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LEAN SIMULATION GAME WITH BIM-BASED PROGRESS MONITORING FOR TAKT CONTROL

Sharina Alves[1], Jürgen Melzner[2], Sebastian Hollermann[3]

ABSTRACT

Lean Construction (LC) and Building Information Modeling (BIM) are two approaches that help to optimize, structure, monitor and control processes better. As a method of LC, Takt Time Planning (TTP) and Takt Control (TC) can lead to an increase in productivity and value creation, as the associated processes are an essential part of the value chain in the construction industry. But while there are already some solutions to link these methods in real life, simulation games in education are currently mostly done analogously and detached from the BIM model. As a result, the benefits of BIM in terms of regularly updated building data are not fully exploited within the simulation game and thus not made clear to the participants.

This paper examines how digital support for TC can be integrated within a LC simulation game. For this purpose, an analogue building model is linked to an associated 3D building model through QR codes and enriched with information about the stage of completion during the process of TC. The possibility of linking both models shown here manages to highlight the advantages of the BIM method and inspires the participants to apply this to their projects.

KEYWORDS

Serious gaming, Lean Construction, Takt Time Planning (TTP), Building Information Modeling (BIM), phase scheduling.

INTRODUCTION

BIM and LC can be considered state of the art in construction project planning and control, as they are promising methods to improve the whole construction process. Both methods pursue the same goals, except that BIM focuses on the product and LC on the process. Therefore, it makes perfect sense to aim for a combination of both (Melzner, 2019). Gradually, the continuous monitoring of performed data on the construction site to support planning is playing an ever-increasing role. It creates up-to-date information that forms the basis for checks on the progress of the project and for generating analysis and forecasts, so that informed decisions can be made on this basis (Jacobsen et al., 2021).

[1] Research Associate, Civil Engineering Department, Jade University of Applied Sciences Oldenburg, Germany, sharina.alves@jade-hs.de, orcid.org/0000-0001-5091-7990
[2] Professor, Civil Engineering Department, Bauhaus University Weimar, Germany, juergen.melzner@uni-weimar.de, orcid.org/0000-0002-6435-0283
[3] Professor, Civil Engineering Department, Jade University of Applied Sciences Oldenburg, Germany, sebastian.hollermann@jade-hs.de, orcid.org/0000-0002-6592-5245

Still, there needs to be a tightening of Lean and BIM Methods in relation to supplying actual data via tracking technology (Heyl & Teizer, 2017).

The situation in practice is also reflected in the simulation games on LC. While LC teaching usually focuses solely on teaching lean principles, digital issues often receive little attention. But a simulation game offers an optimal playground for testing ideas on a small scale. This paper presents an analogue simulation game concerning TTP and TC and shows employing a case study one way in which LC and BIM can be linked through QR codes. The aim is to see how feasible the link between LC and BIM presented here is and whether it adds value to the simulation.

STATE OF THE ART

TAKT TIME PLANNING

At present, digital models are often inadequate in practice and links with processes and resources are not fully digitally recorded. In addition, information on the determination of the Takt of manufacturing processes is often recorded in separate document-based systems (Frandson, 2019; Haghsheno et al., 2016; Yassine et al., 2014). The complex relationships between the BIM model and the TTP are therefore not digitally recorded (Leifgen, 2019).

TTP is currently carried out on this information basis in a predominantly manual way with standard software such as spreadsheet calculation software (Haghsheno et al., 2016). Lean software solutions are also used in some cases, for example VisiLean as an integrated Lean and BIM solution (Dave et al., 2011). But most of the time they are limited to the process level only and do not link to building models or other information domains, like for example BIM 360 (Autodesk, 2022) or vPlanner (Ghafari Associates, 2022).

TTP is a complex optimisation task with several target variables. The aim is to create a plan that makes it possible to build the building in the desired quality in the shortest possible time with an optimal use of resources and at the lowest possible cost. For the current approach several iterations with different variants usually have to be calculated before a decision for a plan is made (Leifgen, 2019; Schmidt & Teizer, 2020; Frandson et al., 2015).

