# A BIM-supported framework for enhancing joint planning in construction

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## Abstract

Modern construction planning philosophies, such as The Last Planner System (LPS), stipulate that those performing the work on site should participate in the planning. In this paper we describe and analyze a variant of LPS that is currently in use in a Scandinavian construction company and explore the possibilities to enhance the process by integrating the use of Building Information Models (BIM). The study is based on the observations of three planning workshops together with a set of semi-structured interviews. Based on the analysis and findings from the workshops we outline the theoretical design of a Computer-Supported Cooperative Work-System (CSCW) that integrates BIM more closely in the method.

**Keywords:** 4D-planning, BIM, collaborative planning, construction planning, CSCW

## 1 Introduction

Construction planning has basically been the same since the late 1950s with the introduction of the Critical Path Method (CPM). This activity based planning method owes much to the work of Taylor and Gantt in the early 1900s (Kenley and Seppänen 2009). In the last couple of decades an alternative to activity based planning has become increasingly popular, namely location based planning, which combines activity time with location. Location based planning combined with the line-of-balance method make it possible to visualize plans that would be hard to visualize in a readable way using traditional activity based techniques as CPM (Büchmann-Slorup and Andersson 2010). The downside of location based planning is that more information than in CPM is required due to the extra dependencies of time tied to location that is added (Seppänen, Ballard and Pesonen 2010). This enhanced need for information has emerged in parallel with the introduction of Building Information Models (BIM). This has also been followed by the change from drawings and descriptions as the main media of communication to an increasing use of information rich 3D models (Sacks *et al.* 2010).

Furthermore, studies have shown that day of the site-manger becomes increasingly more divided and tasks such as planning and scheduling becomes less prioritized. To meet this decline in available time, roles such as specialist planners has been introduced. The use of these specialist planners decouples the site-management from the decisions of the planning (Winch and Kelsey 2005). This has led to a situation where the schedules seldom are used as intended but rather acts as a loose guideline, often with the argument that the schedule was not realistic anyway (Winch and Kelsey 2005). Further Winch and Kelsey (2005) concludes that to get more realistic schedules, the works contractors should be included in the planning. This is one of the core concepts in lean production, where empowerment and the involvement of the workers is vital to reduce waste of time and increase quality (Liker 2005). The response in the construction industry has resulted in the adoption of lean production concepts in the form of lean construction (Ahuja and Thiruvengadam 2004). This has led to lean construction tools such as Last Planner (Ballard and Howell 2003). The Last Planner System (LPS) actually stipulates that those performing the work should participate in the planning (Ballard and Howell 2003). As lean construction and LPS has evolved in parallel with BIM studies of the possible interaction has been conducted and reviewed. Sacks *et al.* (2010) found several potential benefits between BIM capabilities and lean principles, in fact most of the benefits where clustered around BIM capabilities concerning construction management and fabrication rather than design, where the current implementation of BIM is strongest. Sacks *et al.* (2010) also found that key problems of BIM at the moment are the underutilization of the BIM as well as interoperability issues. According to Bhatla and Leite (2012) no framework for implementing BIM and LPS exist today and is therefore needed. As they identify the integration of BIM and LPS can help filter work packages and thus help in communicating standardised processes to workers.

As it is today, several theoretical systems of BIM planning systems exist, but few have actual practical implementations. Hartmann *et al.* (2012) attributes this to development of new processes as well as technologies, thus creating a technology push. The result is that the technologies are not adopted since the willingness and time to alter the processes is not available and the danger of loosing productivity is too big of a risk. To get a wide adoption of new software and technologies it is vital to support current processes rather than invent new ones. Hartmann *et al.* (2012) further concludes that it is possible to some extent alter current BIM-tools to support the process.

## 2 Problem statement

The purpose of this study is to analyze a current planning-processes in a Scandinavian construction company and explore possibilities to enhance the planning process with BIM. Through a literature review, observations and a set of semi-structured interviews the current process is mapped and verified in theory, areas of improvement identified and the framework for the software design constructed. Thus two objectives of the study is clarified:

1. Study the current planning process and BIM use.
2. The theoretical design of a software prototype for enhancing the said planning process.

## 3 Related work

This section describes a selection of planning and collaboration systems and their implementations. The collaboration between stakeholders in computer systems is often termed Computer Supported Collaborative Work (CSCW) (Grudin 1994). Through the human-computer interaction the CSCW system aims to help the participants to build a shared understanding of a common problem. This often bring about new insights and knowledge building and has also shown to help groups reach consensus as well as aided in decisions (Arias *et al.* 2000, Fischer 2000). CSCW has been used to describing the different interaction possibilities in computer systems and are often systematized in a space/time matrix (Boton, Kubicki and Halin 2013, Grudin 1994).

