BIM-BASED SCHEDULING OF CONSTRUCTION – A COMPARATIVE ANALYSIS OF PREVAILING AND BIM-BASED SCHEDULING PROCESSES

Rolf Büchmann-Slorup, M.Sc., PhD-student, rbsl@man.dtu.dk
Niclas Andersson, PhD. Associate Professor, nican@man.dtu.dk
-Department of Management Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark & MT Hojgaard a/s, Soeborg, Denmark.

ABSTRACT
The potential of BIM is generally recognized in the construction industry, but the practical application of BIM for management purposes is, however, still limited among contractors. The objective of this study is to review the current scheduling process of construction in light of BIM-based scheduling, and to identify how it should be incorporated into current practice. The analysis of the current scheduling processes identifies significant discrepancies between the overall and the detailed levels of scheduling. The overall scheduling process is described as an individual endeavor with limited and unsystematic sharing of knowledge within and between projects. Thus, the reuse of scheduling data and experiences are inadequate, preventing continuous improvements of the overall schedules. Besides, the overall scheduling process suffers from lack of information, caused by uncoordinated and unsynchronized overlap of the design and construction processes. Consequently, the overall scheduling is primarily based on intuition and personal experiences, rather than well founded figures of the specific project. Finally, the overall schedule is comprehensive and complex, and consequently, difficult to overview and communicate. Scheduling on the detailed level, on the other hand, follows a stipulated approach to scheduling, i.e. the Last Planner System (LPS), which is characterized by involvement of all actors in the construction phase. Thus, the major challenge when implementing BIM-based scheduling is to improve overall scheduling, which in turn, can secure a better starting point of the LPS. The study points to the necessity of involving subcontractors and manufactures in the earliest phases of the project in order to create project specific information for the overall schedule. In addition, the design process should be prioritized and coordinated with each craft, a process library should be introduced to promote transfer of knowledge and continuous improvements, and information flow between design and scheduling processes must change from push to pull.

Keywords: BIM, planning and scheduling, gap analysis, 4D-modeling, implementation

1. INTRODUCTION

The Critical Path Method (CPM) constitutes the prevailing technique for planning and scheduling of construction projects, since it was introduced in the late 1950s. CPM has proven to be a very powerful technique for planning, scheduling and controlling projects, especially for complex and non-repetitive work (Kenley 2006). However, despite the dominance of the CPM-method there is criticism raised on the method for the management of construction work. The criticism of CPM primarily refers to the inability to manage and monitor resource limitations in a way that corresponds to the reality of construction, i.e. work that to a large extent is characterised by repetition (Kenley 2006). Consequently, resources such as labour, building materials and equipment are seldom allocated to the scheduled activities despite the obvious requirement of work and resource coordination in construction works (Andersson and Johansson 1996). Thus, the activities, and their logical connections, are the principal focus of the CPM-method, whereas it is often assumed that there are unlimited resources available for executing the work. CPM-based schedules that are graphically represented by Gantt charts, the universal graphical

representation of schedules that was introduced by Gantt and Taylor in the early 1900, may result in discontinuous resource usage that in turn will lead to interruptions in the production where each trade suffers from recurrent starts and stops during the project process (Andersson and Christensen 2007). Together with the Gantt chart, CPM provides the common corner stone in the vast number of scheduling software tools available on the market (Kenley 2004).

The implementation of building information modelling, BIM, currently being adopted by many actors in the construction industry, will substantially change the way construction work is organized, performed and documented (Eastman et. al. 2008) and will allow for considerable improvements to the construction delivery process (Goedert and Meadati, 2008). The employment of BIM enhances trade coordination as it turns architectural and engineering design and management disciplines of cost estimating, time scheduling, constructability analysis, risk management, procurement, etc. into parallel and integrated processes (Kousheshi and Westergren, 2008). Though the benefits of the BIM are well documented and implemented among many architects and consultants working in the early stage of construction, the utilization of BIM for the management of construction work, e.g. scheduling, is, however, still about to emerge in industry (Goedert and Meadati, 2008).

