
# Developing support for BIM-based takt time schedules for production control

# DEVELOPING SUPPORT FOR BIM-BASED TAKT TIME SCHEDULES FOR PRODUCTION CONTROL

***Mikael Viklund Tallgren & Mikael Johansson & Mattias Roupé***
*Chalmers University of Technology, Sweden*

***Efraim Ljung***
*Skanska Sweden*

***ABSTRACT:*** *Cost and schedule overruns are a major issue in the construction industry and a variety of location and activity-based planning, and control methods are used to address these issues. Takt time planning (TTP) has recently gained increased attention in Scandinavia through its use of fixed durations, use of location as a resource and demand on trade-completion and control before moving to the next location. The desire is to create a stable pace of work for each trade through a sequence of locations. There are also challenges to accomplish and communicate takt time schedules. However, through a 4D based collaborative planning approach, communication of the plan and a better understanding of the project and its challenges in production is reached. Thus, this paper aims to explore the possible direct connection between BIM, TTP and collaborative planning. The paper starts with a review of current research and practices and then follows with the three cases of application of takt time in BIM projects in production to identifying challenges in practice. From this the paper then compares and analyzes the cases and the three cases. The conclusion is that an integration of takt time and BIM through a collaborative planning system is viable, and that such a system would enable a direct connection between the TTP and the model.*

***KEYWORDS:*** *Takt time; Building information modeling (BIM); Production control; Collaboration; Location based scheduling.*

## 1. INTRODUCTION

Construction projects are often characterized as suffering from cost and schedule overruns (Doloi, 2013). Furthermore, a high fragmentation and specialization amongst contractors and subcontractors are argued to be potential reasons for these cost and schedule overruns (Nepal & Staub-French, 2016). The specialization and fragmentation have also resulted in projects that are more difficult to manage and where coordination of subcontractors become more and more important (Huurne & Scholtenhuis, 2018). Planning and production control has been deemed to have positive effects on the schedule and cost performance, and there have been an increased interest in different planning and control methods in research. Traditional scheduling methods has been criticized to focus on tasks and constraints rather than space occupation and location (Akinci et al., 1998). Location is something disciplines move through with their work rather than the set path products or production results moves along in a factory. Thus, location or space can be seen as a scarce commodity in construction and should be regarded as a constraint, where the capacity of the workplace is considered alongside the activity planned for that location (Ardila & Francis, 2020; Francis, 2019).

Location based planning and control has been popularized by Kenley and Seppänen (2010) and with the rise of Lean construction so has production flow as well (Ballard, 2000; Koskela, 1992). From Lean manufacturing the concept of takt time planning (TTP) has been brought to Lean construction with the aim to stabilize production flow. Takt time has been described as the heartbeat of production, the rate of customer demand, thus matching of the rate of consumption or request. Takt time in manufacturing has been used to set the pace of production to alert workers on when they are ahead or behind the plan (Liker, 2005). The earliest references to takt production in construction, or rather the pacemaker of production, is from the construction of the Empire State Building (Sacks & Partouche, 2010; Willis & Friedman, 1998). More recent reports of the use of takt time in construction is seen in Mullens (2002) for example, and later with Linnik et al. (2013), and the more systematic comparisons between location-based management systems (LBMS) and takt time in Seppänen (2014) and Frandson et al. (2015).

In Frandson et al. (2015), many similarities are stated and the few differences between the LBMS and Takt time are reviewed and found to be with the main buffers and how controlling of the schedule as well as how each of the approaches address resource allocation. A clear value with TTP is that if provides a well-defined daily goal for each activity, which makes more frequent or even daily cost control possible (Dallasega et al., 2021). One of the core concepts in Lean is the involvement of the workers, this is seen in Lean Construction in Last Planner for example or in TTP (A. Frandson & Tommelein, 2014). Furthermore Tommelein (2017) goes on to specify the general TTP process as consisting of five major steps, collecting schedule related data from the different dicsiplines,

defining zones & takt time, creating flow and balance the system, pull plan to reach team agreement and finetune the system, (see right part of Figure 1).

