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SUMMARY*: Construction projects often suffer from backlashes in relation to poor plans and schedules. Especially pre-construction planning has been challenging due to a high complexity, an extensive amount of information, and a lack of site managers time to make the schedule. To solve these issues for pre-construction planning; new planning processes, methods and tools have been developed over the last decade. However, due to a disregard of the current planning processes these tools have been difficult to adopt in practice. In addition, these developed tools and methods are seldom developed from the user's point of view. A promising development is the introduction of integrated planning as a concept in construction companies. It involves the use of BIM models in concert with a planning approach where the subcontractors engage in the planning. However, currently available tools are more geared towards experienced users such as expert planners and does not allow for a fully collaborative and integrated planning approach. While many current tools would tick many of the requirements identified, they still fail to address the base requirements from the collaborative work environment literature. This paper contributes with a user-centric design and development of a collaborative planning application showing the integration of the existing collaborative planning process. By adopting a socio-technical approach, the paper focuses on combining technology and processes supporting the users and their way of working in order to enable adoption of the solution. A design science research approach has been used to gather requirements and develop and evaluate the Visual Project Planner (VPP) application. The VPP application applies a collaborative, visual approach supporting interdisciplinary knowledge sharing between all parties involved where the subcontractors actively can contribute to schedule. The VPP application has potential to reduce time for pre-construction planning regardless of the planning approach used.*

KEYWORDS*: BIM, collaborative planning process, design science, software development*

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1. INTRODUCTION

The AEC industry has been characterized by its low productivity and high specialisation of subcontractors, leading to a fragmentation of responsibilities and inefficient work processes. In part this inefficiency and fragmentation has been related to a widespread culture of poor information exchange and communication amongst stakeholders e.g., contractors and subcontractors (Nepal and Staub-French, 2016). In planning and scheduling, the main purpose is to exchange information and communicate between the actors in order to develop a suitable schedule. Traditionally this scheduling and planning process has been a centralized endeavour, especially in the pre-construction and early construction phase. Pre-construction is a crucial phase for construction planning and scheduling since this is where the construction logic is specified and all necessary information to start construction is gathered (Baldwin and Bordoli, 2014). This paper concerns the end of this phase, just in between the finishing of construction documentation and the beginning of on-site construction work.

Traditionally, the planning and scheduling has often been performed by a specialist planner or the site-manager (Winch and Kelsey, 2005; Styhre and Josephson, 2006). However, research has shown that one of the main challenges for pre-construction planning is the lack of time of the site manager (Winch and Kelsey, 2005; Styhre and Josephson, 2006), which impacts the quality of the planning. The time constrains site-management faces today highlight the possibility for engaging both subcontractors as well as side-contractors in the scheduling process. Earlier research has focused on engaging the users, such as subcontractors or planners, and how their competencies and knowledge are better utilised in the scheduling process either through lean inspired methods or with the help of BIM, i.e., also known as 4D. This has also been addressed in the development of alternative planning methods and tools (Ballard, 2000; Koskela, 2000; Koskela *et al.*, 2014). Although planning has been recognized in research as a crucial aspect and many new planning methods as well as tools have been developed over time to support this activity, construction projects still often fail to deliver on time and within budget. Some research points toward the fragmented information exchange culture as well as inefficient work processes as problems (Nepal and Staub-French, 2016). These problems have been addressed through the development of IT-tools and methods for planning (dos Santos, 1999), but it has been shown that many of these tools do not gain momentum of use in practice (Xue *et al.*, 2012; Saad *et al.*, 2015). To some extent, the lack of adoption of these IT-tools and methods is not due to disbelief in the tools, but rather that the tools imply a different way of working. The pressure of everyday work leads the users often reverting to familiar and tested tools and processes instead of adopting new approaches (Christiansen, 2012; AlNasseri and Aulin, 2015).