BIM-based scheduling, also referred to as 4D-modeling or 4D CAD, in which the time schedule is linked to and visually presented by a 3D-model, is however widely recognised in research studies and literature (e.g. McKinney and Fischer 1998, Koo and Fischer 2000, Kamat and Martinez 2002, Kähkönen and Leinonen 2003, Heesom and Mahdjoubi 2004 and Chau et.al. 2005 among others). 4D-modeling bridges the gap between the 3D-modeling in the design phase and the planning and scheduling of the construction phase. 4D-modeling provides increased possibilities of identifying unanticipated problems and inconsistencies beforehand by viewing the graphical presentation, it facilitates the understanding of the scheduling results and supports the identification of potential time-space conflicts (Koo and Fischer 2000). The possibilities of evaluating and optimizing design and scheduling alternatives in the context of space and time is also brought out by Webb et.al. (2004) as a significant benefit of 4D-modeling, besides that it promotes improved integration and communication between the various participants in the construction process.

Besides the benefits of 4D-modeling identified, there are also obstacles reported on the path towards model-based scheduling for construction management purposes. Porkka and Kähkönen (2007) points out the lack of standardization as one major obstacle, addressing the need for software interoperability and information exchange. Another issue of 4D-modeling that concerns the software systems is the biased focus on aesthetic visualization of spatial-time process, with less developed options for analyses of the scheduling scenarios (Heesom and Mahdjoubi 2004). However, a 4D-representation can contribute greatly to the understanding of a complex schedule. Visual communication tends to increase the involvement of workers, since it allows rapid comprehension of and response to problems (Formoso, et.al. 2002). Consequently, BIM-based scheduling can contribute by illustrating the entire project to project participants, making it easier to envision potential issues, as activities are integrated with building components, time and cost. Thus, BIM-based scheduling can help to reduce risk by enabling project managers to collect, structure, and communicate vast amount of information. The superior communication abilities of BIM-based scheduling can be applied on a detailed as well as an overall comprehensive schedule level.

1.1 Problem Statement

Currently there is a major focus on the use of BIM. As companies start to implement BIM, it seems like a natural step to focus on 3D-design initially and exploit straightforward advantages like design coordination and clash detection. One opportunity to derive further advantages from BIM is to use it for scheduling purposes. But, what challenges are companies facing when implementing BIM-based scheduling? Moving towards BIM-based scheduling of construction implies a significant process of change that will include a number of technological, organizational as well as other challenges for all parties of concern. A change process of this magnitude requires a clearly formulated vision, strategy and communicated goal (Kotter 1999), besides an understanding and awareness of the need for change. Awareness of the need for change has its starting point in the current situation. Thus, a solid understanding of the current situation of scheduling in construction, its pros and cons, is necessary to analyze expected effects on the organization with the introduction of BIM-based scheduling.

1.2 Purpose and Objectives

The purpose of this study is to analyze current scheduling practice in construction and put forward arguments on how BIM-based scheduling can and should effect the organization. Consequently, there are three objectives in the study. One objective is to describe the current situation of scheduling in a case company. The second objective is to analyze the current situation in the light of BIM-based scheduling, and argue how BIM can be integrated to counter the challenges and support best practice work methods. The third objective is to analyze major necessary expected changes to the case company, if the transition to BIM-based scheduling were to be realized.

1.3 Definitions and Delimitations

There are numerous explanations and definitions of Building Information Modeling, BIM, available in literature, e.g. BIM constitutes *"a conceptual approach ... that encompasses three-dimensional (3D) parametric modeling of buildings ... and computer-intelligible exchange of building information..."* (Sacks et.al. 2010), *"… a set of interacting policies, processes and technologies…"(Succar 2009), "a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle"* (Penttilä 2006). (C. Eastman, 2009) refers to a building model *"as the basis for BIM"* and implies that *"BIM is a process."*

Thus, BIM is described in terms of an integrated process or as technology, and accordingly, the BIM-abbreviation refers to both Building Information Modelling as well as Building Information Model. The modelling understanding of BIM refers to the process of generating and managing (building) information in an integrated and collaborative way. It is the BIM process that generates the Building Information Model, which typically includes a 3D representation of the building with information about the building geometry and spatial relationship and quantities and properties of the building components etc. Thus, the Building Information Model constitutes a virtual mock-up that visualizes the building in 3D and enables the various actors of the project to add and retrieve information from the model through the lifecycle of a building. This study connects to the understanding of BIM as the collaborative process that involves and integrates the input from the various actors of the project.

