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COLLABORATIVE SCHEDULING WITH 4D EXTENDED TO VIRTUAL REALITY

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Construction planning and scheduling processes have been relatively unchanged until the last decades when 4D-planning has been promoted along with the rise of Building Information Modeling (BIM). Some 4D-systems have been developed for visualising schedules rather than to aid in the actual creation of the schedule. In contrast, some scheduling software in more recent years has been enhanced with 4D-modeling capabilities. Furthermore, the use of BIM-viewers during scheduling partly enables both design and schedule review before construction. This paper aims to show how an alternative approach to 4D-modelling could be used to produce schedules. The paper presents a prototype software for planning and scheduling where the production-schedule is created directly from the model in a lean construction Last Planner manner from the building components. Findings from evaluations of the prototype indicate a move of 4D-modelling from a passive visualisation to an active modelling process. This move enables knowledge to be created and exchanged in the social co-creation context of the 4D-schedule by the stakeholders. The co-creation and understanding can be further enhanced with the extension into virtual reality using head-mounted displays where the 4D-schedule can be created and reviewed directly.

KEYWORDS: 4D modelling, planning and scheduling, Collaborative work, Virtual reality

1. INTRODUCTION

Schedules are vital and are used throughout all the phases of a construction project. The most common way to use and communicate critical path schedules is by Gantt diagrams and linked bar charts (Baldwin & Bordoli, 2014, Chapter 1; Olivieri et al., 2019). Specialist planners or site managers often create the schedule. Thus, the schedule is based on general knowledge accumulated by the planner. However, it has been argued that site managers do not have enough time to spare to create quality schedules, and specialist planners may lack the more specialised knowledge to create high-quality schedules (Winch & Kelsey, 2005).

Furthermore, research has shown that the involvement of stakeholders, such as subcontractors and the ones executing the work, in the scheduling process removes the guesswork of planning and scheduling. Research also shows that involvement improves in buy-in into the schedule at all levels (Dvir, et al., 2003; Faniran et al., 1994; Laufer, 1992; Viklund Tallgren et al., 2015). Schedules are by nature a communicational as well as a managerial tool, but Gantt diagrams have been criticised, for example for not being able to convey spatial relations (Chavada, Dawood, & Kassem, 2012; Olivieri et al., 2019). It has also been argued that plans are often presented poorly with overly complicated information (Laufer & Tucker, 1987) and that plans are hard to interpret for persons not trained in scheduling techniques (Chrzanowski & Johnston, 1986; Mahalingam et al., 2010). The complexity of communicating information has justified alternative approaches to visualise the schedule, and one such method has emerged in 4D CAD technology and 4D modelling (Heesom & Mahdjoubi, 2004), which has gained firmer ground with the adoption of building information technology (BIM) (Boton et al., 2013). However, scheduling and modelling is often done in separate software's and thus needs to be linked in a 4D software. The literature shows that even though 4D shows promising advantages (Eastman et al., 2011), in for example the communication of the schedule, it still lacks widespread adoption (Crowther & Ajayi, 2019).

Literature also shows that the adoption of BIM has helped the construction industry to move towards more collaborative approaches (Crowther & Ajayi, 2019). This move is supported in the research of Viklund Tallgren (2018), Viklund Tallgren et al. (2020) and Johansson et al. (2014) and has also opened for a more visual approach to communication. Formoso et al. (2002) argue that visual communication increases the engagement of workers as well as their understanding of problems related to the project. The visual approach is further supported by Roupé et al. (2019) who reports that the use of virtual reality (VR) in the design phase allows stakeholders to understand the project better as well as to move from a passive interpreting role to a more active co-designing role. Thus, the stakeholders' tacit knowledge can be worked into the project directly by the stakeholders. Further, the use of VR lessens the risk for misinterpretation since there is less ambiguity in 3D compared to 2D drawings which rely on the user to visualise the 2D drawing for themselves (Roupé et al., 2019). The use of head-mounted displays (HMD) exemplifies how stakeholders could "step into" the model and experience the project in scale 1:1.

Thus, this paper identifies three main issues that it will address:

- **Planning and scheduling software are mostly aimed for expert planners**; thus, the software requires extensive knowledge and training to be effectively used.
- Planning and scheduling today offer **limited collaboration,** primarily through the creation phase.
- Traditional Gantt and linked bar charts offer **poor communication possibilities**, especially with workers on site.

This paper aims to analyse how the collaborative planning and scheduling approach presented within the article differs from the traditional 4D modelling approach. This analysis has been conducted by process modelling of a traditional planning and scheduling process together with an existing alternative collaborative planning approach. Furthermore, the traditional 4D modelling approach and the collaborative 4D modelling approach has also been analysed and process modelled. The use of process modelling, and especially the business process modelling notation (BPMN) is well established and used in the buildingSMART Alliance amongst others to provide a transparent and reproducible way to communicate process flows (Borrmann et al., 2018, Chapter 4). Furthermore, the paper illustrates how this alternative approach differs and addresses the three main issues during the scheduling process.

The paper begins with the analysis and description of the traditional planning approach as well as a traditional 4D approach and then the collaborative planning and scheduling approach. Then follows a short description of the method used in the paper, followed by the description of the enhanced collaborative planning and scheduling process that is web-based and uses BIM as well as VR. The web-based planning and scheduling tool has been presented in detail earlier without 4D visualisation, and VR implemented (Viklund Tallgren, 2018, 2020). Furthermore, the paper discusses how this tool addresses the issues stated earlier, and thus the paper contributes with:

- A comprehensive comparison between 4D modelling approaches
- The introduction of a user-friendly collaborative planning and scheduling tool
- Novel use of VR and HMD in the planning and scheduling phase.

The result shows how the traditional 4D modelling process can go from passive linking of a schedule and a 3D model to active 4D modelling as part of the collaborative planning and scheduling process.