Research around planning and 3D models, also known as 4D planning has been an active topic both before and after the broad adoption of BIM (Boton, Kubicki and Halin 2013). Seppänen, Ballard and Pesonen (2010) gives a detailed description of how a combination of LPS and a location based management system (LBMS) has helped in bringing better schedules for the studied companies. Seppänen, Ballard and Pesonen (2010) studied a series of workshops that used the collaborative LPS. Here sticky notes where used to represent individual activities. The workshops started with the milestones in the master plan and worked backwards, utilizing pull planning for the activities. A key component of the workshops were that the specialists brought their knowledge to the planning of their activities, in line with the theory behind LPS. The combination of LPS with location based planning is symbolized through the use of a location based management system, visualizing the activities as flow-lines. The final workshops consisted of a collaborative optimization of the flow-line schedule (Seppänen, Ballard and Pesonen 2010). The system described above has not been fully implemented yet but the results shows that it is promising. The system exemplifies a CSCW system that utilizes a same-location as well as same-time approach to planning.

Several of the initiatives regarding BIM and 4D planning utilize a different approach, focusing on a different-place, same-time/different-time approach, utilizing the web. Waly and Thabet (2003) describes the main directions for research in digital planning system. They highlight three main areas of development, first the black-box systems, second the combination of 3D and scheduling-systems, and lastly the combination of these two systems. The black-box systems consist of software where the decisions made in scheduling are programmed into the system before any planning takes part. This has the effect that the software creates the logic, without the user partaking in scheduling decisions. The second system combines traditional schedules with the 3D-model. Here the user makes all decisions, without the aid of the system. The third option is a mix between the two, where the user gets assistance in decisions, but ultimately the user takes the final decisions. Furthermore Waly and Thabet (2003) conclude that most 4D system implemented to date forces the user to do the planning in a separate program and then connect the plan to the model afterwards. The system they describe in their paper builds on the 3D-CAD program and an interactive click-and-drag-release approach where the building is virtually constructed. The key point is that the databases support the planning decisions but still puts the planner as the decision maker (Waly and Thabet 2003). The system described is a CSCW-system that allows both different-time and same-time combined with different-location interaction since it is a single user interface connected to a database.

One of the major obstacle for 4D systems being adopted are, according to Büchmann-Slorup and Andersson (2010), the fact that there is a lack of standardisation of the BIM format. Neutral file formats like IFC shows promises to help in this area. Furthermore Büchmann-Slorup and Andersson (2010) argues that BIM can help in supporting implementation of LPS, since BIM helps illustrate the project for all participants. Apart from carrying information needed in the planning process the BIM also helps in communicating up and down the organizational levels, ensuring that what is being planned actually is what is built. When implementing BIM-based scheduling, ensuring that information is pulled from the design is important, leaving the one responsible for certain task to filter the needed information from the model (Büchmann-Slorup and Andersson 2010). One implementation of 4D in their paper exemplifies a CSCW-system with fully separated location but same-time allocation. This system is implemented using the web with a client/server approach (Zhou *et al.* 2011). The system utilizes IFC for classification ensuring that division by discipline is feasible. One of the conclusions in their article is that real-time collaboration is possible but demanding, especially since it needs good social interaction as well as 3D-models (Zhou *et al.* 2011).

The current use of BIM in clash-detection and design coordination may be formed through the more easily observable benefits of BIM (Büchmann-Slorup and Andersson 2010). The use of BIM in planning and scheduling is still low. As observed by Büchmann-Slorup and Andersson (2010) the need for a solid understanding of the current situation and the expected effects of the introduction of BIM-based scheduling, is vital. This paper builds upon these observations and extends them through observations of a current planning processes where BIM are available but not used to its full extent. Thus in the following sections the paper describes the development of a BIM enhanced collaborative planning process.

## 4 Method

This article represents the analysis and design phase of a design science cycle. The papers empirical foundation is a set of 7 semi-structured qualitative interviews together with three observations of workshops besides the literature review. The interviews were conducted on-site as one hour interviews with one worker from the prefabrication sub-contractor, two workers from the ventilation sub-contractor, one from the plumbing sub-contractor, two from the sprinkler sub-contractor, one from the electricity/safety sub-contractor and lastly one from the site supervision.

An additional interview with the specialist planner behind the workshops, called Location-based Production Planning (LPP), was conducted off-site in order to understand the background of the method. The interviews were recorded and transcribed in verbatim. The purpose of the interviews was to gain insight in the thought processes and information needed in planning work activities. The interviewees, apart from the specialist planner, were not the same as the participants in the workshops. This was due to the fact that the project had not reached the right level when the interviews needed to be conducted.