The scope of the study is delimited to BIM-based scheduling. BIM-based scheduling of construction work is, in this context, described as the management processes that make use of, and add to, the Building Information Model of the project. The scope of the study is additionally delimited to the planning and scheduling process of construction, i.e. the coordination of the work activities that take place on the construction site and the processes in the tender and planning phase. Accordingly, the scheduling process is reviewed in light of the construction management team of the main contractor.

2. METHOD

The empirical foundation for the study is based on qualitative interviews, including both individual interviews and focus group interviews. All interviews were conducted within one Danish contracting company with 5.500 employees - MT Hojgaard a/s. MT Hojgaard has its own department for Design and Engineering, which masters 3D-design, but is only beginning to exploit the digital models for other purposes. 20 people participated in the interviews in total. All participants was explicitly selected from their field of expertise, age and knowledge regarding planning and scheduling.

First, individual and focus group interviews were performed with focus on challenges and best practice in scheduling on construction projects. These interviews included project managers, process managers and contract managers representing the operational and tactical level of the company. All interviews followed an interview guide which was sectioned by a holistic transformation process model covering input, process, and output. The model was used to keep focus on the entire scheduling process in the interview guide. The input part included topics like, but was not restricted to, quality, availability, type and integration of information in scheduling. The process part included subjects like interconnections, managing the schedules, responsibilities and automation. Topics concerning the output included use of the output, standards, communication and revisions of the schedules. The same structure was used at all the interviews. As the objective was to explore the current state of scheduling, the interviews was explorative and with open-ended questions.

Secondly, the same subjects were put forward to the interviewees with strategic responsibilities. Participants in this focus group included representatives from top management and senior management all with comprehensive knowledge of scheduling. The interview guide from the first group of interviews was used. However, as these interviews had a strategic focus, this second round of interviews generated completely different outcomes. The purpose of the strategic interviews was to gather information on long term effects of the challenges and best practice of scheduling on the organization. The study is carried out with the purpose of describing one case in depth. Thus, in this study there has been no attempt to generalize the results. The end result is summarized and represented in the following section.

3. THE CURRENT SCHEDULING PROCESS

The account of the current approach to scheduling is divided into two sections. The first section describes the overall scheduling level that comprises the whole project and the second reports on the detailed level that covers a period of one to five weeks. The choice of this outline rests upon the fundamentally different approaches to scheduling identified at the overall and the detailed level.

3.1 The overall level of planning and scheduling

The overall planning and scheduling level refers to the so called production schedule, which is established by the main contractor in the planning stage when the contract has been signed and the onsite activities are to be prepared. The master schedule, which is the most comprehensive schedule, typically established by the client, provides an overall framework for the production schedule. However, the master schedule is primarily considered a legal document, enclosed the contract, and has limited impact on the planning and scheduling of the production. Thus, the overall planning and scheduling in this context refers to the production schedule established by the general contractor.

The overall planning and scheduling process is to a large extent characterised as being an individual endeavour, closely related to the knowledge, professional skills, role and identity of the project manager who establishes the schedule. Managing the scheduling process implies a significant amount of control, power and influence on the production process, and thus, being individually responsible for the scheduling contributes to the role and impact of the project manager. - *"Scheduling does not follow an outlined and predefined process ... different schedulers have their own personal planning and scheduling process."* Scheduling, at the overall level, relies to a significant extend on intuition and the personal experiences of the project manager, rather than on complete well known figures about the construction project and its context. Another example of the individual dimension that characterises the scheduling process at the overall level is stated as - *"Scheduling is an inspirational and intuitive endeavor. The principal scheduling input is not provided by explicit figures and facts about the project, instead the choice of relevant production methods, the establishment of activities and their interconnections, assessment of durations etc. rely on personal experience and intuition of the construction manager."*