2. PLANNING AND SCHEDULING PROCESSES

Traditional planning and scheduling processes can be described in several ways. This paper uses the planning process described by the project management institute (Jones, 2009). The general planning process is further extended with the workflow for site management and subcontractors according to findings in literature and interviews (Baldwin & Bordoli, 2014; Christiansen, 2012; Friblick & Nordlund, 2013). As seen in figure 1, the traditional planning and scheduling have three stakeholder groups, the project planner, site management and sub-contractors. The project planner represents an active stakeholder, while site management and sub-contractors are passive concerning planning and scheduling. The project planner performs both the work breakdown structure (WBS) as well as the definition of work packages which breaks the WBS into distinct units or phases. Each work package is then planned by defining activities or tasks that are needed to complete a work package. When activities are defined, the hard logic of the schedule is defined. Hard logic is how activities depend on each other. The planner then inputs the schedule into a planning software such as Primavera, Powerproject, or Synchro, and once this is done, the logic is analysed, and errors corrected. The result is a draft schedule which is circulated to stakeholders. The draft schedule is reviewed with the stakeholders, working in the feedback into the schedule before it is finalised. As seen, the site manager has a more active role in the scheduling, but the subcontractors are mostly passive recipients of the schedule. In an interview with a project planner he stated that this was often a problem since he would have to push and "sell in" the schedule to gain acceptance for it, and even then, the subcontractors saw it merely as a loose guideline (Viklund Tallgren, 2018). Furthermore, literature also argues that more training is required to enable site management to engage more in the planning and make it more collaborative as well as lightening the planning load from the project manager (Crowther & Ajayi, 2019).
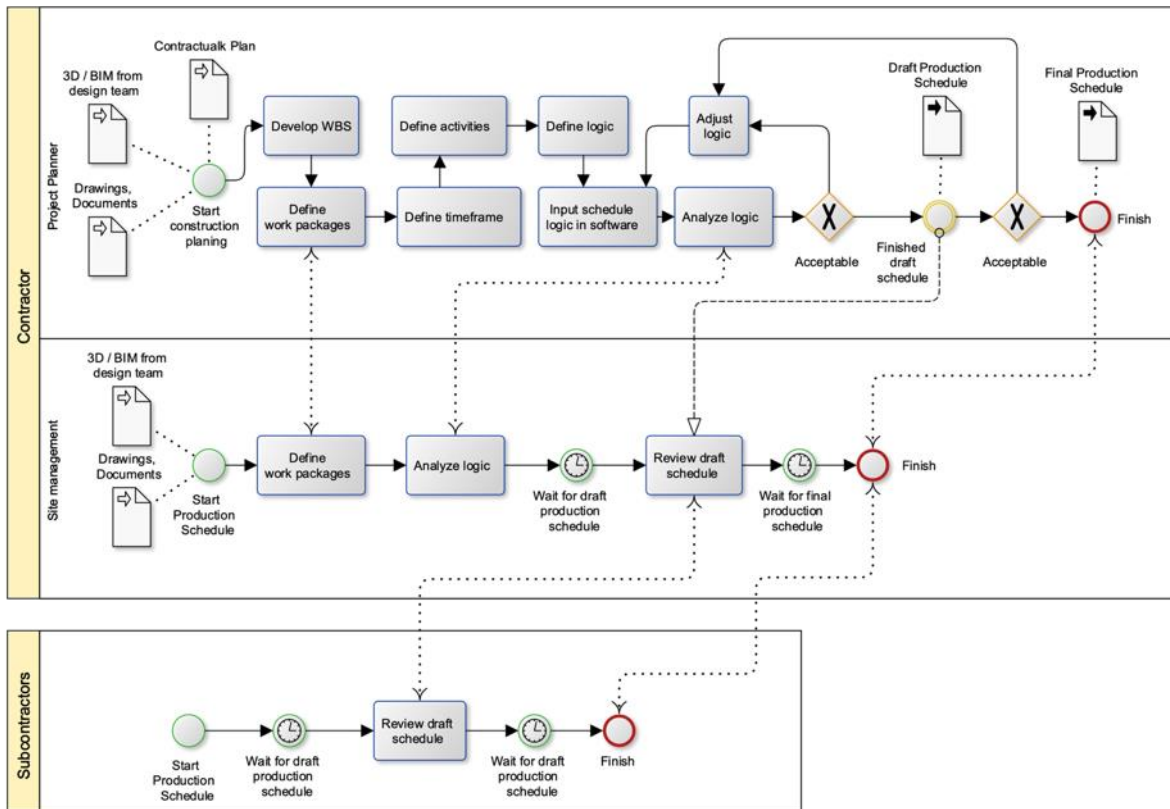
Figure 1: Traditional planning process.

2.1 Traditional 4D planning

The traditional 4D planning approach is well document in literature, and two main approaches have been identified. One is manual stitching of pictures of a 3D model representing stages in the production process which results in a movie that can be played back (Baldwin & Bordoli, 2014, Chapter 9; Eastman et al., 2011). Manual stitching was typical before the introduction of BIM and is the most passive 4D approach. The other approach is a more interactive one where the schedule and the BIM model is linked (Baldwin & Bordoli, 2014, Chapter 9; Crowther & Ajayi, 2019). The most common way to achieve the second approach to 4D visualisation is to conduct the traditional planning and scheduling process as business as usual, indicated in figure 2 in the lower swimlane as a subprocess for stakeholders such as the project planner as described in the general planning and scheduling process. The complete schedule is then given to a BIM specialist like a BIM coordinator who merges the schedule and the models. As seen in the upper swimlane in figure 2, this linking is prepended with two separate preparatory paths. One path is the input of the 3D data / BIM model into the 4D software, and the re-organisation and grouping of components according to the construction strategy, the other is the preparation of the construction schedule by importing it and setting up activity types for visual behaviour to visualise the construction process. This preparation could be done by coding the objects or utilising grouping of objects.