Since the introduction of building information models (BIM) in the beginning of the twenty-first century, several tools to support planning and scheduling coupled with BIM have been suggested and developed (cf. Koskela *et al.*, 2014). Many of these tools are aimed at experienced users such as specialist planners and site management and leaves less experienced users, such as workers, behind. There are professional planning tools that allows for a BIM-model to connect directly to the schedule, e.g. tools such as Asta Powerproject, Vico Office and Synchro to name a few. There are also other tools such as e.g. Navisworks that also allows for such a connection, but which are more focused on the visualisation and information bit of BIM rather than the schedule. The common way to produce aforementioned connection between schedule and BIM, a so called 4D visualisation is to connect a previously developed model and schedule through mapping of activities from the schedule to components in the model (Eastman *et al.*, 2011; Crowther and Ajayi, 2019). Similarly, some design tools, such as Tekla Structures also allows for some schedule data to be incorporated in the objects to enable visualisation (ibid.). As a consequence, it currently exists multiple software that supports both scheduling and 4D functionality (ibid.). However, these are aimed at expert users, experienced in e.g. planning software and BIM authoring software, an experience that to a great extent is missing on-site in construction, especially amongst the workers. There is research that argues 4D-tools need to be as user-friendly tools as possible to gain a broader use (Crowther and Ajayi, 2019). Furthermore, there are examples of how e.g. drawings are generated as needed on site as a collaboration between the site management and subcontractors, which highlights the need for a comprehensive knowledge of BIM technology and tools to use these tools (Berlo *et al.*, 2015). This highlights the need for a different approach to BIM supporting tools and their implementation. Several researchers (cf. dos Santos, 1999; Xue *et al.*, 2012; Saad *et al.*, 2015) discusses and uses a socio-technical approach in the adoption and development of IT-tools, in which technology and people are interdependent.

This paper draw inspiration from the socio-technical approach to develop a IT-tool supporting a specific existing planning and scheduling process. The paper uses design science (DS) as a framework to better align the development process of the new IT-tool for pre-construction scheduling to the current way of working and to put the user in the centre. The DS approach utilises the users to form the requirements for the design of the tool. The documentation and account of this requirement and development further contributes with a more generalised approach to IT development in construction. Thus, the paper contributes with the development of an application and enhances a method that tries to solve the issue of adoption through enhancing a current process in pre-construction planning. This is done through the support of a collaborative and visual approach with which interdisciplinary knowledge/information from all parties involved is used during the planning and scheduling, thereby reducing time from pre-construction planning to a ready pre-construction schedule.

The paper is structured as follows: it starts out by highlighting the context in section 2, mainly by presenting the development of new planning processes or new planning visualisations as ways to address the aforementioned planning problems. The paper then address the development towards more collaborative planning and scheduling approaches. Following this, the needs for adopting a collaborative user perspective during development of supportive IT-tools is done through the discussion of currently available tools and techniques. In section 3, the paper describes the Design Science approach used to frame the method for gathering requirements and build and evaluate a new IT-tool. The requirements for the new IT-tool are developed based on observations, interviews, and a literature review and are mapped with literature from collaborative virtual environment (section 4). The developed IT-tool, the VPP-application, is described in section 5 where the functionality of the application is mapped to the original requirements. Section 6 evaluates the developed application and the paper is summarised and discussed in section 7.

2. BACKGROUND & LITERATURE REVIEW

In order to address the above-mentioned challenges of with time in projects, alternative planning processes and techniques have been developed (Ballard, 2000; Koskela, 2000; Koskela *et al.*, 2014). Below, two broadly defined tracks are discussed: (a) visualisation techniques and (b) planning techniques to highlight the current approaches to solving the planning and scheduling issue (with some overlap in between the two tracks).

Visualisations techniques of schedules have developed over time, where prevailing techniques have been the Gantt bar charts as well as the visualisation of the critical path method (CPM) through interconnected blocks representing the schedule (Baldwin and Bordoli, 2014). Different stages of the construction process require various detailed schedules. Thus, the more complex projects become, the greater is the need to build a hierarchy of schedules to filter what is visible at different levels to keep the schedule legible (ibid.). An early way to address the communication and visualisation of complex schedules was to produce movies of snapshots of different states of the model to simulate the construction schedule (Eastman *et al.*, 2011). This has matured to a faster an easier way where the model is interactively connected to the schedule in so called 4D modelling. Since the late 1990s the use of 4D visualisations has gained momentum, and more so since the 2000s in parallel with the use of BIM (Butkovic and Heesom, 2017). Currently there are three approaches to 4D modelling, (a), a manual approach using snapshots of 2D/3D models combined into movies, (b) a BIM centred approach where built-in features in BIM tools are utilised and lastly (c) an approach where 3D/BIM data is exported to 4D software, connecting parts of the model to the schedule imported from scheduling software (Eastman *et al.*, 2011). It has been shown that 4D modelling is beneficial to interpret the schedule (Heesom and Mahdjoubi, 2004), and it emphasizes communication capabilities of the 4D model (Boton *et al.*, 2013; Trebbe *et al.*, 2015). It has also been shown that views and 4D information visualised specifically for each discipline furthers the benefits of 4D models (Boton *et al.*, 2013). However, there are few documented implementations that are used repeatedly in construction projects, and most of them are related to the design phase, rather than the construction phase (Hartmann *et al.*, 2008; Mahalingam *et al.*, 2010; Brito and Ferreira, 2015). Also, most examples are of passive use of 4D, where the 4D is used to review or as a presentation material rather than active collaboration and co-creation of the schedule in 4D (cf. Sage *et al.*, 2012).