The strong support on intuition and personal experience is, as explained by the project managers, partly a consequence of the overlap between the design and the production phases which delimits the available amount of information in the early planning phase. The building design stretches into the construction phase, although the design is expected to be complete when construction starts. As the design is not complete when needed, necessary information for the overall scheduling is often unavailable. Thus, insufficient communication and scarce coordination of work between the design and the production teams render difficulties for the planning and preparation of the onsite production. However, when the information is available, the project managers often find it difficult to assess and take in the information that is of relevance for scheduling purposes. The overload of information in this context refers to the vast number of drawings, project specifications, contracts, etc. that constitute the extensive project documentation, which is difficult to assimilate and to use as a basis for understanding the project and its characteristics. One problem highlighted in connection to the drawings was that there are too many of them, and the content is not for scheduling purposes but for construction purposes. -*"The amount information in the drawings is difficult to grasp. The vast number of different drawings (A and E) made it*

difficult to get an overview of the project. Rather than going through the set of drawings, the scheduler gets introduced orally to the project by the appointed project manager and the management team." It is the pronounced generic characteristics of the overall scheduling that enables and allows intuition and experience, with only limited consideration of project specific figures, to be the prominent scheduling characteristics at the overall level. - *"The fundamental structure and sequence is basically the same in every building project, which means that part of schedules can be stored and reused in a subsequent project, e.g. the assembly sequence of an elevator, an interior wall, etc., after adjusting the durations of the respective activities."* Another of the interviewed project managers had, however, a different view on this subject. -*"The projects are unique, so it is not possible to reuse parts of other schedules. It is easier to create a new schedule for every project."* The conflicting opinions can both be considered valid depending on the level of detail by which the project is observed. If the construction project is considered on an overall level, very few buildings are identical. However, different construction projects can easily comprise of parts, subsystems or technical solutions which is similar from project to project. Thus some employees find that data of scheduling can be reused and some do not. Regardless of how a project is perceived by the individual employee, the fact is that there is no systematic storage and reuse of scheduling data presently in the case company. Consequently the transfer of knowledge between employees is mostly through personal relations. The case company has launched an initiative, teaching all project managers a standard for scheduling, in order to support knowledge sharing. Despite this effort, the use of the same scheduling standard does not promote knowledge transfer. The individual character of the current scheduling procedure impedes the sharing of scheduling knowledge and skills between colleagues in the projects and in the company. Thus, the approach to scheduling, i.e. how the scheduling process is designed, the information content etc., is again an example of an individual choice by the respective project manager. -*"There are no company processes securing the quality of the schedules, but some best cases are made available on the intranet."* - *"... the company does not express any explicit rules and requirements regarding the schedules developed in a project."*

The traditional scheduling method of CPM and Gantt charts, supported by MS Project, constitute the prevailing approach to scheduling. A Gantt-schedule of a general building project includes about 2 000 – 3 000 interlinked activities. The vast number of activities and links make it difficult to get an overview of the work processes of the project, besides it is difficult to communicate the schedule to subcontractors, suppliers and other actors involved in the project. - *"It does not make sense to make a printout of the schedule or to send it to the subcontractors. It is simply too extensive and I guess I am the only one who can fully understand and read it."* Further, the comprehensive and complex structure of the overall schedule makes it difficult to use as a tool in the daily management and control of the project, i.e. the progress control. -*"… the plans are typically not updated because changes keep coming in and the focus is elsewhere."* - *"If a master plan is too detailed, it will not be used because the craftsmen and other users loose the overview of the plan."* - *"The schedule for the KPMG-project consists of 5000 separated activities, which is of course difficult to use as a basis for progress control."*

3.2 The detailed level of planning and scheduling

The most significant and important improvement of the scheduling process through recent years is represented by the implementation of the Lean Construction philosophy and the Last Planner System, LPS in the construction phase. The interviewees emphasised, in concordance, the importance of the so called process planning and the LPS, in which all actors of concern, meet, discuss and add their professional knowledge and skills as input to the coordination of work. The involvement and commitment of the various actors of the project creates a strong sense of ownership for the plans and schedules that are established. - *"Acceptance and ownership of the schedule is a key issue in scheduling. Scheduling is about communication – input as well as output."* - *"Dialogue, involvement, a sense of ownership and commitment to the schedule among all suppliers to the project is fundamentally crucial to the acceptance and successful implementation of all of the scheduling in the project."*