These steps are repeated throughout the takt zones until the full TTP is created. To summarize, the stated benefits of TTP are:

- Distributed ownership of the schedule through the collaborative creation,
- A creation of flow of production, workers progress through a fixed pattern due to takt time,
- Better predictability of the control through the fixed time frame due to the takt time,

However, in non-repetitive work, the rate of production can be hard to find, and thus focus on the work density and an iterative approach to the definition of takt zone is needed (Tommelein, 2017). Furthermore, Frandson et al. (2013), finds three challenging areas in the implementation of takt time. These are:

- Communicating the production clearly, making sure everyone is on the same page
- The higher level of detail needed of the production plan, need for change in mindset with participants
- A need for a good understanding with all participants of the building process of the project

This supports the more general findings stated by e.g., Dainty et al. (2006) and Gamil and Rahman (2017) regarding the importance of communication in construction and the creation of a common understanding of the project, and thus the production planning as well.

## 1.1 Related works

Collaborative planning and creation of the production schedules with a model-first based approach has previously been described in Viklund Tallgren et al. (2021). The collaborative virtual production planning process described stems from a traditional collaborative planning process (CPP). The process involves all subcontractors in one or several planning workshops where the production schedule is discussed and created, thus are those conducting the actual onsite work contributing to the schedule with their specific knowledge and experiences as promoted in the literature (Büchmann-Slorup & Andersson, 2010). Traditionally CPP used physical sticky notes to represent each subcontractor and their respective activities. CPP break down the project into locations which are clearly defined and share some common traits, like different levels, stores, apartments, or other logical units. Each of these are the collaboratively scheduled through the sequencing of the sticky notes of the related activities of all subcontractors. The physical schedules are then digitized by the project planner. The virtual collaborative planning process (VPP) presented in Viklund Tallgren et al. (2021), reduces the lead time between workshops and production schedules CPP by using Building Information Model (BIM) in a web based collaborative planning system, drawing on research stating that BIM could contribute to better communication, more collaboration, and more involved ways of working (Crowther & Ajayi, 2019; Nepal & Staub-French, 2016).

VPP is centered around a collaborative and an individual process with six steps connected to this process (as seen in Figure 1). Starting with the BIM model taken from the design phase, the major divisions are done through filtering and dividing the BIM model according to disciplines and sub-contractor and then discussing and deciding the areas of work, the zones, in the model. This last stage constitutes the initial review of the project and the collective walkthrough of the project. The fourth step repeated for each zone, and this is where the participants interact with the model to select building objects that make up their respective activities, this is individual work and can preferably be done away from the planning workshop or between workshops. When each discipline has created all their activities for a zone, that zone is ready to be scheduled. The scheduling is a collaborative process, where the participants discuss the construction sequence in a collaborative fashion. Since the objects of the BIM is connected to the activities, a 4D model is created simultaneously as the construction sequence is scheduled. Thus, the model can be seen as being disassembled during the individual work of creation of activities, and then re-assembled during the sequencing of said activities. Observations shows that this dissembling and re-assembling enables constructability review during the scheduling and that constructability issues can be found early and sent back to the design team, thus rectifying issues as early as possible before production starts (Viklund Tallgren et al., 2020). The direct connection between activities and the building objects in the BIM reduces the identified extra effort needed to create 4D schedules as presented by Tulke & Hanff (2007) and Campagna-Wilson & Boton (2020).

Thus, VPP shows the potential to remove the guesswork from the project planner's work and improve empowerment and buy-in into the schedule at all levels, which previously has been highlighted as an issue in scheduling (Dvir et al., 2003; Faniran et al., 1994; Laufer, 1992; Viklund Tallgren et al., 2015). The involvement of the subcontractors in the planning process also creates a social co-creation of the schedule and help the

participants build a better understanding of their respective work, thus moving participants from passive receivers of a schedules to active contributors to the schedule (Viklund Tallgren et al., 2021).