Not only the visualisation techniques but also the planning techniques have developed from the prevailing CPM to others like critical-space-analysis (CSA), critical-chain-method (CCM) and the Last Planner system of production control (LPS) which consist of a fixed set of predefined processes for the production process (Faniran *et al.*, 1999; Sriprasert and Dawood, 2003; Kenley and Seppänen, 2006; Baldwin and Bordoli, 2014; AlNasseri and Aulin, 2015; Bølviken *et al.*, 2015). Along with these planning techniques, the focus shifted from activity-based scheduling towards scheduling which is more based on the location of the activities being scheduled, rather than the type of work they represent. The location-based scheduling has been suggested especially in connection to lean-inspired research (Kenley and Seppänen, 2006, 2009). For location based scheduling, a project is broken down into locations, which opens up the possibility to utilize space more efficiently, as is the case in CSA (Winch and North, 2006), and which decreases the complexity of each location supporting easy identification of the number of concurrently ongoing activities in one location (Kenley and Seppänen, 2006). Location-based planning has been formalised in e.g. Location Based Management Systems (LBMS), as described by Seppänen et al. (Seppänen *et al.*, 2010) and have been integrated with LPS to draw on benefits of utilizing location from the LBMS and by using the collaborative parts of LPS (Seppänen *et al.*, 2010; Seppänen *et al.*, 2015; Olivieri *et al.*, 2016). This is also an example of the integration of processes and tools that is argued to be beneficial (Bhatla and Leite, 2012). Planning and scheduling research internationally has shown that planning needs to be closer connected to those actually performing the work (Winch and Kelsey, 2005), which is seen in initiatives worldwide such as empowerment seen in Lean Construction and especially in the Last Planner System (LPS) of production control with its pull planning (Ballard and Howell, 2003; Lindholm, 2014).

The research context of this paper is set in a Swedish setting. Thus, the Swedish context in relation to planning is relevant to introduce. In Sweden a similar collaborative planning approach to parts of the LPS was developed during the mid-eighties, then known as Integrated Planning (IP) (Söderberg, 2006). IP is independent to push or pull planning approaches, in contrast to LPS which pull based. However, IP is primarily used with push planning, like most traditionally used planning methods. This IP initiative was partly driven by the Swedish Construction Workers Union and initiated partly as an agreement between the unions in the construction sector and the employer organizations and was further developed as a series of research projects (SAF, LO and PTK, 1986). A core component in this concept, which also can be identified in LPS, is the initial phase planning workshop where supervisors representing the different trades attend and provide expertise knowledge to co-create schedules that everybody in the project team can agree upon, creating an understanding for each other's work. This emphasises the social processes and interactions in which workers can share their tacit work knowledge during the collaborative planning processes to better plan and schedule activities. These social processes have been shown to be important to improve the quality of the schedules (Seppänen *et al.*, 2010). Research has shown that this use of workers and their tacit work knowledge is a practical example of empowerment of the workers as discussed in Dainty, Bryman and Price (2002). Despite the indication that IP seemed a successful planning concept, only a few project teams adopted this approach fully at the time. Some arguments against this method at the time was that it would be more costly to involve workers in the planning, which was dismissed by research of Söderberg (2006). However, during the last couple of decades the remnants of the IP method has become more popular, and even so with the rise of the discussion around Lean construction and LPS. However, the switch to lean construction and LPS entails a recommendation to follow its best practices and major techniques. This has been shown to be problematic and organisations seldom manages to align their construction control processes enough to adopt all the major parts, such as planned percent completed, master schedule, phase schedule, lookahead schedule and weekly work plan (Perez and Ghosh, 2018). Today, all of the largest construction contractors in Sweden (and Scandinavia) use variants of collaborative planning to some extent during the construction process, some building on the original IP concept and some more leaning towards LPS. A general problem though in relation to pre-construction scheduling and planning, is that early involvement of site-management and subcontractors is hard to achieve (Friblick and Nordlund, 2013).

2.1 Requirements for adopting a collaborative user perspective

Along with the shift towards more collaborative planning approaches, a concurrent development IT-tools for construction planning and scheduling have occurred. However, these tools often come with a change in ways of working. The implementation and adoption of these new tools imply changes to current processes which are often met with reluctance and resistance (Lindblad, 2013). For example, it is mainly the site management that use BIM tools in the site office. Subcontractors and workers often need the assistance of site management to inquire information from the BIM (Berlo *et al.*, 2015). It has also been argued that many of these IT-tools do not gain momentum of usage in practice (Xue *et al.*, 2012; Saad *et al.*, 2015). A reason for this could be found in research that shows a reluctance in adopting new processes and technology where practitioners (e.g. site management) tend to stick to known methods and processes in an attempt to control the impact on their administrative tasks in production (Christiansen, 2012; Alnasseri, 2015).