LPS puts focus on the day-by-day management of the onsite activities, with a narrow scheduling range of one and five weeks. Despite the short time scope, LPS is dependent on the overall project conditions, e.g. if the overall schedule includes fragmented and overlapping activities then the beneficial contribution of the detailed scheduling is reduced. Thus, the quality of the overall level of scheduling sets the conditions for the detailed level, but the interconnection between the scheduling levels is currently insufficient. One project manager describes this

issue according to the following quote: - *"The interconnection between the top down and the bottom up scheduling is critical. [...] Early decisions are based on the top down schedule, but this provides an insufficient information basis at the time. The problems that follow will show up in the detailed bottom-up scheduling. The two scheduling approaches should eventually meet, and hopefully correspond. However ... the overall schedule provides an insufficient information basis for the detailed weekly scheduling process."*

The disconnection between the overall and the detailed scheduling, referred to as top-down and bottom up planning in the quote above, must be considered a major challenge and drawback in the current scheduling process as it impairs the power of the LPS on the detailed level.

4. MOVING TOWARDS BIM-BASED SCHEDULING

The current state analysis of the planning and scheduling process reveals significant discrepancies in the approach to scheduling at the overall and the detailed levels. The overall scheduling process is described as an individual endeavour carried out by the project manager or the management team of the main contractor. As the overall scheduling is performed individually, sharing of knowledge is restricted to unsystematic personal initiatives. Thus the reuse of data in scheduling is limited in the case company which, further, creates a challenge of continuous improvements regarding the overall schedule. In addition, the design and construction processes overlap, are separate and unsynchronized, resulting in absence of necessary information to the overall schedule. This leaves the overall scheduling to be based on intuition and personal experiences, rather than extensive and explicit figures of the specific project. Finally, the overall schedule is deemed comprehensive and complex, and consequently, difficult to overview and communicate to other project participants. Scheduling on the detailed level, on the other hand, follows a stipulated approach to scheduling, i.e. the LPS, which is characterized by participation and involvement of all actors on a project in the construction phase.

Thus, the main goal with the introduction of BIM-based scheduling in this context must be to ensure a better match between the top-down overall scheduling and the bottom-up scheduling approach of LPS. As the interviewees express great satisfaction towards the LPS, focus for further improvement of scheduling should be directed towards the overall top-down scheduling. By ensuring improved overall schedules, the project team will have a better starting point for the LPS and in turn more precise control of the project and finally improved risk management of time.

4.1 Personal experience and intuition, design coordination

Although the potential and importance of early involvement of subcontractors is clear, it is limited to the construction phase. By including the subcontractors in the early tender and planning phase, qualified and project specific information can be include in the schedule – similar to LPS. However, the manufactures also have a lot of knowledge regarding time consumption and processes, related to their products. E.g. several lift manufactures supply both the physical product and mange the installation process. Thus both subcontractors and manufactures should be included in the initial planning phase of a construction project to provide scheduling input. Incorporating direct input from subcontractors and manufactures in the overall schedule can potentially enhance the precision and create a closer connection to the bottom-up planning of LPS. However, there will still be a problem of missing information due to late design decisions.

4.2 The design continues into the construction phase

One option is to design the building completely before construction starts as it is expected to currently. However, this is, as described, difficult to obtain currently and it is uncertain whether the introduction BIM can counter this issue. Another option is to allow for design alterations in the construction phase and promote coordination of the design effort. By incorporating subcontractors and manufactures early in the design phase, the project team could decide on the macro design and prioritize solutions fundamental to the progress of the project. Thus, in a collaborative effort the project team could decide on which areas, elements or systems that must be readily designed before construction can start. Only when the macro design has finished, and agreed upon by the engineer, architect, contractor, and client, construction can commence. During construction, the coordination

process between design and construction can continue, but with focus on the earlier de-prioritized areas of the building. By introducing this form of concurrent engineering to overall scheduling, the construction team can obtain the right information, at the right time in the right level of detail. Thus, involvement of subcontractors and manufactures can address both the issue of schedules being created from personal intuition and experience as well as the issue of absent information due to the uncoordinated design process. However, the use of subcontractors and manufactures does not secure knowledge sharing and continuous improvements of the overall scheduling internally in the company.