Similarly, the schedule is imported, then the visual behaviour is defined, usually to indicate visual behaviour for objects of activities that are existing, being built, finished, temporary or demolished. After the preparations, the BIM coordinator works through the activities, linking components from the model to the schedule. Once all components are linked, and additional temporary tasks modelled, the 4D visualisation can be produced. The 4D visualisation is done either as a movie or as an interactive model. As seen here, specialist competence is needed to produce 4D visualisations. One reason for this is the need for a good understanding of the information structure in the 3D / BIM model as well as knowledge of the 4D systems, which often are more advanced than standard scheduling software.
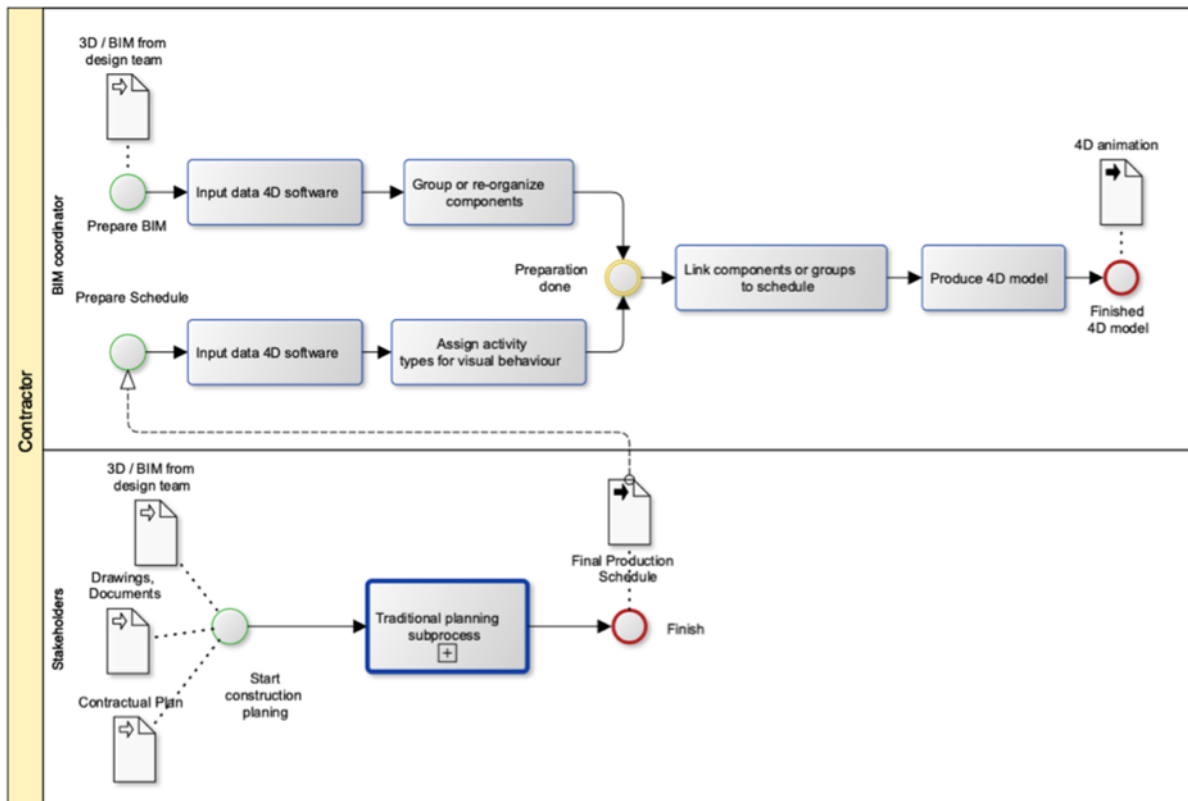
Figure 2: Traditional 4D modelling process.

2.2 Collaborative planning and scheduling

The collaborative planning process described here is defined in Viklund Tallgren (2018), and further elaborated in Viklund Tallgren et al. (2020) and builds upon the collaborative planning, and scheduling approach developed during the late eighties and early nineties (Friblick & Nordlund, 2013; Söderberg, 2006). In Scandinavia, these approaches were driven by the union and with a strong belief in co-determination and flatter hierarchies, leading to workers or at least the supervisors from the different subcontractors participating in the planning and scheduling process (Söderberg, 2006). This approach has similarities to the Last planner approach but is not as strict in the use of pull planning vs push planning and the use of specific schedule visualisation techniques (Friblick & Nordlund, 2013).

The main difference is that the planner does not actively plan; thus, the planner does not define activities or the hard logic of the schedule. Instead, the planner acts as a moderator during the sequencing of the activities. Figure 3 shows the basic layout of the collaborative planning process. The main difference compared with the traditional planning process in figure 1 is that the project planner works closely with the site management in defining work packages. These work packages are then used during the collaborative planning workshop to limit the scope of the scheduling. One work package is planned and scheduled at a time. This is illustrated by an individual planning process, shown in Figure 4. This move of responsibilities is the main difference to traditional planning. Supervisors from the site management and subcontractors respectively are responsible for planning their specific activities, thus moving the planning and scheduling from the expert planner to the ones performing the work. The observations of these workshops show that much of this activity definition is done during the scheduling workshop while actively communicating with closely connected disciplines, thus minimising the risk for misinterpreting other disciplines work. Activities are created on sticky notes, one activity per sticky note, with name, resources, duration, and location stated. This process is similar for subcontractors as well as for site management, who plans the general works to be conducted in each work package. Once all activities in a work package are defined, the sequencing of the schedule starts. The sequencing work is the switch from independent individual planning work to collaborative scheduling work. This is illustrated in figure 5. The observations show that the project planner takes more of a managing role in seeing that all stakeholders share knowledge and define the best possible sequence for the work package at hand. All stakeholders are responsible for their activities, as well as adding their sticky notes to the big sheet of paper representing the current work package at an agreed-upon sequence. This sequencing