The remainder of the study was then conducted as a participant observation, in order to understand how the LPP-method was conducted in action. This enabled hands on experience of an LPP-workshop and enabled and deeper insight in how the method and workshop interacted. The observations were recorded through field-notes after each workshop. These were then coded and analyzed. The processed field-notes together with the interviews as well as previous works acted as an input for the framework for the prototype software.

### 4.1 Delimitations

The scope of the study is delimited to construction planning and scheduling in the pre-construction phase. The planning is restricted to phase planning and as such concerns mostly the contractors and sub-contractors on-site. Further the scope is limited to the description of the design of the software prototype. The software prototype is conceptually constructed but the actual creation of the software prototype is outside the scope of this paper. As a final remark of the delimitations, it is worth noting that the cultural context of an Scandinavian construction company acting in Scandinavia may have implications for the ability to generalize the results.

## 5 The current collaborative planning process – pre-workshop

The main reason for these collaborative workshops was to involve all actors in the project. Thus firmly anchoring the construction schedule with the ones responsible for performing the actual work-packages. The schedule that was the result of the workshops was a detailed phase schedule, with each of the activities durations specified in full days. Before the workshop the specialist planner divides the project into zones as well as levels. These zones are then rated in a hierarchical structure, where the most critical zones are prioritized. The specialist planner also gathers the available material in the form of drawings, descriptions and BIM-models and makes sure that each participant in the up-coming workshop has access to all the information they need.

After this, the workshop was called and conducted. The workshop was held in an ordinary conference-room with the walls filled with project information. Drawings of each level as well as the ground-works hung on the walls together with drawings illustrating the divisions of zone at each level. On two of the walls big blank sheets of paper were hung, these were used to sequence the activities. The workshop is broken into three parts, the first, stage one illustrated in figure 1, is the walkthrough of the model. This is followed by stage two, the individual planning of activities (illustrated in figure 2). The final stage is stage three (illustrated in figure 3), where the collaborative assembling of the activities in the sequence they are supposed to be built, is performed.

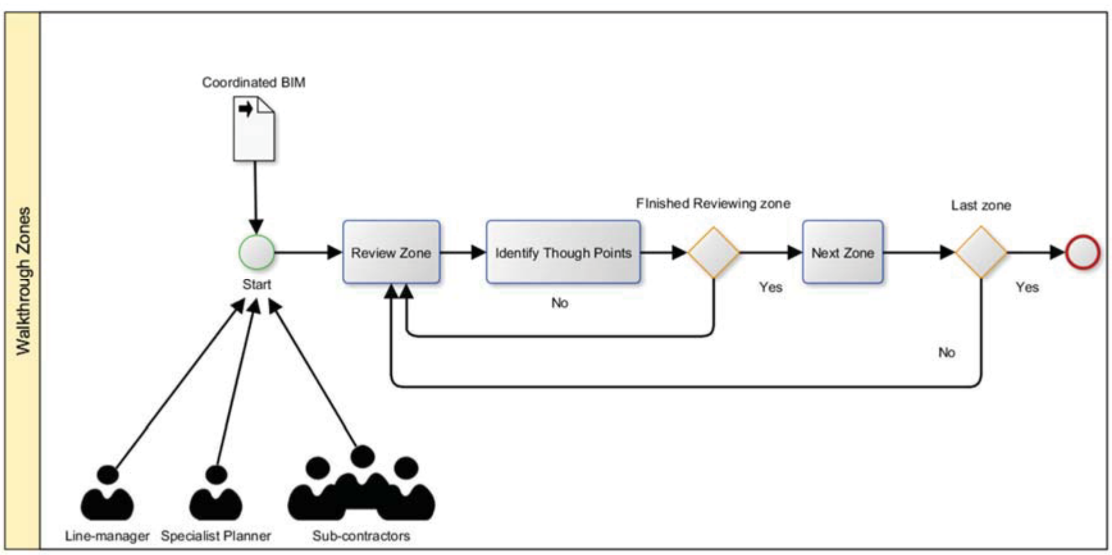


**Figure 1: Process mapping of stage 1 - Walkthrough.**

### 5.2 Workshop stage 1 – walkthrough

In the workshops observed the first task on the list was a short presentation round to get an indication of the participant's affiliation. This also serves as a short get-to-know-one-another exercise. Of the three workshops observed the presentation was only done in the first two, and only because all participants were not present at the first workshop. In this stage the main use of the BIM was observed. Here Solibri Model Checker (SMC) were used to navigate through the zones. At the second workshop this stage was combined with a briefing of the currently planned activities. The participants had a hard time following along in the model, mostly since the route through the model was by each zone. And the zones where view by how critical they were for the project. The ordering of zones this way meant that there was no straight way through the model, but rather a constant zigzagging between levels and different zones in each level. Further confusion was added since the participants tried to map the 3D screen to the corresponding locations on their drawings, an arduous task since the zones was not supplied on the drawings.