4.3 Knowledge sharing and continuous improvements

The case company will need to secure information obtained on each project with the goal of reusing it. However, as stated earlier, many participants in the interviews supports the view of construction projects being unique, while others find the final product unique, but with several sub-systems and the associated processes are repeated in most cases. If it is assumed that objects and consequently processes can be reused, it would be obvious to create an object library. The concept of an object library is well known. E.g. Autodesk Seek. Each BIM-object is stored in a database containing relevant information or links to information for the specific object. Likewise, a library for processes could be created containing historic data of how systems, subsystems or objects from the object library were processed. However, it is unlikely that each object, subsystem and system in the object library, can be linked to standard processes and reused directly on new projects. E.g. the same window installed on the 20^{th} floor in an apartment building and in a single story house, would require different processes. Thus it is unlikely that the schedule can be created directly by use of object from prior projects. Despite this challenge, a process library could supply historic data in areas of the master schedule where information from subcontractors and suppliers is not obtained, due to the time pressure in the tender, design and construction phase. Thus, with the use of BIM-based scheduling, the master schedule can be created from explicit knowledge from subcontractors and suppliers on highly prioritized areas of the project, while the remaining parts can be created from the library until there is time to detail it. Consequently, the purpose of the library will be to create a foundation from which the schedule can be created. Expectedly it will always require a critical approach from individuals with explicit knowledge. However, a process library can support systematic use of data, knowledge sharing and function as a starting point on each new project. Further, the introduction of the library is obviously a long term investment, and it will probably take a few years to become effective. However, it also has the potential of countering the challenge of continuous improvements of overall scheduling in the case company. As there undoubtedly are numerous challenges combined with the creation and implementation of a process library, it is an apparent subject for future research.

4.4 Information overload

As stated in the previous section there is currently an issue of information overload from drawings and specifications of the design. Thus, the introduction of BIM-based scheduling should ensure that only relevant information is processed. Consequently, when transitioning into BIM-based scheduling, the flow of information from the design to the scheduling processes must change from the current push approach to pull. Instead of basing the overall scheduling on technical drawings and specifications, the person accountable for the schedule should be able to pull necessary information from the design, at the relevant level of detail. However, with the use of BIM, both options are possible. Potentially, the case company can continue to produce and use technical drawings and specifications as basis for the overall scheduling even if BIM is introduced. Consequently, in order to counter the current problems of improper information for scheduling purposes, the case company must transform the tendency of pushing out information in terms of drawings and specifications and allow employees to pull information from a model or other information source.

4.5 The overall schedule is comprehensive and complex

BIM-based scheduling is an obvious solution to the issue of comprehensive and complex schedules. Communicating the overall schedule, regardless of the complexity of the schedule, has proved to be very effective

with BIM-based scheduling and it is well documented, as stated in the introduction. However, there is a difference between communicating the end result of a schedule in a 4D-animaiton and working with the underlying schedule. If the schedule contains several thousand activities, it will still be difficult to overview work in progress despite introduction of BIM-based scheduling and 4D-animations. Thus, although BIM-based scheduling has potential of enhancing communication of the schedule, another tool or approach is needed to promote the usability and comprehension of the schedules under development. One option is to introduce Location Based Scheduling (LBS). Jongeling and Olofsson (2007) claim that Location-based scheduling (LBS), which combines the dimensions of time and location of the activities of the project, can enhance the usability of 4D-modeling for improved work-flow analyses of production via the Line of Balance method. As Line of Balance summarizes similar activities and illustrates them by location and time with lines, an overview of the entire schedule can be shown in one single diagram. As commercial software which integrates LBS with BIM is readily available, and the advantages of LBS and BIM are well covered in the literature, this issue will not be subject of further analysis in this paper.