Furthermore, available tools still lack a collaborative, user-friendly environment. Thus, the 4D scheduling and planning processes used in these tools have been exemplified as mainly suitable for standalone 4D authoring tools and individual usage rather than a collaborative environment (Koo and Fischer, 2000; Zhou *et al.*, 2014). While many of the currently existing scheduling and planning tools have filtering and grouping capabilities that are needed for visualising zones and disciplines commonly used in scheduling and 4D visualisations (cf. Boton *et al.*, 2013), they still lack the interactive and collaborative functions needed to enable synchronous collaborative work (Zhou *et al.*, 2014). As mentioned earlier, the available tools also require expert-users to aid the workers (Berlo *et al.*, 2015), which creates a barrier for usage. The development of new tools, especially collaborative ones, should be taken from a more holistic approach where the tools support and encourage the individuals to engage collaboratively (Fischer *et al.*, 2005; Zhou *et al.*, 2014). Such an approach is the socio-technical approach, which originates from the need to describe the interaction between people and technology from the context and work processes in which the technology is applied (Fischer *et al.*, 2005; Sackey *et al.*, 2014). This approach is supported by several studies were these new tools and technologies are aligned to the users and their processes (Hartmann *et al.*, 2012). By creating a shared understanding through collaborative scheduling, 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 consumer roles. In a more general sense, this is described in Collaborative Virtual Environments (CVE), which are used as a way to facilitate and improve collaboration across different stakeholders in more general development of information systems. Nine requirements are listed in order for a system to support creation and progression in a social creative process as seen below (Snowdon *et al.*, 1998; Fischer *et al.*, 2005).

C1 - Create awareness of each other's work and provide mechanisms to help draw out the tacit knowledge (Fischer *et al.*, 2005). Through understanding of others tacit knowledge and activities related to the problem, the team can build up a shared understanding (Snowdon *et al.*, 1998);

C2 - Enable co-creation in multiple forms: simultaneous, parallel, and serial (Fischer *et al.*, 2005);

C3 - Allow participants to **build on the work of others** (ibid.) (C3);

C4 - Provide **individual reflection and exploration** (e.g. reflection space and action space) (ibid.).

C5 - Shared Context is supposed to give the users a representation of the problem to enable **shared understanding** and interactive activity in a group of different participants, during discussions. (Snowdon *et al.*, 1998).

C7 - Transition between shared and individual activities is a process through which an **individual's work evolves into collaborative work.** It is important that collaborators know what is currently being done and what has been done in the context of the task goals (ibid.).

C8 - Negotiation and communication consist of conversations and gestures crucial during collaborative activities. In this context **face-to-face communication** is vital for supporting natural communication through the human body such as facial expression, gestures, postures (ibid.).

C9 - Flexible and multiple viewpoints are problems and tasks that often require the use of **multiple representations and visualisations**, each tailored to different points of view and different subtasks and users (ibid.).

These five points (C4-C9) highlight how a tool can be instantiated to create and support a social creative process as specified by Fischer *et al.* (2005). The list discussed above, results in nine points that form requirements which need to be addressed in a collaborative tool.

3. DESIGN SCIENCE

To better align the development of the tool described in this paper with the existing planning and scheduling process a Design Science Research (DS) approach has been used. Design Science is a design research paradigm that aims to create models, methods and systems in the forms of artefacts that supports the development, use and maintenance of IT-solutions. Thus, these artefacts created aim to effectively produce an impact on its environment (March and Smith, 1995; Johannesson and Perjons, 2014). In the core concept DS consist of two main activities, build and evaluate, seen in the middle box of Fig. 1 (Hevner, 2007). This main activity is conducted in a design cycle, which iterates over a relevance and rigor cycle. The rigor cycle represents the connection to the scientific knowledge base and are grounded in theory. Furthermore, the relevance cycle anchors the artefact in the local problem environment and context. The relevance cycle, to the left in Fig. 1, helps forming requirements. The actual design work is performed in the design cycle and also evaluated against the requirements from the relevance cycle and is conducted in an iterative manner. The main aim of the research is to develop an application from the user-perspective while enhancing the current planning method and the DS approach supports this aim. By using the DS approach, the contribution can be validated both against utility to practice but also as a contribution to the more general knowledge base of the development of information systems (IS) in a construction context.