Through a link with the BIM model, at least parts of the TTP could be automated, such as the determination of the Takt areas. Based on this, the always up-to-date planning status can make it possible to carry out regular plausibility checks and prevent implausible planning at an early stage (Schmidt & Teizer, 2020; Sommer, 2016).

TAKT CONTROL

In the execution phase, permanent monitoring and control of the construction processes takes place within the framework of TC. The basis for this is the constant monitoring, processing, availability and visualisation of information about the current status of the construction site (Haghsheno et al., 2016). As a central control tool, Takt Control Boards (TCB) are used for each Takt section in a construction project that is planned according to the Takt principle. Takt, floor plans, construction time schedules, etc. are displayed on them (Haghsheno et al., 2016; Sommer, 2016).

When working with analogue TCB, newly acquired information is initially only recorded daily and locally on the construction site (Binninger et al., 2017). In order to

transfer this information into a digital system, such as digital construction models, digital schedules or digital construction diaries, it must be digitalised afterwards (Leifgen, 2019).

In addition, a major challenge is the spatial separation of the monitoring of data and its users. The collection of data gained through the TCB would theoretically enable detailed reporting. However, construction companies are often involved in several widely distributed construction projects. It is therefore not sufficient to present information on the progress of the construction site exclusively in analogue form on site (Benninger & Wolfbeiß, 2018).

LEAN CONSTRUCTION SIMULATION GAME

Experience has shown that purely theoretical training is not as effective as training that combines theory and practice. The reason for this is that theoretical knowledge learned in simulation games can be actively tested directly and is thus not only better remembered, but also allows the advantages of the methods learned to be recognized directly in a playful manner (Binninger et al., 2017). In this way, the transfer of lean principles to the construction industry can be made clear and engrained patterns of thought can be broken.

In the field of TTP and TC, various games have already been developed by consultancies or in-house (Teizer et al., 2020). One of these games is the hotel model presented here, which was created according to VDI guideline 2553 for specialists and managers as well as process managers from construction-related sectors such as building owners, architects, project developers, engineering offices, construction companies or construction suppliers. Figure 1 shows the model as a whole and Figure 2 shows the drywall components as an example.

Figure 1 and 2: LC game hotel model (figure by authors)

The aim of training with this model is to teach the basics of TTP and TC. An understanding of the Lean values is conveyed by the participants themselves experiencing what is value creation and what is waste. In addition, soft skills such as team building, appreciation of the customer, communication, and cooperation are also taught (Binninger et al., 2017).

So far, there has been no connection to a digital model. In the modern world, it is generally no longer sufficient to do the monitoring of the manufacturing process in analogue alone. Large construction sites are often so complex that several TCBs are needed simultaneously for different areas. In addition, a construction manager, like the subcontractors, often oversees several construction sites at the same time (Dlouhy et al., 2016). Only a digital solution about the current production status can provide the necessary overview and at the same time also support the formation of key figures, which in turn are the basis for decision-making for the further planning of the construction site (Sommer, 2016). Therefore, it is important to map the interaction of digital and analogue in the simulation as well.

PROCEDURE OF THE LEAN CONSTRUCTION SIMULATION GAME

The simulation game presented here has already been established in LC workshops. However, there are no publications on it yet. Accordingly, the process of the game is presented here in detail.

The entire game is divided into three stages, in which the participants try anew each time to finish the hotel. At the end of each stage, the participants themselves reflect on the points in the construction process where they see an opportunity for improvement. Through reflection and theoretical knowledge imparted between the stages, the participants acquire more knowledge bit by bit, which they apply directly in the respective game stages. This simulation game is accordingly orientated toward the five levels of reality like it is described in Binninger et al. (2017).

At the beginning of the game, each participant is assigned a different role: There is a client, a construction manager, a building inspector, and the trade partners needed for the construction of the hotel. The hotel commissioned by the client must be finished according to a specified schedule within 22 minutes, where one day corresponds to one minute. For this, the participants receive components, some of which still have to be manufactured. The execution of some trades depends on the decisions of the client, which he only makes during the course of the game.