5. CONCLUSION

Overall the study finds that most challenges with scheduling in the case company originate from the early stages of the construction project. The case company has great success with the LPS in the construction phase, scheduling and controlling the project from the bottom up. The major challenge is to create trustworthy overall schedules. The issue is that, the detailed bottom up scheduling of the project builds on assumptions created in the early phases from the top down approach of the overall scheduling. Accordingly, there is a clash between the two scheduling approaches, with most issues originating from the overall schedule. One challenge is that the overall schedule is created from personal experience and intuition. This limits accuracy of the schedule and in turn the trustworthiness. In addition, as the overall schedules are created from personal experience and intuition, it is difficult to share knowledge systematically and thus secure continuous improvements. Moreover, necessary information to the overall schedule is often limited, as the design and construction processes overlap, are separate and unsynchronized. This again, leaves the overall scheduling to be based on intuition and personal experiences, rather well defined figures of the specific project. Finally, employees accountable for the overall schedule have difficulties processing the vast amount of information stored in the building design, as schedules are created from technical drawings and specifications not suited for scheduling purposes.

As BIM-based scheduling is an ambiguous concept and has no bounded goals, configuring and implementing the technology is very much a matter of adapting it to the needs and current state of the organization. In this case it is evident that BIM-based scheduling cannot solve the current challenges without a restructuring of processes, work methods and norms. Involvement of subcontractors and manufactures in the very beginning of a project is vital for the success of BIM-based schedule in this case. If scheduling is not based on project specific figures, little is gained with BIM-based scheduling. There might be an advantage of visualizing the schedule in a 4D-animation, but if the schedule is not based on input derived directly from the design and realistic solutions, the full potential of BIM-based scheduling is not exploited, and the current issues are not addressed. However, if subcontractors and manufactures are involved, BIM-based scheduling can constitute a centralized platform for coordination and communication between the design team, subcontractors, manufactures and the person accountable for the overall schedule. Involvement of subcontractors and manufactures can also play an important role in coordinating and prioritizing the design effort, effectively securing a trustworthy project specific estimate of time consumption at the right level of detail and at the right time. Securing transfer of knowledge between knowledge and employees and reusing it for continuous improvements purposes is also a challenge which is dependent new work methods if BIM-based scheduling is implemented. Although not unproblematic, a process library, linked to an object library can potentially form the foundation for the overall schedules and fill out gaps where project specific knowledge has not yet been obtained from the subcontractors and manufactures. Applying a library of processes enables experience from prior projects to be transferred and reused on new projects. The historic data can obviously not be applied uncritically. Human judgment will still be of essence. However, a process library can potentially increase effectiveness and promote knowledge transfer as data can be shared systematically. Solving the current challenge of information overload with BIM-based scheduling also requires

renewed work methodologies. When introducing BIM-based scheduling, the system must allow that information is pulled from the design, contrary to the push of information which occurs presently. By pulling the information from the design, the person accountable for the overall schedule, subcontractor or manufacturer can sort out unnecessary details, ending up with more comprehensible data for use in the overall schedule.

Conclusively, introducing BIM-based scheduling is not a question of simply applying a new tool to the current organization. Without a thorough change of current practices, norms and processes BIM-based scheduling can only improve some of the challenges faced by the case company. In fact, several of the challenges could be countered without the use of BIM-based scheduling. However, the challenges have not been resolved so far. Thus, BIM-based scheduling can solve some challenges directly and concurrently be the mean to initiate and facilitate new processes, work methods and norms which counter the remaining challenges of scheduling in the case company.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude towards MT Hojgaard a/s and all participants from the interviews for open straight forward answers and clearly useful information.

REFERENCES

Andersson, N. and Christensen, K. (2007) "*Practical Implications of Location-based Scheduling*", CME25, Construction Management and Economics: Past, present and future, July 16-18, Reading, UK

Andersson, N. and Johansson, P. (1996), "*Re-engineering of the Project Planning Process",* CIB W78 Construction on the Information Highway, Bled, Slovenia.