Furthermore, there is more general construction management research pointing towards construction projects embracing a production-oriented model-based approach (Disney et al., 2022). This research shows that projects and construction sites where 3D geometry and added information have been the focus has started to appear. This type of approach and concept, focusing totally on BIM as the information placeholder and carrier have been called TotalBIM. The TotalBIM concept offers new possibilities regarding the integration of the VPP-method. Essentially, as the model becomes more and more adjusted for production, both in terms of geometry and information, it becomes more suitable for the VPP-method. In connection with this approach, it has been recognized that most of the TotalBIM projects use the model for quantity-take-off and connect this to sub-contractors and takt planning to different zones.

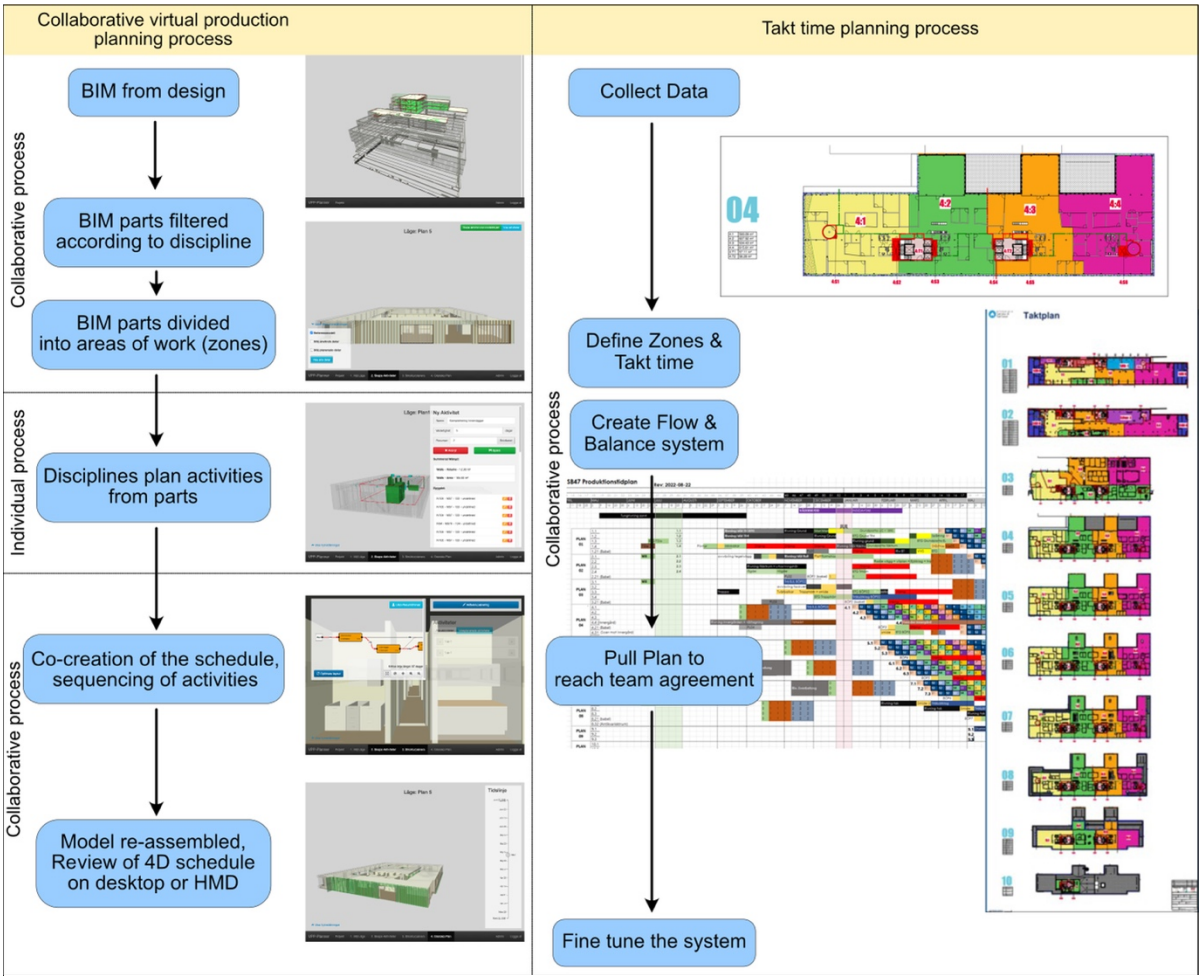


Figure 1. The collaborative production planning process Tallgren et al. (2021), side by side with the takt time planning process adopted from Tommelein (2017)

## 1.2 Research questions

With the challenges found in TTP and the similar characteristics of the collaborative production process described above this paper aims to

- Explore how TTP can be created collaboratively from BIM objects
- Explore the possible connection of a 4D collaborative planning approach and TTP

The paper draws heavily on a collaborative planning process and system developed in prior research by the authors and thus explore how TTP can be extended through this system.