### 5.3 Workshop stage 2 – distributed work

After the walkthrough was done, the workshop was split into sub-groups by contractor/sub-contractor. Now each of the participants estimated their tasks on sticky-notes, noting activity name, duration and resources. This was repeated for each activity in each zone. This activity took a couple of hours and during this work the participants actively used their drawings and descriptions to try to understand each zone and the requirements. The participants also actively inquired each other if need for additional information was needed, especially concerning how certain elements interacted between professions. On occasion some of the participants even took the help of the BIM to understand certain situations. Figure 2 illustrates the process during the workshop of stage 2.

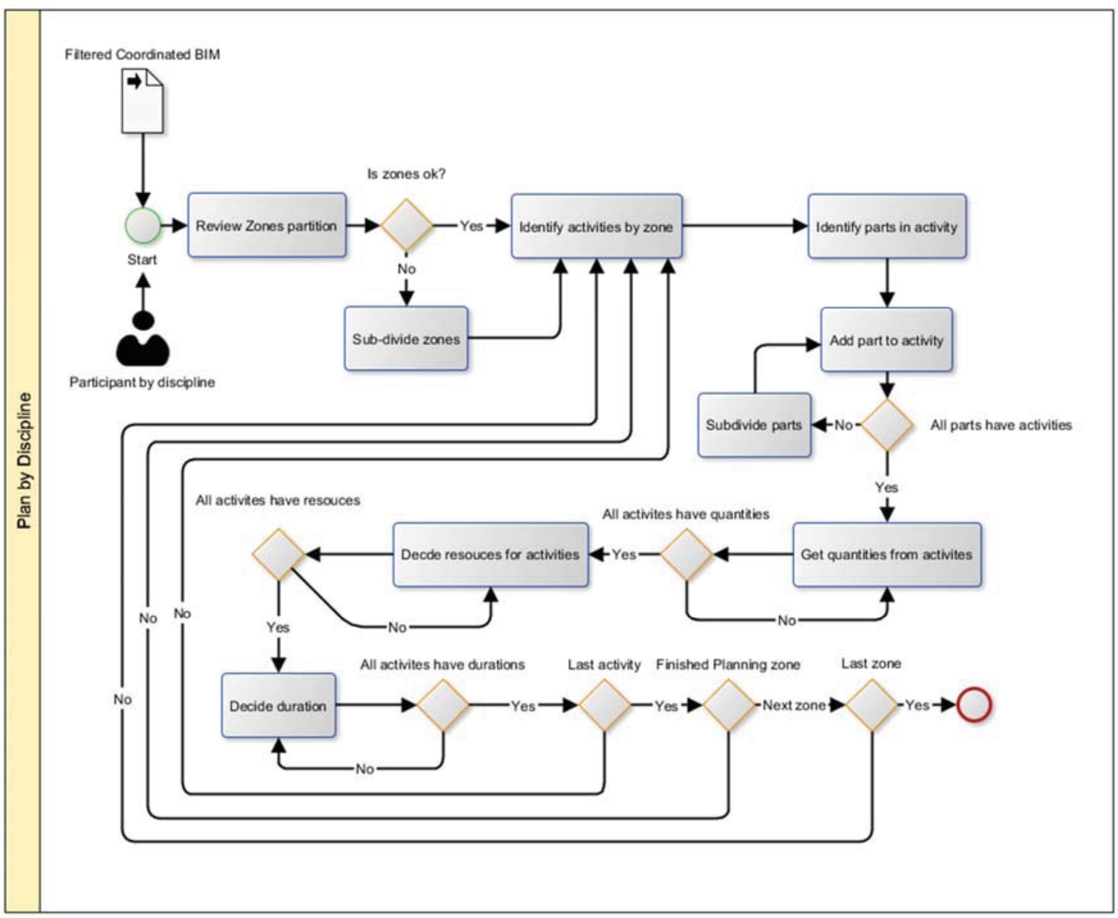


**Figure 2: Process mapping of stage 2 –Planning by discipline.**

### 5.4 Workshop stage 3 – Manual assembly

The third stage of the workshop was a collective and collaborative exercise. Each of the zones where reviewed and activities posted on the big sheets of paper on the walls. The activities were posted in the order they were to be constructed, thus manually assembling the project. Each of the activities was connected with predecessors as well as successors, forming a schedule prepared for manual input into the scheduling software. This is illustrated in figure 3.