Chau, K.W., Anson, M. and De Saram, D.D. (2005) "4D dynamic construction management and visualization software: 2. Site trial, Automation in Construction, Vol. 14, Issue 4, pp. 525-536

Eastman, C., Teicholz, P., Sacks, R., Liston K. (2008), *BIM Handbook A guide to building Information Modeling for owners, Managers, Designers engineers, and Contractors.* John Wily & Sons, Inc.

Formoso, C.T., Santos, A.D. & Powell, J.A. (2002), *An Exploratory Study on the Applicability of Process Transparency in Construction Sites*, World Scientific Publishing Company.

Goedert, J. and Meadati, P. (2008) "Integrating Construction Process Documentation into Buidling Information Modeling" Journal of Construction Engineering and Management, ASCE, pp 509-516

Heesom, D. and Mahdjoubi, L. (2004). Trends of 4D CAD ap-plications for construction planning. Construction Manage-ment and Economics, Volume 22, Number 2, February 2004, pp. 171-182(12).

Jongeling, R. and Olofsson, T. (2007). "A method for planning of work-flow by combined use of location-based scheduling and 4D CAD. "Automation in Construction 16(2): 189-198.

Kamat, V.R., and Martinez, J.C. (2002). Comparison of Simulation-driven Construction Operations Visualization and 4D CAD. Proceedings of the 2002 Winter Simulation Confer-ence E. Yücesan, C.-H. Chen, J. L. Snowdon, and J. M. Charnes, eds.

Kenley, R (2004) Project Micromanagement: Practical site planning and management of work flow. *In: 12th Annual Conference on Lean Construction*, 3-5 August, Elsinore, Denmark. International Group of Lean Construction.

Kenley, R (2006) Location-based Management. *In: 31st AUBEA Conference*, 11-14 July, The School of the Built Environment, University of Technology Sydney, Australia. Australasian Universities Building Educators Association (AUBEA)

Koo, B., Fischer, M. (2000). Feasibility Study of 4D CAD in Commercial Construction. Journal of Construction Engineering and Management, Vol. 126, No. 4, July/August 2000, pp. 251-260.

Kotter, J. P. (1999); What effective general managers really do. Harvard Business Review, Vol. 77, Issue 2, pp. 145-156

Kousheshi, S. and Westergren, E. (2008) Building Information Modeling and the Construction Management Practice: How to Deliver Value Today?, Emergin Technologies Committee, BIM White paper. Construction Management Association of America.

Kähkönen K. and Leinonen J. (2003): Visual product Chronology as a Solution for Accessing Building Product Model Data. *Proceedings of the CIB W78 conference*, Auckland, New Zealand.

McKinney, K., and Fischer, M. (1998). Generating, evaluating and visualizing construction with 4D-CAD. Automation in Construction, 7(1998), 433-447.

Penttilä, H. (2006) "Describing the changes in architectural information technology to understand design complexity and free-form architectural expression", ITcon Vol. 11, Special Issue The Effects of CAD on Building Form and Design Quality , pg. 395-408, www.itcon.org/2006/29

Porkka & Kähkönen (2007): Software Development Approaches and Challenges of 4D Product Models. *Proceedings of the CIB-W78 conference*, 2007, available at: http://itc.scix.net/data/works/att/w78-2007-013-096-Porkka.pdf

Sacks, R., Kaner, I., Eastman, C.M. and Jeong, Y.S. (2010) "The Rosewood experiment - Building information modeling and interoperability for architectural precast facades", Automation in Construction, Vol. 19, Issue. 4, pp. 419-432

Succar, B (2009) "Building information modelling framework: A research and delivery foundation for industry stakeholders", Automation in Construction Vol. 18, pp 357–375

Webb, M., Smallwood, J. and Haupt, T.C. (2004) "The Potential of 4D CAD as a tool for construction management" Journal of Construction Research, Vol. 5, No. 1, pp. 43-60

Internet:

(C. Eastman, 2009), http://bim.arch.gatech.edu/?id=402, updated August, 2009, accessed September 2010.