It improves the understanding of configuration of activities, the involved actors, the required information, and the consumed and produced information (Figure 1).

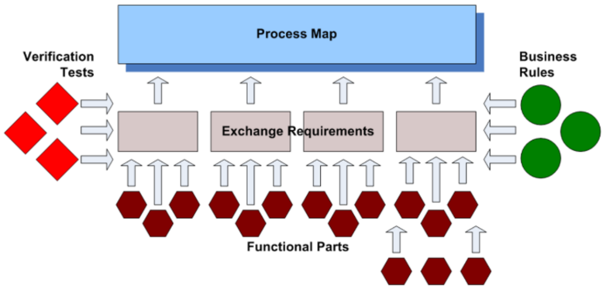

Figure 1. BIM-based lean construction production model [4]

The exchange requirements are a set of information that needs to be exchanged to support a specific business requirement at a particular stage of a project. An exchange requirement represents the connection between process and data. It applies the relevant information defined within an information model to fulfil the requirements of an information exchange. Finally, the functional parts are units of information used by solution providers to support an exchange requirement [4].

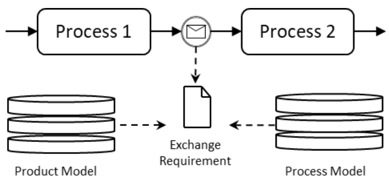

Figure 2. Scheme of Exchange Requirements

This paper describes the requirement of the BIM process to facilitate takt-time planning for a building information model.

3 Background

3.1 Building Information Modeling

The core of BIM-based project management is an integral digital building data model. The aim of the Building Information Model is to combine complex and heterogeneous data from the project participants into a consistent database. The flow of data between project participants and project phases is best handled digitally in a Common Data Environment (CDE). The current projects are largely concerned with the digital product model and less with the processes surrounding a construction project, even if the BIM vision focuses on process-related project execution.

Digitalization in the construction industry and the application of modern information technologies offer a great potential to improve construction safety and health in the planning phases. According to Eastman et al. [5], “BIM is one of the most promising developments in architecture, engineering, and construction (AEC) industries. With the BIM technology, an accurate virtual model of a building can be digitally constructed.” The BIM-based risk management, clash detection, cost estimation, and 4D simulation have now become established features to support construction project management [6]. It supports the design through all its phases until the project is completed, and also allows better analysis and control than existing manual processes [7].

Building Information Modeling (BIM) represents a promising development in the architecture, engineering and construction industries. With this method, accurate building models can be digitally displayed. It supports the design through all its phases till the project is completed and allows better analysis and control than existing manual processes.

3D-model-based clash detection, risk management, cost estimation and 4D animation have become established methods to make construction management more efficient [8]. The use of BIM for construction project planning offers many other advantages [9].

3.2 Lean Construction Management

A production system is based on fundamental principles, standards, methods, and tools. It describes the standardized way of working and organizing companies according to lean principles. The goal of Lean Management in the construction industry is to avoid waste, to focus on the customer, and to increase the added value of its product. So far, the application scenarios used in the construction industry have focused predominantly on analogous processes for planning and controlling construction [10]. The inherent focus of Lean Construction's production system is on the process level, system control, and process-based organizational design.

It is clear from these statements that the two methods have different modes of operation. The Building Information Model represents the product and the Lean Construction Method describes the process

Building Information Modeling (BIM) and Lean Construction are two different methods of improving the construction process originally developed by different stakeholders with different goals. Over the past decade, both methods have begun to spread fast in practice.

Recently, however, it has come to be realized that these two methods have considerable synergy and that it is advantageous to implement them together. In view of this, there is an increasing need to sensitize BIM users to Lean principles and methods as well as Lean users to the BIM project workflows.

3.3 Synergies

A combination of the BIM and Lean methods can generate synergies if the two methods are harmonized. On closer inspection, it can be seen that the two methods are complementary in many target images, but the approaches and modes of action are different. A detailed study examining BIM applications and lean processes was conducted by Sacks et al. a. and showed 56 interactions of both methods [11]. In order to realize the synergies of the two methods, concrete intersections have to be identified.