FIRST STAGE - WITHOUT LEAN APPROACH

In the first stage, the participants start with the construction of the hotel according to the schedule. Yet, they have not received any introduction to TTP and TC. This inevitably leads to a very unstructured, uncommunicative and inefficient way of building. Typically, the participants therefore barely finish even one of the specified rooms.

In the debriefing of the first stage, the participants note that there were no clear agreements between the trades, which led to a lack of clear structures for who works on which room and when. As a result of this inefficient way of working, there is a lot of time pressure at the end of the construction stage, which in turn leads to poor quality.

SECOND STAGE - TAKT TIME PLANNING

In the second step, the participants are taught the eight steps of TTP similar to how it is described in Binninger et al. (2017) and Frandson et al. (2013). This leads the participants to finding the Standard Space Unit (SSU), in this case two hotel rooms, and defining work packages for every SSU in the right sequence. Next, they allocate detailed work steps to every package and calculate the amount of work for every step. They then agree to a Takt time, which in the game is one minute, and perform Takt levelling. Following this, the

trade groups are staffed according to the results of the Takt levelling and a construction strategy plus the Takt schedule are determined. Each trade is given a Takt schedule as shown in Figure 3, on which it can view its operating times. In addition, the trades that are dependent on the client's decisions receive a sheet as shown in Figure 4 on which the client must have entered decisions by certain dates.

Figure 3 and 4: Takt plan of a trade and sanitary objects with client decision sheet (figure by authors)

In the debriefing of the second stage, the participants note that the construction phase went much better than before. This time, some rooms have already been completed, even if the entire hotel was not finished in the allotted time. Despite the strong improvement, the participants should look for further opportunities for improvement, true to the Lean approach. The lack of construction meetings between the Takts is usually mentioned, in order to determine whether the previous trade has actually been completed, or whether deficiencies need to be remedied so that other trades can continue to work.

THIRD STAGE - TAKT CONTROL

In the last stage, the participants are taught TC so that they now conduct regular (minutely) meetings on-site. These meetings are moderated by the construction manager and managed through a standardized TCB. That leads to another improvement of the building process as the persons responsible for execution are integrated in problem-solving processes.

The third stage of the simulation game is also carried out in an analogue way alone. In the course of the Continuous Improvement Process, it should be questioned to what extent a link with the digital model can lead to an increase in customer value.

IMPLEMENTATION OF THE DIGITAL MONITORING

The simulation game has already been played with hundreds of participants within two-day LC workshops. From these previous workshops, the question about the digitisation of the TTP and TC came up repeatedly in the feedback forms and discussions. This makes it clear that there is a need for a digital link from the participants' point of view. The aim is to teach TC in conjunction with BIM during the simulation game and highlight the principle of this link and the benefits this brings to the construction site, although this might not directly add value to the simulation.

To create a link between the analogue model and the BIM model, the rooms in the BIM model are equipped with additional attributes. On the one hand, they receive an attribute about the Takt to which they are assigned. Secondly, they receive attributes for

each trade wagon that passes through the Takt area. These attributes are assigned logical values that indicate whether the trade has already been completed or not.

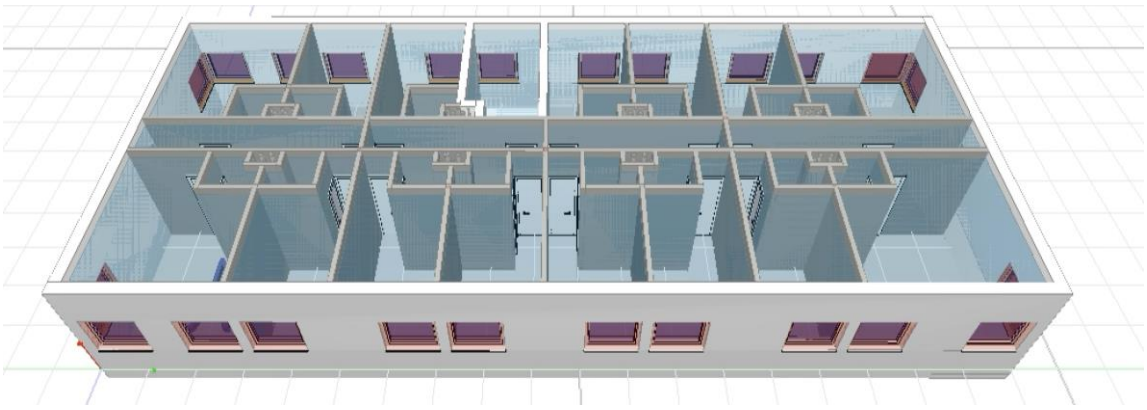

Figure 5: BIM hotel model (figure by authors)