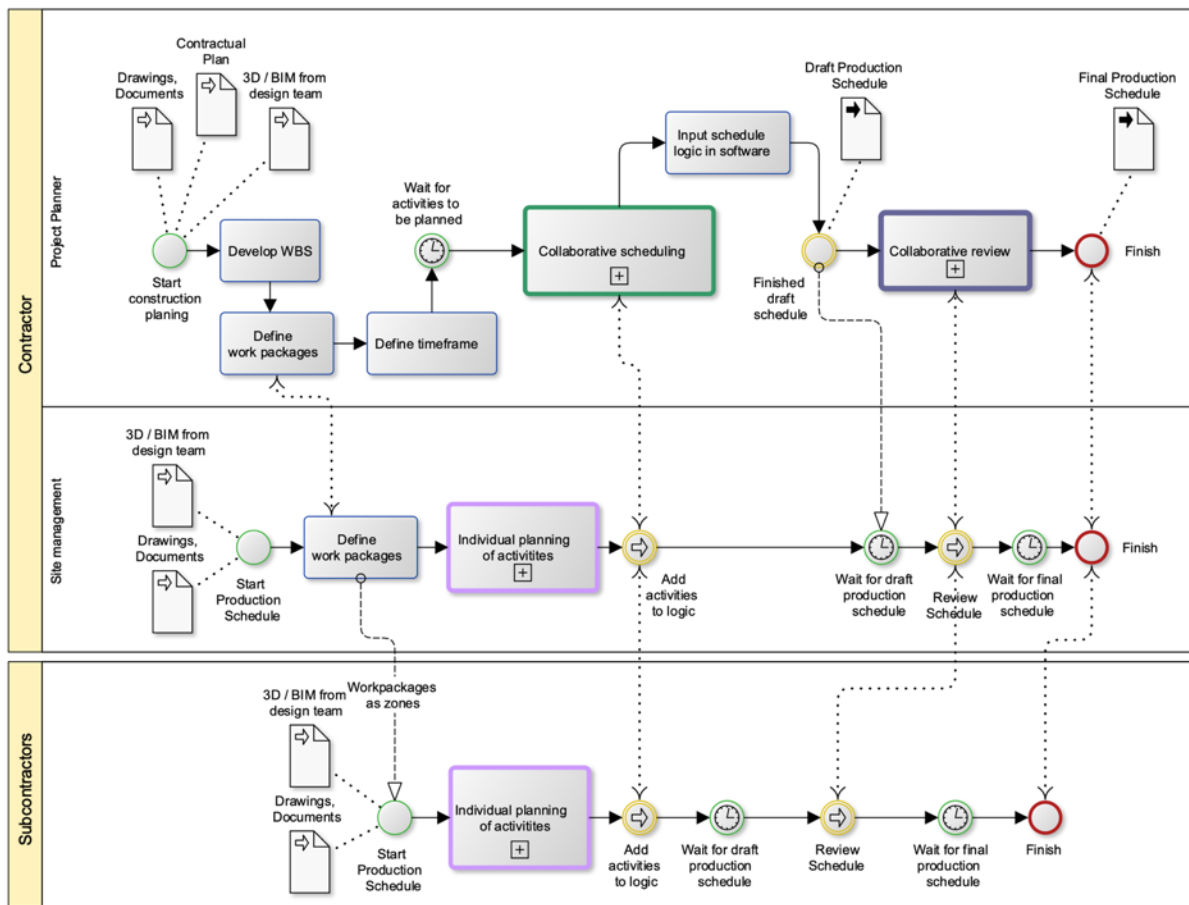goes on until all activities are sequenced and all hard logic defined.

Figure 3: General collaborative planning process.

Observations conducted during such workshops shows that some constructability issues can be identified and fed back to the design team, thus rectifying issues before they start the construction (Viklund Tallgren et al. 2020). Once this is done, the Project planner reviews and analyses the schedule together with the stakeholders to identify potential problems or errors; this is shown in more detail in the collaborative review subprocess in figure 6. Here the observations showed that to some extent some rework of the logic was done, and information on activities were supplemented, and sometimes even new activities added. This addition usually meant substantial rework of the logic. Thus, as a first draft, a pencil was used to draw connections. Once the schedule logic was finalised, the logic was permanented markers. During discussions with project planners from several Scandinavian construction companies, some mentioned that they used whiteboards instead of paper to record the logic, then photographing the finalised logic (Viklund Tallgren 2018; Viklund Tallgren et al. 2020).
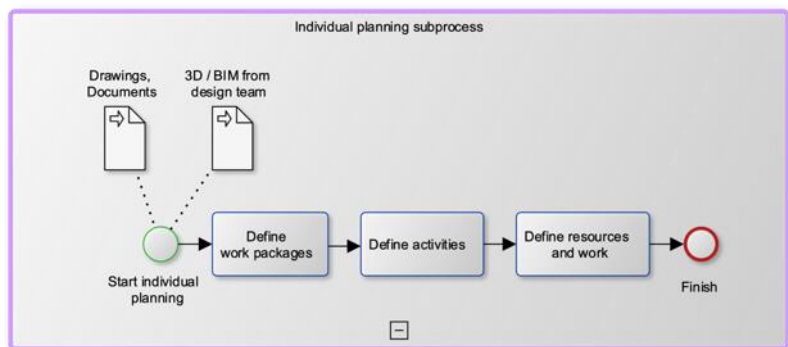

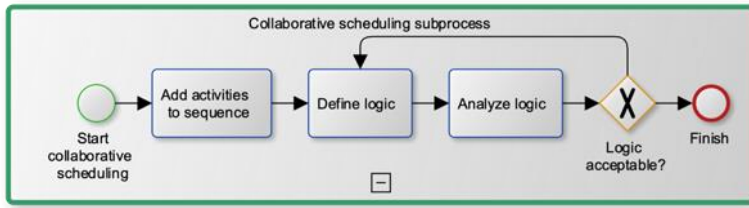Figure 4: Individual planning subprocess.

Figure 5: Collaborative scheduling subprocess.

Once all the work packages are worked through similarly, the project planner takes the sheets of papers and records the schedule in scheduling software. Observations and interviews have shown that the number of projects the project planner is responsible for affects the time possibility to finalise the work, which could take up to a couple of weeks. The planner mentioned that errors in the logic are common in the physical plan (Viklund Tallgren 2018; Viklund Tallgren et al. 2020). These errors are often identified during input in the software, which leads to the planner drawing assumptions to solve the errors. The resulting schedule is typically an idealised schedule that needs to be optimised to adhere to the contractual plan. The un-optimised schedule creates the need for a follow-up workshop. During the follow-up workshop, the draft schedule is collectively reviewed, and hard logic is suitably adjusted until the timeframe of the schedule coincides with the contractual plan. In an interview with the planner, he mentioned that the philosophy behind this approach is to let the group initially be free from time constraints and thus being able to focus on hard logic such as the right sequences and relations between activities (Viklund Tallgren, 2018). Thus, optimisation can be done in a second step, once the logic is in place. The project planner reworks the schedule and the logic adjusted and agreed upon before a final schedule is produced and then sent out to all stakeholders.
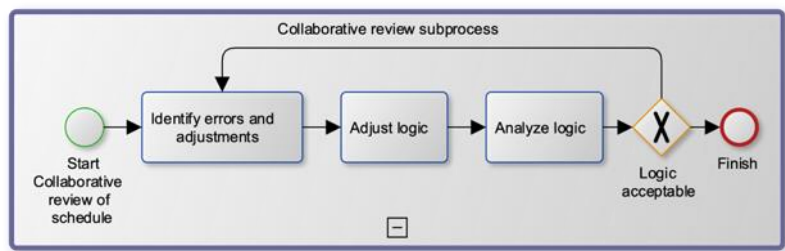

Figure 6: Collaborative review subprocess.