## 2. METHOD

This paper uses a literature review in the introduction and related work to create a context, this context is supplemented with three cases where a current implementation of TTP in production described in three different projects. The three types of projects represent three major building types present in construction projects. Hospital projects are comparable to housing projects with relatively high degree of repetition, but with more advanced degree of technical solutions. The airport terminal represents projects with less repetition. The office and laboratory building also features more repetition, and thus is closer to housing projects as well.

### 2.1 Data collection and analysis

The literature review was conducted through a review of relevant articles through Scopus, Web of Science and google scholar, using a snowballing technique to find relevant articles (see e.g. Wohlin, 2014), to explore the concept of TTP, the importance of collaboration in construction and the use of BIM in scheduling and planning.

The cases were compiled from three sets of recorded presentations from site study visits of the different projects together with publicly available data on the projects. The data was complimented with notes from unstructured interviews with several of the site managers and representatives from respective companies.

After the initial literature review, the cases were revisited and analyzed. The VPP process and TTP processes were compared, and similarities and differences noted and contrasted to takt implementation of the cases.

## 3. CASES

Below follows a summarized description of the three cases observed in relation to TTP in use in the industry currently.

### 3.1 Case 1 – A combined Office and Laboratory building

The project is a 12 000 $m^2$ combined office and laboratory building in central Scandinavia, with high ambitions in sustainability aiming for LEED Platinum. The project had high ambitions on being a fully digital project with no drawings. Thus, the project was one of the first in Sweden to embrace the TotalBIM concept (see Disney et al., 2022), and adopt a model-based approach to design, construction and during operations and maintenance. The project was managed onsite by a specialized construction management company. The project utilized a centralized project server, housing all models, with a daily update and push of models to ensure that the latest information always was available. The site management used multiple software to administrate the project, but in all site meetings and communication with subcontractors the web-based tool StreamBIM was used. The project used a variant of TTP, where the site management prepared takt zones in the BIM model, and then coded parameters in the corresponding objects in the BIM model. The information added was takt zones, subcontractor and contract-numbers. The parameters were filled directly in the design software with the help of spaces and a plugin that could map parameters from objects such as spaces onto objects contained in a space. The CM company expressed that the coding of the takt zones was time consuming, utilizing design software and then exporting the models to IFC for use in StreamBIM. The TTP itself, however, was administrated in Excel, handling statuses and comments etc.

### 3.2 Case 2 – A University Hospital

The hospital project, situated in northernmost Scandinavia, was a collaboration between the municipality, a regional healthcare company and a university. The hospital stretched over 33 500 $m^2$ divided in five levels with room for specialist healthcare, medical and nursing education, emergency room and a community health center. The hospital was divided into four blocks. The contractors took part in the design phase and was thus able to introduce StreamBIM as a project platform in the process from the beginning. The contractor worked with several levels of schedules with different detail depending on phase. The overarching contractual schedule and master schedule was a more traditional Gantt schedule with the four blocks of the hospital specified and divided into phases. TTP was only used in the frame completion phase of the project and the contractor mentioned that working with new subcontractors some resistance to the TTP approach was common. However, often it ended up with the subcontractor optimizing their work to a level that meant fewer resources needed than initially planned to keep the schedule. The contractor worked closely with the design team and defined the takt areas themselves, to match the takt areas with the production setup. A weekly takt time pace was chosen, and since the construction site was remote but still on a limited construction site, a great deal of logistics planning was needed. To administrate the TTP the contractor used Excel, while the visualization of the TTP status was done through StreamBIM through the model and workflows.