4 Methodology

This research contributes to the improvement of construction process planning by using the information of a Building Information Model to develop a takt-time plan according to lean construction principles.

In this research, two main data sources are needed for construction process planning. Information about the building including all objects and quantities will be delivered via a Building Information Model (BIM). Second, information about the processes is needed. The process information will be derived from the process model database. The major parts of the proposed framework are shown in Figure 3.

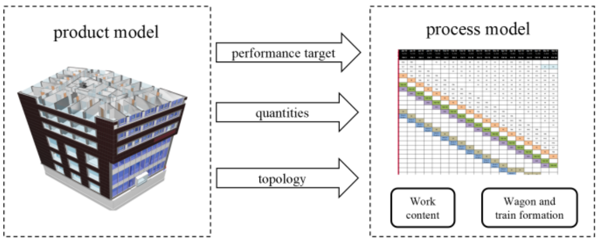

Figure 3. BIM-based lean construction production model

Decision-making in construction management is commonly based on empirical knowledge, because it is not easy to evaluate different execution strategies by using traditional scheduling methods. Although the number of possible solutions is limited by numerous constraints, the remaining possible execution strategies are almost unlimited. However, they are influenced in terms of production technique and production costs due to different constraints [12].

The objective of this approach is to integrate basic and methodical knowledge of construction management into the model. In order to achieve this objective, four steps need to be defined:

1. Capture the relevant requirement from users point of view,
2. Describe this requirement within a model,
3. Develop abstract solutions by using empirical knowledge and
4. Implement the solutions by adapting them for a specific project.

Building components are represented in an object-oriented context in this work. Accordingly, objects belong to a class with their individual properties. Furthermore, building information models contain geometric data about the material, location, weight and other properties. The building structure is hierarchical. The building is structured in floors, groups of objects (e.g., walls, slabs) and individual objects. Objects must be uniquely identifiable.

5 Use case: Takt-time planning

5.1 BIM-Lean Integration

How can the two methods, Lean Construction and BIM, be combined on a practical level? Lean Construction is operationalized through application-oriented methods. An essential method in construction is the takt-time planning aimed at reducing the size of batches to simplify the control of construction processes. The way to a Lean Construction takt-time planning can be sustainably supported by the consistent and reliable information provided by BIM-based project handling.

The basis of the timing of the construction process is a precise reflection of the performance target. The performance target is guaranteed in the BIM project by a model-based calculation of the construction work. The content of the model-based calculation is the spatially separated quantities and service items and their combination with effort and performance values. Further calculation bases from the product model are - for example, the building topology to derive a zoning for the building. These data can be incorporated directly into the takt-time planning from basic quantities or used as a control entity for plausibility calculations. The link between the production processes and the objects of the building information model enables the simulation of execution strategies and their return to a harmonized production schedule.

5.2 Product Model

The input data for the generation of the schedule are project-specific data generated from the building information model. This model provides the building with specific input data e.g., building objects, hierarchical order, and quantities.

Building components are represented in an object-oriented context in this work. Accordingly, objects belong to a class with their respective properties. Building information models contain the geometric data about the material, location, weight, and other properties. The building structure is hierarchical. The building is structured in floors, groups of objects (e.g., walls, slabs, rooms) and individual objects. Objects must be uniquely identifiable (Figure 4). In the model-based cost calculation phase, every single object will be calculated.

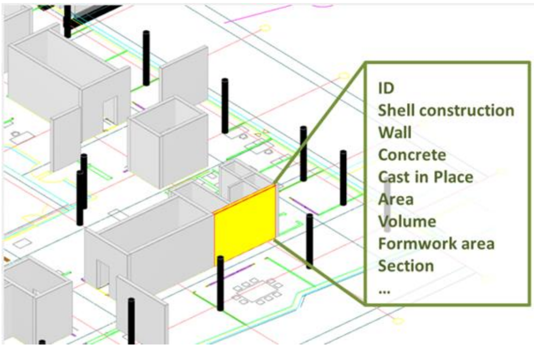

Figure 4. Definition of the building structure

In the cost calculation process, the individual costs of the part services are already determined for every single object. This includes, for example, the costs of wages, materials, and equipment. In the following, this object-oriented cost calculation allows these component and room-specific values to be used as a basis for process planning.