3. METHOD

The research presented in this paper is a part of a larger research project, where design science (DS) has been used as the overarching research framework. The basis is a practice-based problem, linked to the body of knowledge of the field as well as in-situ observations. DS as an approach is broadly defined as consisting of three activities, Design, Build and Evaluate, all of which are interrelated (Hevner et al., 2004). The data in this paper is compiled from observations, field notes, interviews and evaluations performed in the broader research context. In total, seven scheduling workshop observations with four different projects, seven interviews with nine workers and managers, as well as 14 prototype evaluations have been conducted (Roupé et al. 2014, Viklund Tallgren et al. 2015; Viklund Tallgren 2018; Viklund Tallgren et al. 2020).

The projects were selected because of their use of the collaborative planning approach described in Section 2.2. The projects were observed in their natural setting, with as little disturbance as possible. All workshop was observed as business as usual, and after the initial short presentation, the participants quickly went about the workshop at hand, ignoring the researcher. All but the first workshop was recorded with video and sound to ease the capture of interactions and communication. All workshops were documented with field notes that were thematically coded and analysed.

All but one interview was conducted as semi-structured interviews, where an interview guide helped guide the interviews around the information need during construction planning and scheduling. The last interview was conducted as an unstructured interview. The last interview aimed at capturing the project planners' approach to planning and scheduling in general and especially regarding the collaborative planning approach that he was pushing onto the projects for which he is responsible.

The 14 prototype evaluations focused on the usability and fit of the developed tool for the collaborative planning and scheduling process. Four of these evaluations were small informal evaluations with the closest research group to test functionality. Seven evaluations were to test the process and evaluate against best practice, conducted with groups of middle managers, BIM coordinators and project planners from Scandinavia's five major construction companies. Three evaluations validated the tool against the process and were conducted with construction management students, knowledgeable in the collaborate planning method. A more in-depth description of the approach to the primary data collection can be found in Viklund Tallgren (2018), where all but the last two

observations, and the three evaluations with BIM coordinators and project planners are covered. The collected data has been recorded and transcribed, then thematically coded with Nvivo 12.

The analysis and modelling of processes have proved to be an effective way to compare and communicate processes as well as to specifying software system requirements (Aram et al., 2010; Ouyang et al., 2009). This paper uses the four-step approach defined by Saluja (2009) to model the process:

1. Identify the set of activities that make up a particular task;
2. Identify the agent(s) involved;
3. Identify the intermediate and end goal for the task; and
4. Identify what resources will be referred to or used for the completion of the task.

However, the paper uses the original BPMN notation rather than the layout presented in Saluja (2009). Furthermore, a literature review, observations and the interview with the project planner has been the basis for the process modelling of the planning and scheduling approaches.

4. THE VIRTUAL PROJECT PLANNING SYSTEM FOR PLANNING AND VISUALISATION

The virtual project planning system (VPP) is the extension of the collaborative planning and scheduling method described in subsection 2.2, figure 3. However, it enhances it with a BIM-based web-interface for each stakeholder to plan and schedule their activities. Figure 7 illustrates the steps of the web-interface connected to the VPP system for the enhanced collaborative planning and scheduling process, where the BIM model is used as the information carrier and a schedule as well as a 4D visualisation is the outcome of the collaborative planning and scheduling process. The development of this process is described in more detail in Viklund Tallgren (2018) and is used to describe the process model seen in figure 8. The user interface has been developed during iterative evaluations in collaboration with the construction industry, as described in the method section. The goal has been to keep the process as close as possible to the traditional collaborative planning and scheduling process while still having a user-friendly interface. The primary process is modelled on the collaborative planning process in figure 3. However, all stakeholders interact with the BIM model therein to create activities rather than physical sticky notes and thus results in the process seen in figure 8.

Since the system is web-based, it requires the BIM model to be uploaded to the VPP system. Preferably somebody with the project responsibility does this, such as the project planner, project manager or a BIM coordinator. Similarly, as in the traditional 4D modelling process in figure 2, there is a need to define the WBS and work packages in the form of locations. This process is done already in the design phase through the coding and classification according to the delivery manual. Thus, the classification and coding resemble the grouping of parts grouping parts that is done in the preparation stages of the traditional 4D modelling process in figure 2. The classification and coding system used in the model helps to filer the model disciplines according to subcontractors.

Once the model is in the VPP system, the collaborative planning and scheduling workshop can take place. Each discipline creates its activities by selecting components of the BIM model. These components make up an activity, and the user put in name, resources and duration in the activity, see the middle part of figure 7, marked individual planning. These digital activities replace the sticky note and enable the user to get information directly from the objects that are part of the activity. Thus, the activity is connected to the model already in the creation-phase of the activities.

The sequencing of the logic is done as described earlier in figure 3, collaboratively. However, instead of physical sticky notes, each stakeholder drags and drops the activity to the work package schedule and connects it with the logic that is needed, see the lower part of figure 7, the collaborative scheduling and review. In the background, the system calculates the critical path as well as work package duration based on the duration of the logic and critical activities. The result is an instantly reviewable schedule. Evaluations of the VPP system with participants experienced in the sticky-note version of the collaborative planning method mentioned that the VPP system was more natural to grasp (Viklund Tallgren et al. 2020). Mainly because the overview of schedule was the better and the ease in adjusting the schedule compared to the physical sticky notes and arrows on big sheets on paper. The possibility to easily rearrange and adjust connections between activities were especially appreciated.