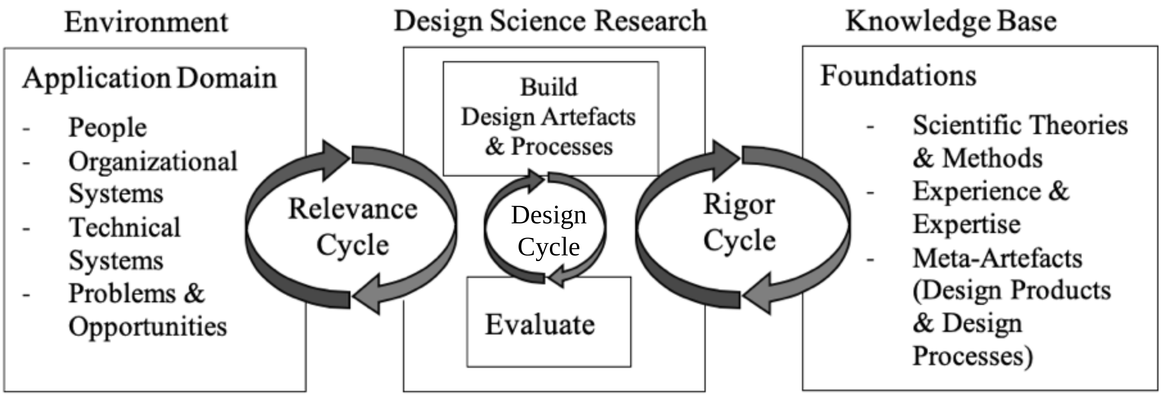

FIG. 1: Design Science Research Cycles (Hevner, 2007).

In this paper DS has been used to develop the general requirements from the knowledge base of CVE and planning and scheduling in general. The environment provides with the more problem specific requirements, where observations and interviews has led to the specific requirements needed. Thus, DS is used to describe the development and evaluation of the artefact, in this case the Visual Project Planner (VPP) application prototype. The prototype has been developed in three design cycles with an iteration of rigor and relevance cycles; these are summarized in a description of the end prototype in section 5. The three design cycles are discussed more in detailed in previous work (Viklund Tallgren, 2018). The development of the artefact is part of a larger research project and the feasibility of such a tool has been addressed in a previous paper (Viklund Tallgren *et al.*, 2015).

3.1 Data collection for requirements

To understand the setting and the localized context, four field observations were performed in two ongoing construction projects with each with a different main contractor. The initial main data collection was done by observing practice "as-is" and documented in field notes (Bryman and Bell, 2011). The projects were a commercial building and the extension of an existing Hockey-stadium with an attached aquatic centre with a restaurant and café, (the Swimming pool project). The commercial building is a furniture store of approximately 30 000 m_2 with a budgeted cost of about 240 MSEK, the Swimming pool project is 4 100 m_2 with an additional 1600 m_2 for the restaurant and café, budgeted at 141 MSEK. The observations were conducted in four half-day collaborative planning workshops. Field notes were logged during the workshops and subsequently supplemented after each of the workshops. The observations focused on the activities of the workshop's participants and on how the workshops were performed. Additionally, seven semi-structured interviews were conducted with practitioners (Kvale, 1996). Interviews about needed information for activity planning were held with a project planner, a site manager, a senior fitter from the electrical subcontractor, a plumbing subcontractor and a prefab concrete subcontractor, a HVAC and a sprinkler subcontractor. The selection of interviewees was based on availability in the project, but with focus on accessing as many subcontractors as possible and select personnel that worked on-site participating, mainly foremen or similar positions with all subcontractors. The interviews were recorded in field notes like the observations, apart from being recorded and transcribed verbatim. The field notes and transcriptions were then coded and analysed, and themes were identified and recorded for later use during e.g. requirement identification. Furthermore, the observations are analysed in relation to three areas relevant within socio-technical studies, i.e., people, process and technology also called the PPT model (Prodan, Prodan and Purcarea, 2015; Liu, Van Nederveen and Hertogh, 2017). The rigor cycle has been characterized foremost by a literature review. The motivation here was to relate the observed planning method to the existing knowledge base of planning methods. The literature review and observations also helped to identify the base requirements and evaluation requirements.

3.2 Data collection during the evaluations

The evaluation of the artefact has been a continuous iterative process, which is a typical approach in design work and especially in DS. However, a more formal evaluation has taken place in four stages of the design and development of the VPP-application. The project used for the evaluation of the tool was an actual multi-family five-story house being built, consisting of 3 stairwells with elevators and exterior corridors. In total the house has a floor area of 7 000m2. The project was sub-divided into zones, where a zone on level 2 was chosen due to a good encapsulation of building parts in the specific zone. The selected zone consisted of 4 apartments with a total area of 350 m2 including corridors. The model used was limited to the structural parts, HVAC and plumbing. This limited selection building parts was chosen as they represent spatial bounding elements as well as highly detailed parts of the building, thus aiding in evaluating the collaborative potential while still limiting the available parts to plan and schedule. This evaluation setup was used extensively both in the internal interim evaluations as well as with the external evaluation groups.