### 3.3 Case 3 – An Airport Terminal Building

The third case was an airport terminal in the far north of Scandinavia, where the same company as in the second case were the contractor. The terminal building was a project consisting of the remodeling of part of a terminal building, the demolishing of the old international terminal as well as a new build of a terminal building of 10 000 m2 over three levels. The build almost a doubled the capacity of the airport from 1.4 million passengers yearly to 2.7 million passengers yearly. The project was conducted as a target cost project, where savings where split equally between the client and the contractor. Thus, the contractor allowed the client full access to the project's financial statements.

The contractor entered the project late, after the design. This limited the possibility to take production into account in the design. While the contractor had more than ten years of experience of working with TTP in housing and hospital projects, this was their first airport project, thus new challenges not apparent in earlier projects arose. The contractor expressed that while a takt area breakdown was possible to achieve on drawings, these areas were much harder to identify onsite during construction, the division is seen in Figure 2. Especially the second floor of the terminal building was hard to find clearly defined takt areas in, due to large open spaces. Areas connecting the old terminal building and the new terminal building also posed challenges with extensive changes and extra work being ordered, delaying some activities.

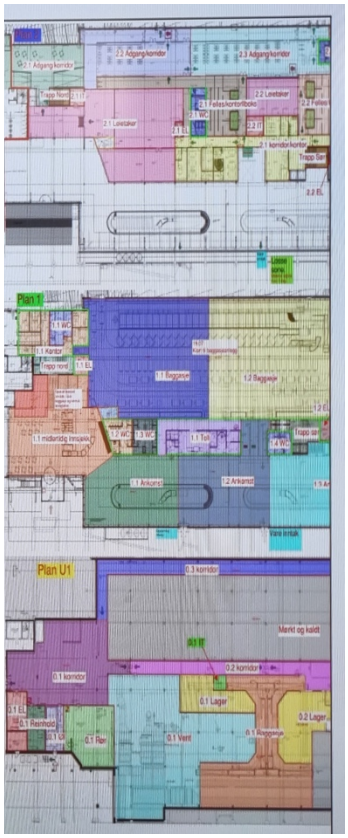


Figure 2: Takt zone definition of the airport terminal in drawings.

The disconnect from the design phase also meant that the definition of takt areas in the model never got implemented, and zones was only communicated though the drawings, as seen in Figure 2. Thus, the project managed the TTP primarily through Excel, especially during the production status meetings, control, and follow up meetings. The project otherwise was primarily model based, using StreamBIM as the onsite tool. In the model even the old terminal was modelled. The contractor mentioned that the project utilized several project documentation systems as a legacy of the design phase. The contractor mentioned that in the future they would like to switch over fully to StreamBIM, to centralize information. This project had meant a lot of transferring information between systems.

## 4. ANALYSIS AND DISCUSSION

As described in related works there is obvious similarities in the VPP and TTP processes. On a high level, both utilize a high degree of collaboration to engage the subcontractors in the planning process. VPP engages the subcontractors mainly in the review and co-creation of the schedule, only involving participants in the zone definition if the initial definition is non-functional. In contrast, in TTP the individual subcontractor provides information like activities, preferred structure of their respective activities etc. beforehand, while this is part of the VPP workshop, with some of the planning individual planning done in the middle of the workshop.

In TTP the participants are an active part of the tentative zone definition, and the zones are then discussed and adjusted according to need in an iterative manner during the planning. The zone definition differs a bit between VPP and TTP, and while the VPP process sees the zone definition as a preparatory step to the workshop, it could just as easily be conducted during the workshop, thus aligning with the suggested approach in Tommelein (2017). However, as seen in the cases, none of them strictly follows the suggested TTP approach. The takt areas or zones were often defined centrally by the site managers rather than as suggested collaboratively by the team together. This is a major difference between theory and practice. However, the team still reviewed the zones and built a collaborative understanding of the production of each zone before the takt sequence was set. Thus, the team together decided upon how to best conduct the production. In one of the cases, the hospital, the TTP was defined from a functional point of view, in this case the model only included suggestions for main routes for water and a symbolic position of faucets. The plumbing contractor in this case design a production model to more clearly understand and internally plan their work. Another finding from the cases was that a tool good enough to work with both the takt zone definition and the takt plan itself was missing. All three cases had tested multiple software and scheduling tools, but all cases stated to administer the takt mainly through Excel, with statuses and process related information stored in StreamBIM and exported to the Excel if needed.