In order for the trade teams to be able to easily indicate whether their trade has been completed, each Takt and each trade receives a QR code. Accordingly, the schedule that each trade receives for its trade at the beginning of the third stage is equipped with QR codes for each Takt area.

The possibility of tracking each component is waived here, as only the completion of trades and not of individual components is considered here for a start. Of course, in addition to the QR code technology, there is also the possibility of creating a link to the digital model via NFC (Li et al., 2018), RFID (Majrouhi Sardroud, 2012) or similar.

Each time the trade has completed a Takt area, it scans the QR code with its smartphone (see Figure 6). This takes the participants directly to a form where they can enter the completion. The information about the completion of the trade for the scanned Takt area is thus transferred directly to the BIM model as the form is linked to the rooms of the scanned Takt as well as the attribute of that specific trade.

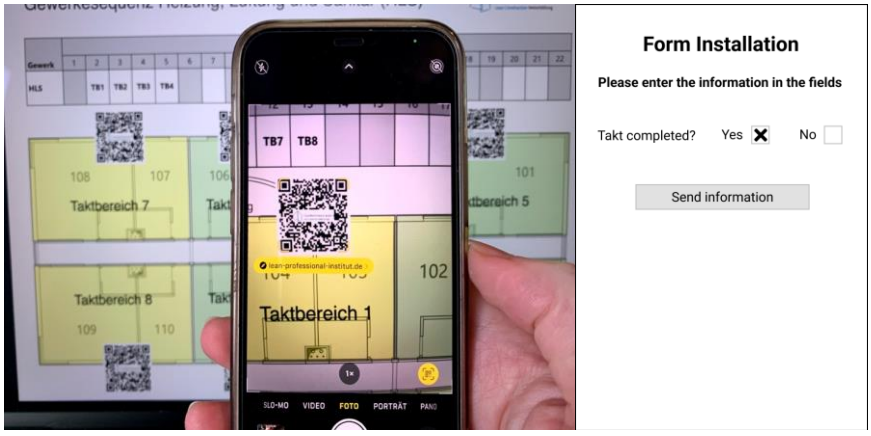

Figure 6: Scanning of QR code and installation form (figure by authors)

Information about the completion of the hotel model for each trade is accessible through the BIM model during the whole building process. Figure 7 shows the degree of completion using colour schemes in “desite md” (Ceapoint aec technologies GmbH, 2022), a software with which 3D building models can be visualised and analysed. In the middle there is the diagram of room 104, where you can find the attribute of the Takt and every trade attribute. The trade attributes indicate whether the respective trade in the room

has already been completed ("true") or is still to be completed ("false"). On the left side the Takt areas that have already been completed by the plumbing and heating I trade on Takt day 5 are shown in green. On the right site you can see the total stage of completion for every room.