The first two evaluations focused more on the technology part of the VPP-application, evaluating the VPP-application according identified technical requirements, while the later evaluations also paid attention to the user and the support of the current process. The first two evaluations were made in a lab setting during the design loops, with the aim to develop the prototype to a stage where practitioners could test the majority of functions used in the original workshop. The participants were mainly selected from the research team, with two researchers and a expert planner participating. In these evaluations the data was mainly gathered through observations as well as a sound recording of the workshop. One researcher acted as observer and support, guiding the participants through the process if needed, while simultaneously asking questions.

The third evaluation was conducted with nine practitioners, most of the practitioners were managers or project planners. The group were selected from the reference group of the research project and thus selected because of their general knowledge of planning, but no specific knowledge of this kind of planning workshop. Here the focus was on the user friendliness of the tool and appropriateness of information conveyed in the tool. The last evaluation was performed by three groups of in total nine civil engineering students specialising in construction management. In contrast to the practitioners, these evaluators had basic experience of the collaborative planning process used, but little or no general experience of construction production practice. This group of evaluators was selected based on this first-hand knowledge of the planning and scheduling process, as they could compare and contrast between the tool and the unenhanced process. Thus, the focus of this evaluation was more on the process, how the tool related to and complimented the collaborative planning process. In this evaluation, the feedback was collected in four ways. (a) a video recording of the evaluation workshop, where the evaluators were encouraged to interact as well as think out loud. (b) semi-structure interviews: the researcher once again had a semi-structured interview-guide of points concerning the process and the tool. These were noted during the workshop, and later enhanced with the analysis of the recordings. (c) Each users' interactions were screen-recorded as well as logged to identify strenuous tasks and limitations in the tool compared to the process. (d) An exit interview in the group setting. The exit interview was almost as long as the evaluation workshop itself, where the participants discussed the tool more in depth in comparison to the unenhanced version of the planning process. The evaluation was part of the design cycle that aimed to review and connect the eight general requirements for social collaborative processes and collaborative virtual environments with the derived requirements for the planning process. Thus, showing how DS form requirements and helped in the development of the VPP- application as well as how the VPP-application solves the problems identified in the workshops.

4. PROBLEM EXPLICATION

This section will highlight the observed planning approach. The documented planning approach is illustrated as observed in Fig. 2, with three main phases appearing, the initial review of zone, phase 1, followed by the planning of each zone, phase 2, and then finished with schedule of the zone, phase 3. Fig. 2 is also vertically divided in collaborative and individual work; highlighting was each of the phases belongs on a scale from individual to collaborative work. The dashed arrows symbolise iterative work, e.g. the repetition of a set of activities but in a new zone. The observations are structured according to these phases and finally observed problems from the workshops are summarized in a table.