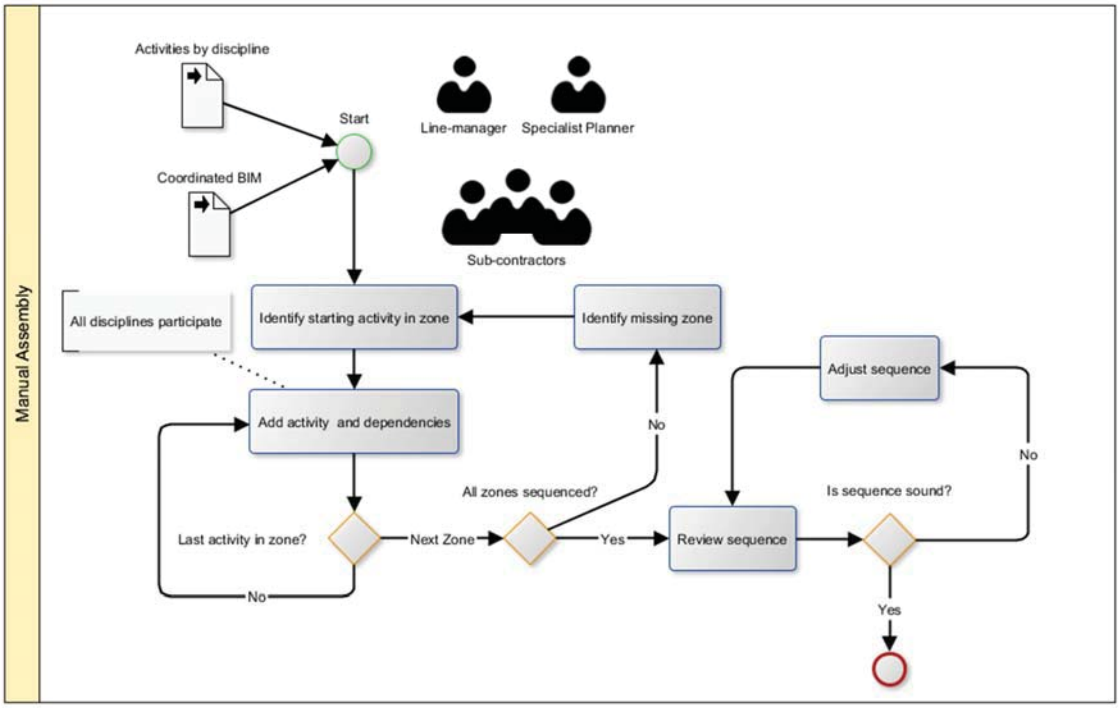


**Figure 3: Process mapping of stage 3 - manual assembly.**

### 5.5 Post stage 3

All stages where repeated in all of the workshops observed. However, in workshop 2 and 3 the rough schedule was done and as such stage 2 was awarded less time, just enough to update and add missing activities. At the end of the workshops each zone was once again reviewed, this time without the model, only checking that predecessors and successors was suitably connected. This resulted in a review of the proposed sequence of activities, and served the purpose of getting everyone to agree upon the order of activities.

### 5.6 Post-workshop

After the workshop the specialist planner recorded the suggested schedule into the scheduling software. During this process some missed activities where noted and brought to the next workshop. The specialist planner attributed these misses to the fact that the walkthrough did not follow a logical path through the building and zones and as such the interaction between zones where not that easily observed. The final action after the schedule was input was to distribute the schedule to all participants. The first iteration of the schedule seldom resulted in keeping the stipulated milestones from the master plan, thus the need for extra workshops. These workshops was spent on adding tasks that were missing as well as agreeing on actions to take in order to achieve the milestones.

## 6 Identifying current shortcomings

The analysis of the observations of the different stages resulted in several areas of improvement identified. In general the method for planning that was observed has many similarities with the method studied by Seppänen, Ballard and Pesonen (2010) but it differs in that a strict LPS was not used and the scheduling was location based but not in a LBMS.

One of the main areas of improvement from the observations was the high cognitive load that the mixed use of drawings and BIM model introduced. The need for the participants to view the screen as well as their own drawings and descriptions made it hard for them to follow and slowed the initial walkthrough with lots of questions. These questions could have been avoided if the cognitive could be lightened with more information available on-screen.

Adding to the cognitive load was the lack of ability for the participants to orient themselves, especially since the zone drawing was a separate drawing. If this information had been integrated and visualized in the model the participants would have more easily followed along.