The described preparation process from modelling the building and determining the component-specific costs provides the information needed in the following multi-level process planning.

5.3 Takt-time planning process

Takt-time planning is one of the most used methods in the Lean Construction context. The German word "Takt" means "beat". In this context, it means the processes on the site follow a standardized takt developed in the following eight steps (Figure 5).

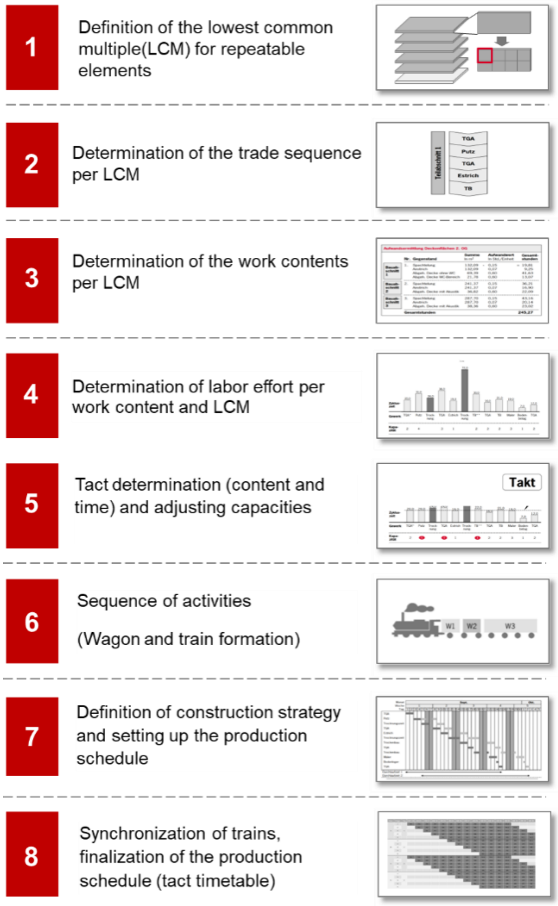

Figure 5.Takt-time planning workflow

In order to determine the exchange requirements with regard to process planning, the eight steps must be examined with regard to the following criteria:

- **Who** is requesting?
- **Why** is this information important to exchange?
- **When** is the information needed?
- **What** information supports the request?
- **To Whom**? Actor that fulfills the information need.

In the first step of the workflow is the analysis of the lowest common multiple (LCM) (Figure 6). Projects with a high repetition factor on similar construction stages are well-suited for takt-time planning. In this case, all services of internal works for a LMC have to be calculated at once and multiplied by the repetition factor.

With the traditional method of process planning, steps 1–4 involve considerable effort. All information must be gathered together from different documents e.g., tender specifications, and expert reports (Figure7).

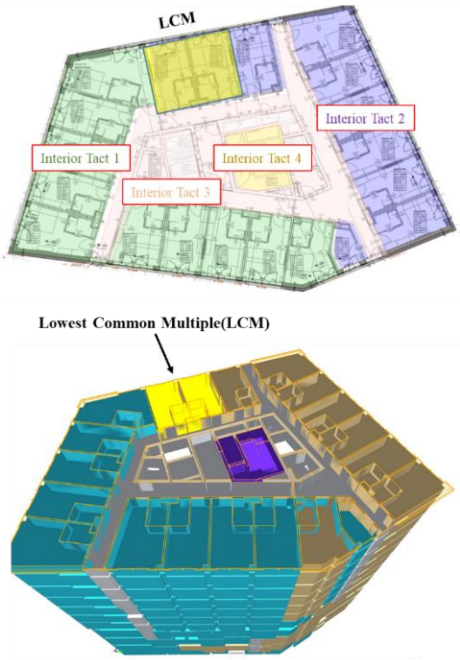

Figure 6.Visualization of interior takt areas on a 2D-plan (on the top) and BIM-Model (below) with the lowest common multiple.