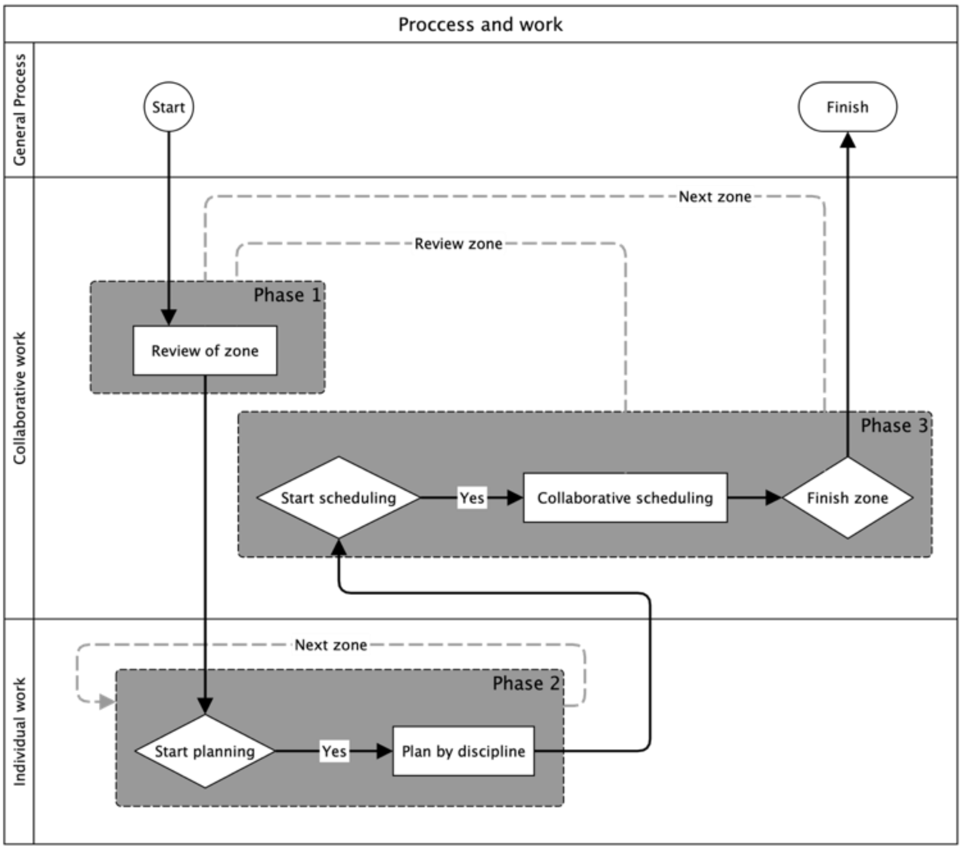

FIG. 2: Planning and scheduling process with main phases; review of zone, plan zone, schedule zone.

4.1 An approach to collaborative planning

The collaborative planning approach described and observed here draws upon the work done in the eighties (Friblick and Nordlund, 2013), combined with inspiration from Lean and Last Planner and generally consists of a set of collaborative planning and scheduling workshops. The approach includes several different steps of the planning, scheduling and follow up during all construction phases. This paper focuses on pre-construction planning and scheduling, in the creation of a production schedule, se Fig. 3. Thus, the work is done late during the design, almost at the beginning of construction, but still before actual construction works starts on-site. Thus, a contractual schedule exists, but this planning and scheduling workshop aims at involving all stakeholders in creating first an ideal schedule, without regards of dates, focusing on getting the sequence right, and then re-iterating the process looking at the dates and the process and identify possible optimisations at a second stage. This is primarily done through a series of workshops where the client, contractor, subcontractor and preferably representation from the design team participates.

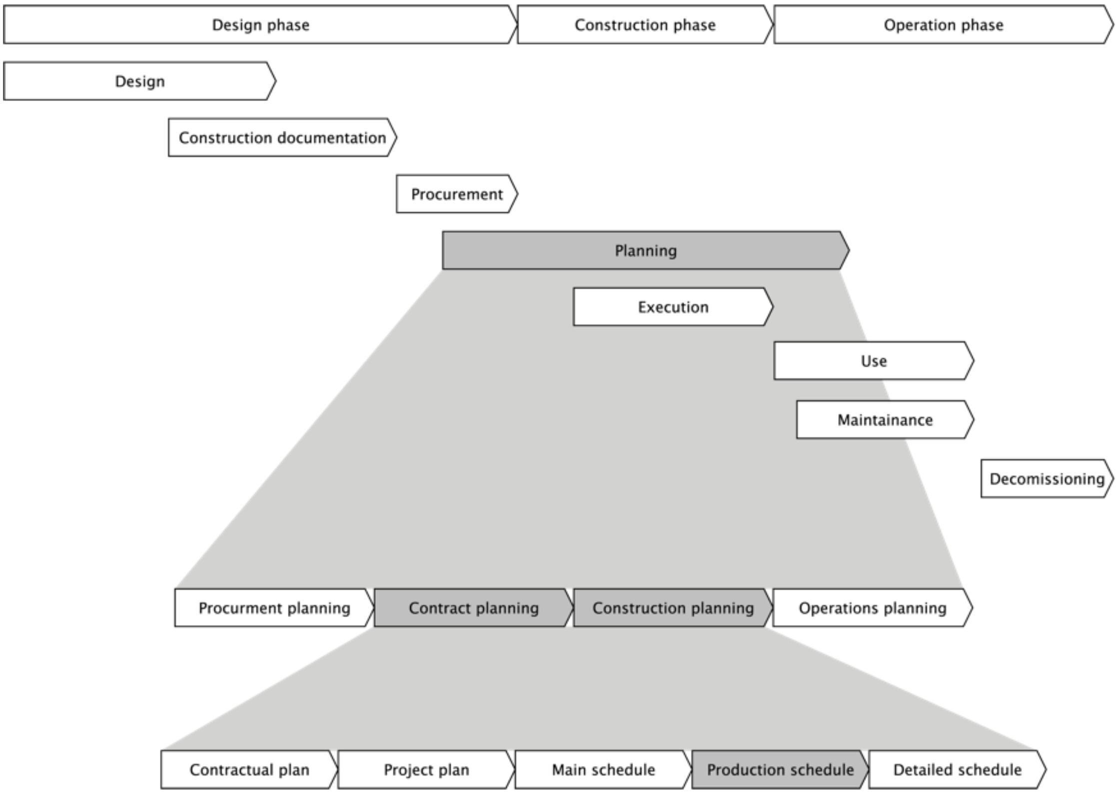

FIG. 3: The hierarchy and different levels of planning and scheduling.