The third area was filtering, ultimately the discipline drawings are used to filter the information to visualize the most important information, and usually the discipline is overlaid the architectural drawing. Thus if other disciplines drawings is to be referenced the user need to compare or overlay the drawings. The Ventilation-contractors as well as the plumbing-contractors mentioned that they frequently used several of the other disciplines drawings, suggesting that they spent a lot of time coordinating what they saw in the drawings.

The fourth area for improvement is the quantity takeoff. The reliance on descriptions and drawings meant that a substantial amount of time was spent on interpreting and counting occurrences of elements in the drawings.

The fifth area of improvement is concerned with the assembly of the sequence. As the sticky notes were put on a physical paper there was a substantial work left for the specialist planner once the sequencing was done. The manual input of the plan into the planning and scheduling software introduced a delay in the collective review of the sequencing of the plan. The walkthrough at the end of the workshop helped somewhat in identifying missing predecessors/successors but did not give any input about how the plan was in regards to dates. This became apparent only after the plan had been input and formed as such a basis for the forthcoming workshop to optimize the plan and trim it within the given deadlines.

The sixth and seventh area is quality checking and constructability. By walking through the model the participants effectively reviewed the model while planning it, both in terms of constructability and general quality checking. But, as noted by the specialist planner even though the participants did a collective walkthrough after the activities had been sequenced, some connections between activities were missing. The initial walkthrough and orientation of the model resulted in input to the design team for some alterations that if left alone could have caused problems.

## 7 Virtual Production Planning – a BIM enhanced process

Tying back to the observations these seven areas of improvement is applicable throughout the three main stages of the workshops. Using the BIM more effectively could lower the cognitive load that is introduced by using mixed media. BIM could also be lower the cognitive load and thus improve the understanding of the building as a whole and help in the learning of other disciplines activities and issues. As it is today, SMC color-codes the model depending upon discipline, but the participants had a hard time to map the current zone to the model. Thus a more clear way of illustrating zones and filtering the view is needed. One way to address the cognitive load as well as the filtering issue is to utilize a second view. This view differs from the main view by filtering the model by discipline and fades the remaining disciplines. Thus utilizing the information that is inherent in the BIM and reducing the need for physical drawings. Regarding the orientation issue, the traditional implementation of a 2D overview in the corner of a view is not enough to convey sufficient information of the zone partitioning. As such the view should be accompanied with additional information, preferably a visual queue with zonal information.

Furthermore one of the issues identified was concerning feedback of planned building parts as well as sequenced activities. A simple way to utilize the BIM model to visualize the addressed objects would be to remove the objects addressed by hiding or adding them to a different view. This further ensures that no objects are missed, as it serves as a visual check and as such acts as quality assurance of the planning, making sure that no building parts are missed.

As the BIM is used in the planning method today, the ability to extract quantities directly from the model is not used. While BIM enables the quantities to be extracted, few integrated commercial solutions exist today. The implementation of such a system integrated into the planning tool could assist in reducing the need for consulting several sets of drawings and descriptions. This would result in less time spent on information gathering since the information is collected from one place.

The sequencing of the activities show several areas of improvement possible, the main issue being the lack of direct feedback during the sequencing as well as after the sequencing. Digitizing the sticky notes and appending them to the objects in the BIM aid the process of inputting the schedule into the scheduling software. Thus, manual labor is reduced and instant feedback in the form of play back of the planned sequence is instantly available, both during and after the finished sequencing activity. This further allows quality of the planning as well constructability to be checked. Again visual feedback as described by hiding and moving building parts between views would enhance the process.

## 7.1 Framework system design

The main philosophy behind the suggested system is to keep the current workflow, and only assist it where possible. The enhancements stated in the previous section in conjunction with the observed method, forms the foundation for the framework. Thus the stages of the workshops stay the same. The system is divided in a main application and a supporting client application, interconnected through a server as seen in figure 4.