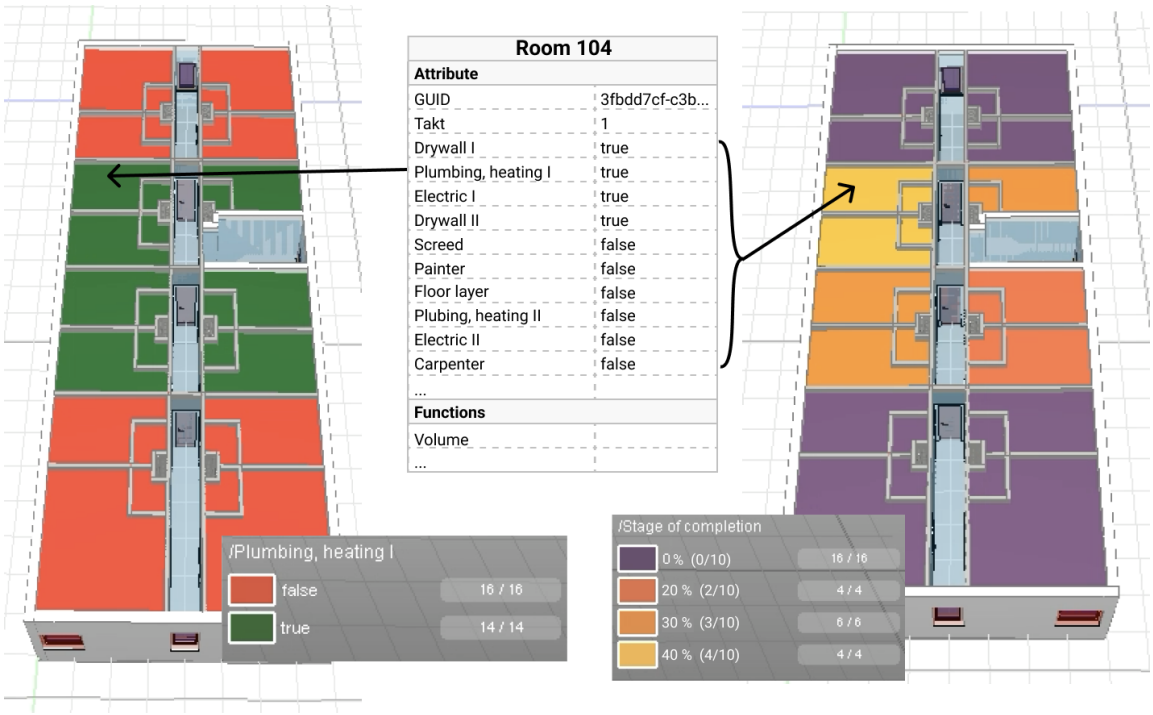

Figure 7: Colour scheme of the stage of completion for one trade and in total on Takt day 5 in “desite md” (figure by authors)

After each Takt day is over, the role of the construction manager can check in the BIM model for each trade whether the respective trade has done all its work. Checking which trade has completed which Takt area is made easier by the fact that it can be displayed visually in the 3D model (Schmidt & Teizer, 2020). Likewise, the owner can get a quick overview of which rooms have already been completed. The regular meetings are not replaced by the digital monitoring, but supported. A binding statement about the production status of each trade has then already been made in advance and the 3D model can be used as a basis for discussion in the meeting. The visual representation of the stage of completion in the digital model increases the quality of the meeting.

The installation form shown here is kept rudimentary, as it is only intended to convey completion in this context. Of course, there is also the possibility of transmitting further information via the form.

In theory, there is still potential to link further processes with the digital model. As mentioned at the beginning, it is also possible to track an individual component of the simulation game via QR codes or similar. This would make it possible to see via the BIM model which components have already been prefabricated and which of them are already on the construction site. The quality of the work carried out can also be noted directly in the digital model via a form and sent to the responsible trade (see schematic representation in Figure 8). However further discussion is beyond the scope of this paper.

Figure 8: Comparison of analogue and digital TC process (figure by authors)

RESULTS

The implementation of digital monitoring presented here was pretested with a group of 15 people and then discussed with participants as well as with a cross-section of teachers and practitioners of the construction industry. The outcome of the discussions was that the possibility of linking both models shown here manages to highlight the advantages of the BIM method for the participants. An information model that is always up-to-date and accessible from anywhere is the core of BIM, but brings added value to the TTP and TC as well. The participants realise that a visual representation of the Takt plan in the 3D model not only brings added value to the regular meetings, but also to the client, who can readily identify which parts of the building have already been completed. In addition, it has the potential to automate many processes such as the creation of key figures. If you think about larger construction sites, for which this training is ultimately designed, then it makes sense for these reasons to teach the participants directly one way on how to link the building with a BIM model. But the most important point is that this can help to inspire the participants to come up with their own implementation ideas for linking to a BIM model that fit their respective projects. The positive feedback leads to the fact that the developed teaching framework will be tested and improved on further participants of the LC workshops.