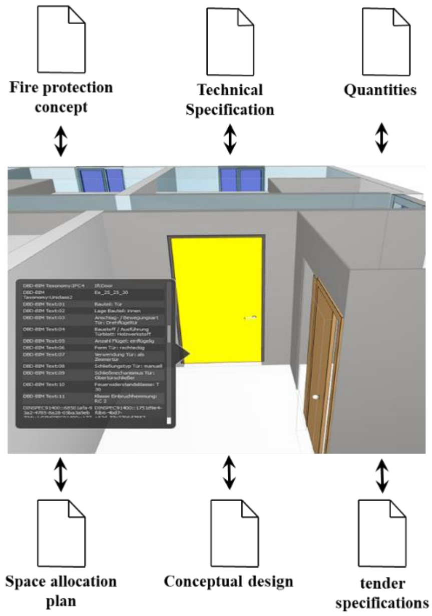

Figure7. Sources of information for building specifications

In BIM-based process planning, the information for steps 1–4 is generated directly from the BIM-model. However, the questions raised before must be addressed.

Who is requesting? <<Process planner>> According to a uniform classification system such as OmniClass.

Why? Process planning according to Lean Construction methods requires detailed information on the performance and structure of the building.

When? The information is transferred after the technical description of the elements before the work preparation.

What information? A set of attributes are the minimum requirement for the process (Table 1).

Table 1. Minimum requirement for process attributes for rooms

Attributes	Attributes
ID	Ceiling surfaces
Component type	Floor area
Classification	Floor
Room number	Construction phase
Length, Width, Height	Takt number
Ceiling height	Process code
Structural height	Costing code
Wall surfaces	

To Whom? <<Architect>> According to a uniform classifications system such as OmniClass.

In step 5, the previously calculated workload must be adjusted to the set takt time (e.g., one week). This happens through the variation of different parameters. This includes the shifting of services within the interior work train, adjusting the number of employees (Figure 8).

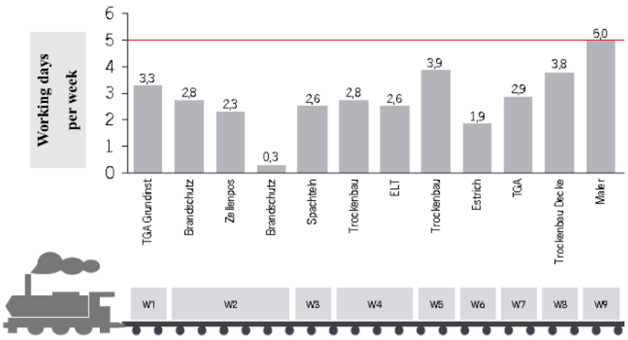

Figure 8. Takt adjustment

Work packages can be grouped together in one wagon if there is a no collision. Such a grouping can be seen in the picture 8 wagon "W2". There, three trades together become a wagon because with simultaneous execution no mutual influence is to be expected.

The first resulting Step 6 is a train of trades to complete the work. Now you can change the construction process by changing the construction strategy. For example, the number of trains and the direction of the construction work flow can be varied. In the proposed framework, the effects can be analysed directly on a 4D model. Figure 9 shows a 4D-takt-time sequence of shell construction work. The wagons “W1”- concrete walls - and "SL1"- concrete slabs - alternate floor by floor between the construction sections. Through this sequencing of work, an optimal use of resources is ensured.