A difference with the VPP system compared to the traditional 4D modelling process is that the 4D modelling is created continuously as the project is planned and scheduled. A 4D visualisation becomes an additional result along with the schedule once the sequencing is done. Using the 4D visualisation to review the schedule during all parts of the sequencing can eliminate the need for waiting to document the schedule in the scheduling software. See the bottom of figure 7 for the collaborative scheduling view and 4D review view. Hard logic can be reviewed continuously if uncertainties of the best sequence should arise. The ability to instantly review the schedule reduces the lead time between the workshop and the completed schedule. The resulting schedule can be exported to a scheduling software in a matter of minutes, and the project planner can bring up and make the final edits in the workshop before concluding the workshop, thus shortening the time from workshop to finished and agreed upon production schedule.
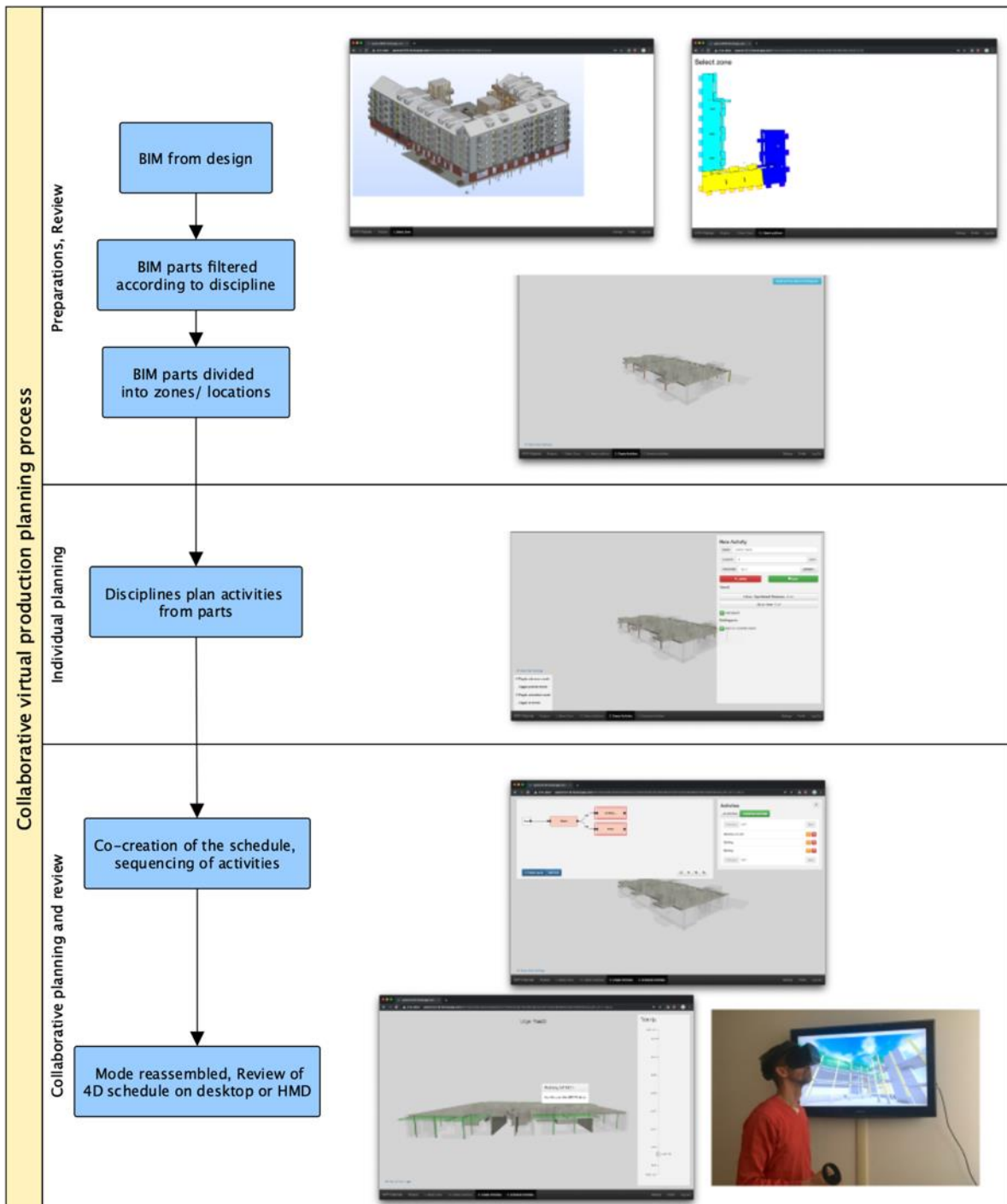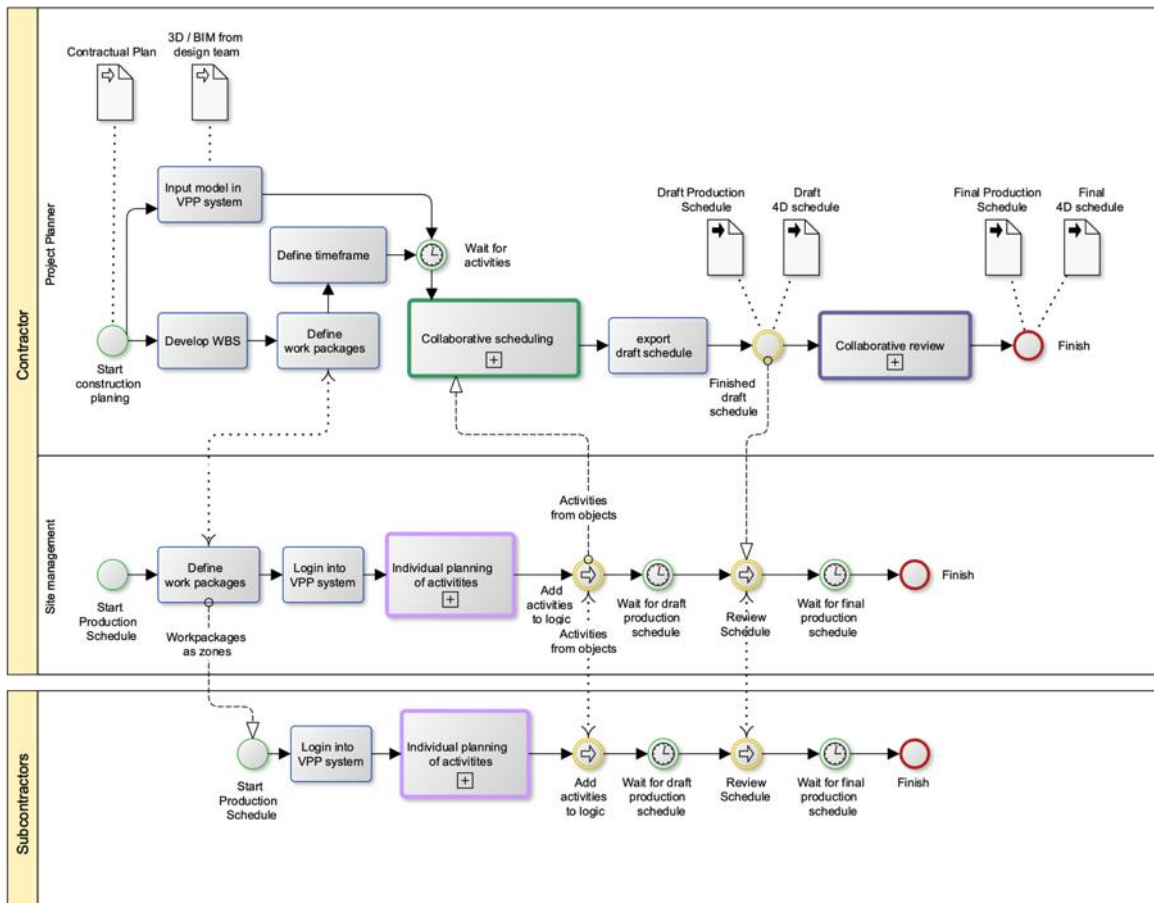