Figure 9 shows a comparison of the analogue model and the digital model with a colour scheme for the different Takt days during the third stage of the simulation, which provides a good visual overview of the production status of the individual rooms in the building.

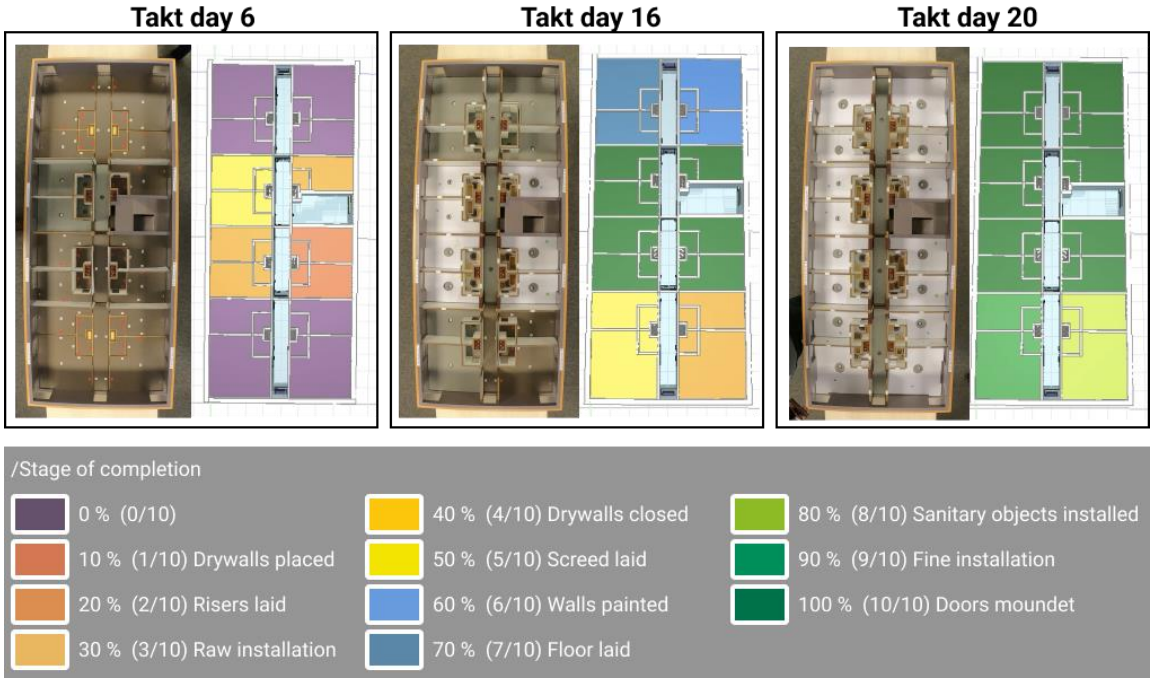

Figure 9: Comparison of the analogue model and the digital model of the third stage (figure by authors)

CONCLUSION AND OUTLOOK

In the modern world, it is generally no longer sufficient to do the monitoring of the manufacturing process in analogue alone because of the complexity of construction sites. Therefore, it is important to depict the interaction of LC and BIM in the simulation game. The possibility of linking both models shown here manages to highlight the advantages of the BIM method for the participants. An always up-to-date Takt plan that can be accessed from anywhere and its visual representation with the help of the BIM model not only add value to the TC in the simulation, but the concept can also inspire participants to apply this to their projects. The positive feedback of the pretest leads to the fact that the developed teaching framework will be tested and improved on further participants of the LC workshops.

As mentioned at the beginning, it is also possible to use the BIM model to improve the TTP, e.g. to automate the determination of the Takt areas. A workshop also offers suitable framework conditions for testing such concepts in a playful way. This approach could be explored in future work.

A schematic sketch was made of the further digitalisation potential of the simulation. Future work may find a way to incorporate these profitably into the simulation and further tighten the link between Lean and BIM.

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