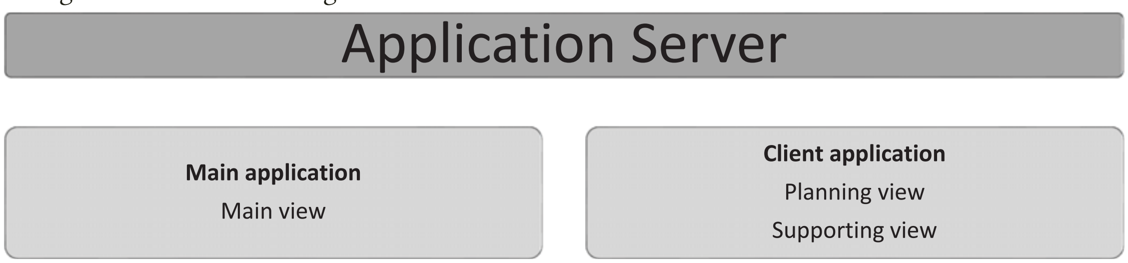


**Figure 4: Overview of system design.**

The main application serves the collaborative work amongst all disciplines, while the client application is more geared towards individual work. The main application and its ***Main view*** should be presented on a large screen or projector, while the client application with the ***Planning***- and ***Supporting view*** should be used on laptops or tablets. During the first stage (as seen in figure 1) the main application shows the coordinated view of the model as the ***Main view***, color-coded by discipline. This view is supported by the client application with the ***Supporting view*** on each respective disciplines laptop/tablet (as seen in figure 5). The ***Main view*** is used for the walkthrough of the zones, displaying the information suitable as described earlier.

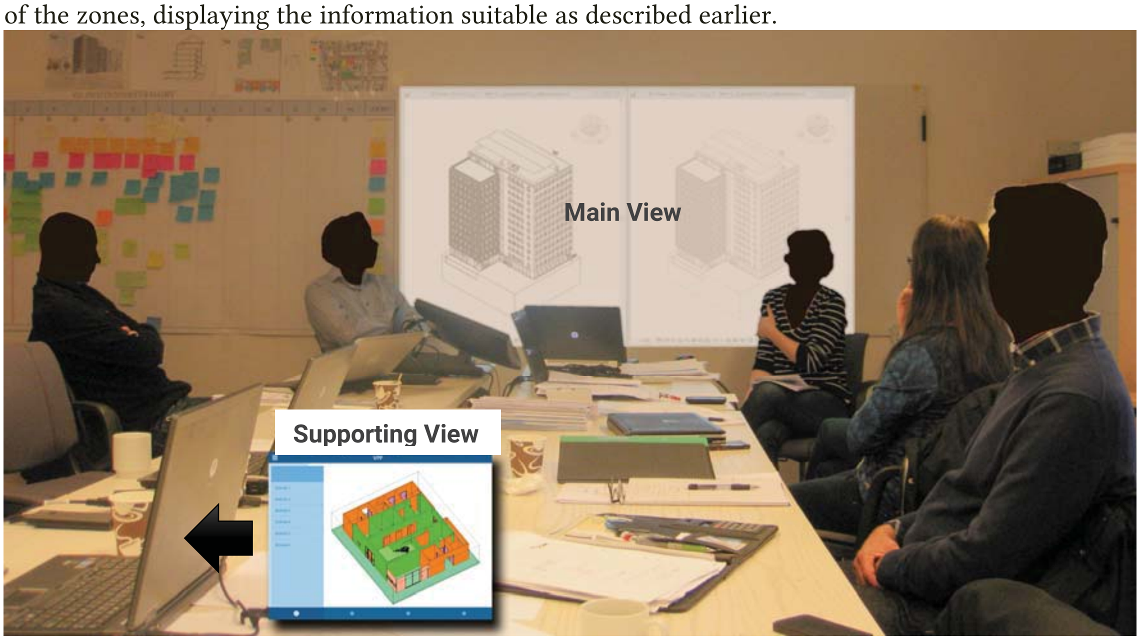


**Figure 5: Main view and Supporting view illustrated.**

Stage two, as described in figure 2, marks the beginning of the individual work amongst the disciplines, thus the ***Main view*** acts as an overview in the background while the client application utilize the ***Planning view*** for the actual planning of each zone. Figure 6 displays how the main application is used to convey information on an oversight scale, while the client application addresses each zone individually. Thus, the client application deals with portions of the full model, displaying and working zone by zone. The main application filters and illustrates all disciplines, while the client focuses on the discipline at hand.

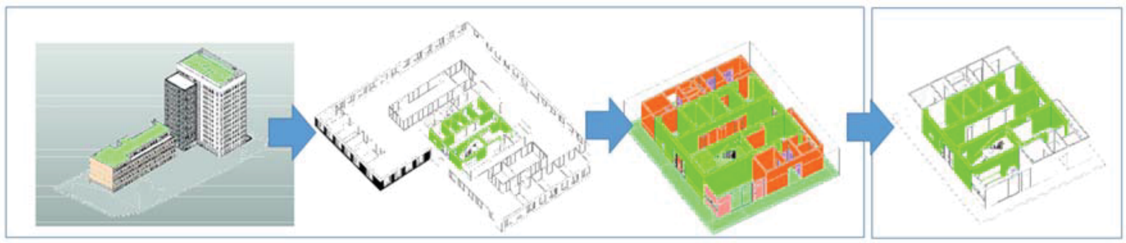


**Figure 6: Illustration of division between main and client application.**

When entering the client application in stage two, the activities are identified per zone and building parts grouped by discipline and zone. Following this, the activities are resourced and durations estimated. The BIM is utilized to supply the quantities, thus supporting the estimation. As the activities are planned, the building parts are gradually hidden from the view, in order to provide the visual feedback mentioned in earlier sections. This work continues throughout each of the zones, resulting in a list of activities and “empty” zone views.