Figure 7: VPP 4D approach.

Figure 8: Enhanced VPP process, for details of Individual planning subprocess, see Figure 4, Collaborative scheduling subprocess see Figure 5 and for Collaborative review subprocess see Figure 6.

4.1 Extension into VR

Since the VPP system was designed with a web interface that uses an application program interface (API) to communicate with the server, it enables connecting other interfaces as well. Since the web interface is somewhat limited concerning the size of the model it can handle, another tool called BIMXplorer (Johansson, 2016) is used to visualise the full model. The connection between tools is facilitated by a WebSocket communication protocol, which means that the VPP system can connect to one or several BIMXplorer clients. Thus, the workshop participants can utilise BIMXplorer to review the 4D-schedule in scale 1:1 in an HMD, as seen in figure 9. The 4D-capabilities in VR is realised by setting the visible state of objects according to the schedule. The VR-client loads the same BIM as is used in the VPP system, and then registers for notifications from the VPP-server. With each object in the BIM having a Globally Unique Identifier (GUID), the VPP-server only needs to send the GUID together with a boolean indicating visible/invisible state to update the VR-model according to the schedule. The change of the 4D time-slider broadcasts a list with the affected GUIDs to any connected clients. The clients use the list to update the visible state of the corresponding objects in the client. When in VR, participants can freely navigate around in the BIM in scale 1:1 and take distance measurements and query objects for properties in the same way as previously described in Johansson & Roupé (2019).

Figure 9: A site manager reviewing the 4D visualisation in an HMD.

5. DISCUSSION AND CONCLUSIONS

This paper has presented and compared a collaborative planning and scheduling method (e.g. VPP) with traditional 4D scheduling using process modelling (BPMN). The result and analyses of the process modelling show that traditional 4D method relies on existing schedules produced by specialist planners in cooperation with BIM-coordinators and often has limited support for collaboration, primarily through the creation phase. There is a need for a more user-friendly interface since traditional 4D systems are often complex and specialist competence is needed to produce the 4D visualisation, as seen in the analysis of the traditional 4D process. Furthermore, traditionally the 4D model is mainly used for reviewing the existing construction schedule in 3D. These types of reviews have shown to increase the understanding of the schedule and have been effectively used as a passive visual communication tool of the construction schedule. However, the traditional 4D modelling process is limited when it comes to collaboration during the creation phase of the schedule.

We argue that by using the presented collaborative planning and scheduling method and the VPP system instead of traditional 4D-scheduling, it is possible to support and enable co-creation in a more user-friendly interface. Thus, it is possible to increase engagement of workers and subcontractors and let the ones executing the construction work, plan and schedule in 4D. The outcome from this process removes the guesswork from the project planners work and improves empowerment and buy-in into the schedule at all levels, which has been a highlighted issue then it comes to scheduling (Dvir et al., 2003; Faniran et al., 1994; Laufer, 1992; Viklund Tallgren et al., 2015). The process modelling (BPMN) also reveals how the traditional 4D scheduling process can go from being a passive process of linking the prepared schedule and with a 3D model, to become an active and socially creative 4D modelling process. This social creativity is achieved by using the VPP-system and the collaborative planning and scheduling method. By supporting this collaborative process, it is possible to provide opportunities and resources for activities embedded in a social, creative process in which all stakeholders can actively contribute rather than having passive receiving roles. The VPP collaborative scheduling can enable co-creation and creates a shared understanding were the participants create awareness of each other's work and provide mechanisms to help draw out the tacit knowledge during negotiation and communication about how to plan and conduct the project. The use of multiple representations and visualisations gives the participants the possibility to understand different points of view and different subtasks of the project and further enhances the understanding of the project.

Furthermore, with the possibility to also support 4D visualisation in immersive VR, the construction workers and

subcontractors are enabled to "step into" a 4D-schedule and experience and review the scheduled sequences in 1:1 scale. VR has shown to give a much better understanding of the project, and since "everyone sees the same thing" with VR in contrast to drawings, VR is predicted to facilitate communication between different parties as it reduces the risk of misinterpretations, according to Johansson & Roupé (2019). The 4D visualisation in immersive VR could thus be argued to support better design and constructability review of the construction. Also, as the 4D visualisation in immersive VR is seamlessly integrated with the VPP-system, it is possible to do changes in the 4D schedule in the web-based scheduling interface, and have the changes instantly updated in VR. The integration supports a better interactive design and review of the 4D schedule and construction. As the 4D is not static, it promotes co-creation in different spaces and could give a better understanding of different points of view and different subtasks between different sub-contractors.

In the future, it would be interesting to explore and evaluate if VR also could be valuable and used as an interactive interface during the actual VPP process. By seamlessly integrating the same tools and processes as the VPP-system supports today, it would be possible to explore and work with the planning and scheduling in different virtual spaces. Thus, the possibility to support multiple representations and visualisations give the participants new ways to understand different subtasks. For example, the *Individual planning subprocess,* described in figure 4, could be performed in VR. During that process, the user selects and groups BIM components into defining activities or tasks that are needed to complete a work package.