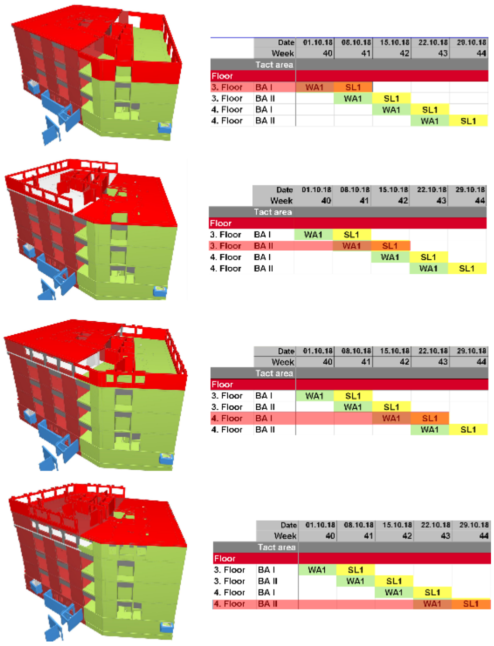

Figure 9. 4D-takt time sequence

6 Results

The following investigations are presented using the example of a real construction project. An object-oriented 3D building information model of a 17-story hotel building was selected for the case study. The hotel building has 220 guest rooms. The 3D model represents all the structural elements of the concrete shell structure such as foundations, beams, walls, columns, and slabs. Furthermore, the model includes all rooms with their specific attributes to determine the interior work processes. The building model contains approximately 55000 objects (Figure 10). The objective of this study was to determine the practical benefits and limitations of the developed system.

The benefit for a process planner is the developed querying function that automatically determines the quantities and labour hours from the model and calculates the duration for each of the planned activities. The developed semi-automated takt-time planning approach has been found to assist the workflow and quality during construction process planning. However, there are some current limitations and challenges. The framework requires a comprehensive knowledge of the construction processes and its subsequent activities. The gathering of all the necessary input information is a crucial point when generating quality results. While activities related to concreting work were investigated, further investigations have to be done in developing process templates for the major construction works. In order to make use of the full potential of the method, the IDM with all elements must be described in further work.

Figure 10. BIM-Model for evaluations

7 Conclusions

BIM and Lean Construction are promising methods to improve construction processes. Until now, these methods used to be developed and applied separately. Linking the methods may create currently undiscovered benefits. However, finding an effective way to join both methods is difficult. First, this work has determined the minimum information requirements for process-oriented project planning using BIM.

It initially demonstrates the application of an Information Delivery Manual (IDM), specially the exchange requirements to determine the standard attributes that are necessary for takt-time planning.

By using digital building information models, construction processes can be planned in detail. Both the planning and the execution processes are, thus, holistically considered and coordinated. The next development steps are the further expansion of the method for more Lean methods and the integration of the takt control in the framework. Thus, the planned processes with actual site data are evaluated.

References

[1] Koskela L. Lean Production in Construction. *Proceedings of the 10th ISARC*, pages 47-54, Houston, USA, 1993.

[2] Egan J. *Rethinking Construction*, London, 1998.

[3] Hollermnann S. *An object-oriented approach to knowledge-based project planning*. Bauhaus-Universität Weimar, Ph.D. thesis, 2016.

[4] BuildingSMART International User Group http://iug.buildingsmart.org, Accessed: 28/01/2019.

[5] Eastman C., Teicholz P., Sacks R., and Liston K. *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors*, volume 2. John Wiley & Sons, 2011.

[6] Hartmann T., van Meerveld H., Vossebeld N. and Adriaanse A. Aligning building information model tools and construction management methods, *Automation in Construction*, vol. 22, pages 605–613, 2012.

[7] Melzner J., Teizer J., Zhang S. and Bargstädt H.-J. Objektorientierte sicherheitstechnische Planung von Hochbauprojekten mit Hilfe von Bauwerksinformationsmodellen“, Bauingenieur, Vol. 11, pages 471-479, 2013.

[8] Hardin B. *BIM and Construction Management: Proven Tools, Methods, and Workflows, Wiley, Indianapolis*, 2009.

[9] Hartmann T., Gao J. and Fischer M. Areas of Application for 3D and 4D Models on Construction Projects. *Journal of Construction Engineering and Management*, 134 (10), pages 776–785, 2008.

[10] Sitzberger R., Ditandy J. and Wolf R. End-to-End Projektmanagement: Mehr Transparenz und Stabilität in Bauprojekten. *Jahresausgabe Bauingenieur*, pages127-129, 2018/19.

[11] Sacks R., Koskela L., Dave B. A. and Owenet R. Interaction of lean and building information modeling in construction. Journal of Construction Engineering and Management, 136(9), pages 968-980, 2010.

[12] Melzner J., Hollermann S., Elmahdi A., Le Ha Hong, and Bargstädt H.-J. Pattern-Based Process Modeling for Construction Management. *Proceedings of the 14th International Conference on Computing in Civil and Building Engineering (14th ICCCBE)*, Moscow State University of Civil Engineering, 2012.