Regarding the takt zone definition, two of the cases stated that they put takt zone information into the BIM models themselves, a laborious effort. In the third case they wished they had the takt info in the model but had not the time or competence at the site to do it themselves, neither had their architect the time to help them. This third case was also the case that was hardest to adhere to the takt zones on-site, as was more open spaces than the other projects (see the large spaces in Figure 2). One could thus question if the guidance of a BIM model divided in takt zones would have aided the workers in more easily understanding the different zones? This discussion highlights the possible use of BIM, and while the VPP process mandates BIM objects to be present and act as the main hub of information collection and creates activities from objects, the TTP process described in Tommelein (2017), merely suggest that BIM could be used to define the zones, but drawings is just as likely to be used. A downside of using drawings as the basis for the TTP is that the detail level of a drawing is significantly less than what a model can produce, where the design models today give a significantly clearer picture of what is supposed to be achieved, as could be argued seen in case three.

The third step in TTP, creating flow and balancing the system aligns partly with the individual planning of activities in the VPP process since the work density needs to be understood in TTP. Once again, the VPP process leverages the BIM aspects of showing work density through the model, but while the VPP process mandates activities, resources, and durations to be defined for activities here, the TTP process collects the corresponding information in the data collection phase. The TTP process thus focuses on creating a flow through the zone for each of the subcontractors. The fourth step of the TTP process aligns with the co-creation of the schedule, the difference is that Tommelein (2017), suggests a pull planning approach to the takt zone sequencing and that the TTP process uses the flows defined in the third stage to discuss a suitable schedule. The result of both the VPP and TTP process is a schedule on the Phase level. Furthermore, while pull planning is mandated for TTP, the VPP system is agnostic to push vs. pull planning and can accommodate both types of approaches. Both approaches strive to reach team agreement her. Finally, the fine tuning of the system in the TTP process aligns with the review of the schedule in the VPP approach. During this stage the plan is review and adjusted and missing.

To summarize this analysis and discussion, both approaches rely heavily on the collaborative aspects and benefits of engaging all subcontractors in the planning process, especially when work is not repetitive and scheduling knowledge lies much with the subcontractor's tacit knowledge. From the introduction the three challenging areas are communication of the production clearly, higher level of detail needed of the production plan and to get all participants to create a understanding regarding the building process of the project. These are precisely the aspects that the VPP system addresses and as found in the analysis there are many similarities in the processes. This implies that the VPP system could probably extend the TTP process, even though it was not developed to support this process specifically. Contrary to the literature, as seen from the cases, a high degree of BIM use does not necessarily mean that takt plans are communicated more easily. This is especially true if the takt information is not added to the BIM. But if takt information is added to the BIM model and not just stored in excel, along with statuses from follow up meetings during construction, 4D reviewing of the model is possible and statuses on the takt plan could be visualized through objects in the model.

## 5. CONCLUSIONS AND FUTURE WORK

The analysis and discussion show how TTP should be possible to extend through a BIM interface to the creation of the plan. The collaborative processes are similar and the system itself does not hinder the application of TTP even though it was developed for a more traditional scheduling approach. The VPP system would enable a direct link to collaborative 4D scheduling not available to TTP at the moment as far as the authors know.

In the future it would be interesting to explore the potential of utilizing the control possibilities of VPP combined with the continuous status control of TTP to enhance daily/weekly status review meetings during production. The 4D schedule would enable a clear visible approach to check status and health of the TTP schedule at any given time of the project. It would also be interesting to explore an integration of the VPP system with StreamBIM through a widget, to leverage the collaborative planning and scheduling process combined within a tool that participants already use in their TotalBIM projects.

This would make planning, scheduling, and the resulting plans more accessible to the projects. And hopefully enable the clear communication of the actual status of the plan compared to just the takt time train/wagon diagrams.

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