Furthermore, the *Collaborative scheduling subprocess*, described in figure 5, could also be conducted in different spaces, for example, immersive VR. An example could be the projector displaying the environment along with the client views. However, space could also be different physical locations. In this context, the VR interface could maybe be a more natural user interface and give a better understanding when it comes to creating activities and scheduled sequences in 1:1 scale. The VR interface could also help review and identify worksite safety problems more intuitively.

6. REFERENCES

Aram, S., Eastman, C., Sacks, R., Panushev, I., & Venugopal, M. (2010). Introducing a New Methodology to Develop the Information Delivery Manual for AEC Projects. Exchange Organizational Behavior Teaching Journal, (Nibs 2008), 16–18.

Baldwin, A., & Bordoli, D. (2014). Handbook for construction planning and scheduling. John Wiley & Sons.

Borrmann, A., König, M., Koch, C., & Beetz, J. (2018). Building information modeling: Why? What? How? In Building Information Modeling: Technology Foundations and Industry Practice. https://doi.org/10.1007/978-3-319-92862-3_1

Boton, C., Kubicki, S., & Halin, G. (2013). Designing adapted visualisation for collaborative 4D applications. Automation in Construction, 36(0), 152–167. https://doi.org/10.1016/j.autcon.2013.09.003

Chavada, R., Dawood, N., & Kassem, M. (2012). Construction workspace management: The development and application of a novel nD planning approach and tool. Journal of Information Technology in Construction, 17, 213–236.

Christiansen, F. (2012). The Planning Process at a Construction Site. Chalmers University of Technology.

Chrzanowski, E. N., & Johnston, D. W. (1986). Application of linear scheduling. Journal of Construction Engineering and Management, 112(4), 476–491. https://doi.org/10.1061/(ASCE)0733-9364(1986)112:4(476)

Crowther, J., & Ajayi, S. O. (2019). Impacts of 4D BIM on construction project performance. International Journal of Construction Management, 0(0), 1–14. https://doi.org/10.1080/15623599.2019.1580832

Dvir, D., Raz, T., & Shenhar, A. J. (2003). An empirical analysis of the relationship between project planning and project success. International Journal of Project Management, 21(2), 89–95.

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors. John Wiley & Sons.

Faniran, O. O., Oluwoye, J. O., & Lenard, D. (1994). Effective construction planning. Construction Management and Economics, 12(6), 485–499.

Formoso, C. T., dos Santos, A., & Powell, J. A. (2002). An exploratory study on the applicability of process transparency in construction sites. Journal of Construction Research, 3(01), 35–54.

Friblick, F., & Nordlund, T. (2013). Framgångsrik planering i byggprojekt.

Heesom, D., & Mahdjoubi, L. (2004). Trends of 4D CAD applications for construction planning. Construction Management and Economics, 22(22), 171–182. https://doi.org/10.1080/0144619042000201376

Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design science in information systems research. MIS Quarterly, 28(1), 75–105.

Johansson, M. (2016). From BIM to VR - The design and development of BIMXplorer. Chalmers University of Technology.

Johansson, M., & Roupé, M. (2019). BIM and Virtual Reality (VR) at the construction site. Proceedings of the 19th International Conference on Construction Applications of Virtual Reality. Bangkok, Thailand.

Johansson, M., Roupé, M., & Viklund Tallgren, M. (2014). From BIM to VR-Integrating immersive visualisations in the current design process. Fusion-Proceedings of the 32nd ECAADe Conference-Volume 2 (ECAADe 2014), 261–269.

Jones, E. F. (2009). Scheduling 101 - the basic of best practices. Orlando: Project Management Institute, Inc.

Laufer, A. (1992). A micro view of the project planning process. Construction Management and Economics, 10(1), 31–43.

Laufer, A., & Tucker, R. L. (1987). Is construction project planning really doing its job? A critical examination of focus, role and process. Construction Management and Economics, 5(3), 243–266.

Mahalingam, A., Kashyap, R., & Mahajan, C. (2010). An evaluation of the applicability of 4D CAD on construction projects. Automation in Construction, 19(2), 148–159. https://doi.org/10.1016/j.autcon.2009.11.015

Olivieri, H., Seppänen, O., Alves, T. D. C. L., Scala, N. M., Schiavone, V., Liu, M., & Granja, A. D. (2019). Survey Comparing Critical Path Method, Last Planner System, and Location-Based Techniques. Journal of Construction Engineering and Management, 145(12). https://doi.org/10.1061/(ASCE)CO.1943-7862.0001644

Ouyang, C., Dumas, M., Van Der Aalst, W. M. P., Ter Hofstede, A. H. M., & Mendling, J. (2009). From Business Process Models to Process-Oriented Software Systems. ACM Transactions on Software Engineering and Methodology, 19(1), 1–37. https://doi.org/10.1145/1555392.1555395

Roupé, M., Johansson, M., Maftei, L., Lundstedt, R., & Viklund-Tallgren, M. (2019). Seamless Integration of Multi-touch Table and Immersive VR for Collaborative Design. Advances in Informatics and Computing in Civil and Construction Engineering, 263–270. https://doi.org/10.1007/978-3-030-00220-6_32

Roupé, M., Viklund, Tallgren, M., Johansson, M.,& Anderson R. (2014) Virtuellproduktionsplannering med hjälp av BIM och visualisering. SBUF Rapport 12851. Göteborg.

Saluja, C. (2009). A process mapping procedure for planning building information modeling (BIM) execution on a building construction project. Architectural Engineering.

Söderberg, J. (2006). Concordia – försök med integrerad planering. Lund.

Viklund Tallgren, M. (2018). Developing a collaborative planning tool for construction - A Building Information Model-enhanced planning and scheduling tool for production. Chalmers University of Technology.

Viklund Tallgren M, Roupé M, Johansson M, & Bosch-Sijtsema P. (2020) BIM tool development enhancing collaborative scheduling for pre-construction. Journal of Information Technology in Construction 25: 374–397. DOI: 10.36680/j.itcon.2020.022.

Viklund Tallgren, M., Roupé, M., & Johansson, M. (2015). An empowered collaborative planning method in a Swedish construction company - A case study. 31st Annual ARCOM Conference, 793–802. Association of Researchers in Construction Management.

Winch, G. M., & Kelsey, J. (2005). What do construction project planners do? International Journal of Project Management, 23(2), 141–149. https://doi.org/https://doi.org/10.1016/j.ijproman.2004.06.002