When stage two is complete, stage three commences and the main view is once again the center of attention. The main application serves as the virtual pin board for doing the manual assembly of the building. Instead of using sticky notes the activities and the building parts from the second stage forms the basis for this process. Each participant represents a discipline. The activities that each participant has planned are listed in their client application. During the sequencing each participant trigger their activity in the order the activities is to be performed. The collaborative process means that the participants collaboratively create and connect the schedule. During this stage the ***Main view*** is divided in two sub-views, one representing un-sequenced building parts and activities, and one representing the finished schedule, as illustrated in figure 5. The un-sequenced view is gradually emptied, while the other view grows. At the end of stage three the sequence is reviewed.

## 8 Discussion and conclusion

The planning workshop and method observed shows parallels to earlier studies such as Seppänen, Ballard and Pesonen (2010) and as such serves as a validation of earlier studies while the earlier studies implies that the techniques used are sound. The identified areas of improvement matches the suggested areas of lean and BIM interaction put forward by Sacks *et al.* (2010). The suggested system also follows the recommendations by Hartmann *et al.* (2012), in such a way that technology pull is the driver for the development of the system. That means that current methods are analyzed and used as basis for developing the framework for the system described. Today there are a lot of different implementations for 4D planning, but few integrate the use of the BIM as the main vehicle for planning. Fewer still utilizes the location based planning paradigm as basis for scheduling. The framework outlined here is such a system and further studies are needed to develop a prototype that can be validated and tested in a real environment.

## References

Ahuja, V and Thiruvengadam, V (2004) Project scheduling and monitoring: Current research status. *Construction Innovation: Information, Process, Management*, **4**(1), 19-31.

Arias, E, Eden, H, Fischer, G, Gorman, A and Scharff, E (2000) Transcending the individual human mind—creating shared understanding through collaborative design. *ACM Transactions on Computer-Human Interaction (TOCHI)*, **7**(1), 84-113.

Ballard, G and Howell, G A (2003) An update on last planner. *In*, *Proc., 11th Annual Conf., International Group for Lean Construction, Blacksburg, VA*.

Bhatla, A and Leite, F (2012) Integration framework of bim with the last planner systemtm. *In*, *IGLC 2012 - 20th Conference of the International Group for Lean Construction*.

Boton, C, Kubicki, S and Halin, G (2013) Collaborative 4d/nd construction simulation: What is it?, *Cooperative design, visualization, and engineering*, pp. 161-8: Springer.

Büchmann-Slorup, R and Andersson, N (2010) Bim-based scheduling of construction–a comparative analysis of prevailing and bim-based scheduling processes. *In*, *Proc., 27 th Int. Conf. of the CIB W78*, 113-23.

Fischer, G (2000) Symmetry of ignorance, social creativity, and meta-design. *Knowledge-Based Systems*, **13**(7), 527-37.

Grudin, J (1994) Computer-supported cooperative work: History and focus. *Computer*, **27**(5), 19-26.

Hartmann, T, Van Meerveld, H, Vossebeld, N and Adriaanse, A (2012) Aligning building information model tools and construction management methods. *Automation in Construction*, **22**, 605-13.

Kenley, R and Seppänen, O (2009) Location-based management of construction projects: Part of a new typology for project scheduling methodologies. *In*, *Winter Simulation Conference*. Winter Simulation Conference2563-70.

Liker, J K (2005) *The toyota way*. Esensi.

Sacks, R, Koskela, L, Dave, B A and Owen, R (2010) Interaction of lean and building information modeling in construction. *Journal of Construction Engineering and Management*, **136**(9), 968-80.

Seppänen, O, Ballard, G and Pesonen, S (2010) The combination of last planner system and location-based management system. *Lean Construction Journal*, **2010**(1), 43-54.

Waly, A F and Thabet, W Y (2003) A virtual construction environment for preconstruction planning. *Automation in Construction*, **12**(2), 139-54.

Winch, G M and Kelsey, J (2005) What do construction project planners do? *International Journal of Project Management*, **23**(2), 141-9.

Zhou, W, Georgakis, P, Heesom, D and Feng, X (2011) Model-based groupware solution for distributed real-time collaborative 4d planning through teamwork. *Journal of Computing in Civil Engineering*, **26**(5), 597-611.