This research has shown that the four largest construction companies in Scandinavia all use variants of this approach. The main idea behind the workshops is to involve the supervisors or workers from the subcontractors and guide these in the planning and scheduling of their on-site work. In one of the interviews a project planner says that:

"…Even though all actors in the production are gathered one or two times for the full day workshops, less time is spent on planning. It is also done with greater accuracy due to the practice knowledge put in by the participants…"

Fig. 4 shows a typical building site-conference room used as basis for the workshop, on either side of the table the schedules for zones are placed on the walls. In the middle front of the table, the zone overview as well as some additional weekly planning and Q&A boards are located. When needed a screen and projector were used to show specific views or walkthroughs in Solibri model Checker (SMC), the only BIM tool used onsite, handled by an expert user, like an engineer from the design team or a supervisor from the main contractor.

FIG. 4: Pre-study workshop in action.

The first workshop is conducted after the winning bid in the construction process, but before the main work starts on-site. The workshop is divided in three phases, hereafter called review of zone, plan zone and schedule zone, as seen in Fig. 2. Before the review phase, the project is divided into levels and zones by the site manager and project planner by dividing and colouring plan views of drawings. The review of the zone phase consists of a walkthrough in SMC of each of the levels and zones and involves a general discussion around the work to be conducted. In this phase, information is presented to the participants through the use of a combination of SMC BIM-models, printed drawings and other documentation, with some possibilities to inquire for more detailed information through asking the person handling SMC (often a supervisor or site-engineer).

The plan zone phase is where the zone and work are divided in respective discipline. Every participant or team of subcontractors plans their activities in each respective zone. Sticky notes are used to convey each activity, with a unique colour allotted to each discipline. On theses sticky notes, the name of the planned activity as well as the duration of the activity - measured in full days - and the required number of resources which are mostly defined as persons are listed. This process is performed throughout each of the zones until all activities have been identified in all zones. The result is that each of the subcontractors have a set of sticky note-activities for each of the zones.

In the schedule zone phase of the workshop, all sticky note-activities are put onto a big sheet of paper hanging on a wall. This is often done through a discussion of the order and then by giving the sticky notes to the expert-planner. This forms a collaboratively developed schedule. This is the manual virtual assembly of the building, done through the sequencing of the activities and thus relies heavily on the tacit knowledge of the participants. Therefore, all participants have a say in where their activities should be placed. The general dependencies between the activities are also identified and connections are specified. This is repeated for each zone, as seen in the middle right part of Fig. 2. Fig. 5 shows a typical zone, the arrows between the sticky notes imply traditional finish to start (FS) relationships but can be specified with other dependencies as seen in Fig.5.

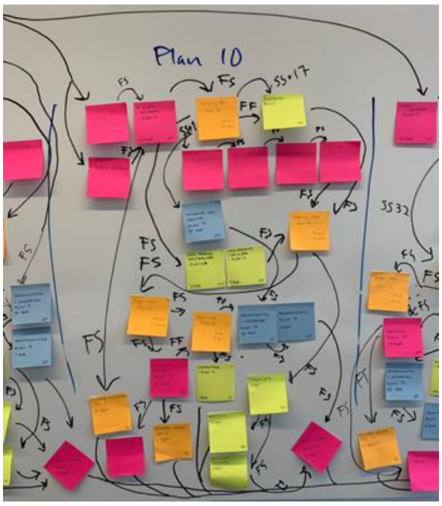

FIG. 5: Typical schedule of a zone.

When the zone is fully planned the team reviews the sequence before moving on to the next zone. The aim of this is to try to catch easily identified mistakes in the scheduling early as well as rectify logical inconsistencies in the scheduling. This process is repeated until every zone is planned. Once every zone is planned, the collaborative workshop is finalized. Now the planner takes the scheduled zones and starts digitalizing the schedule by placing all activities and dependencies into a scheduling software. In interviews the planner stated that this usually takes one to two weeks. The finished digitalized schedule is then sent out for review to the participants or is reviewed in another workshop.

4.2 Observations from the workshops

From the observations a number of drawbacks were observed concerning the whole planning process as well as in the three specific workshop phases - review, plan and schedule zone phase. The core problems observed are categorised into three themes – People, Processes and Technology. Below and in Table 1, the main problems are discussed.

4.2.1 Review zone phase

In the first phase which is the review zone phase, problems related mostly to the process and technology dimension, as seen in Table 1. In the starting phase the participants were fairly passive. When needed, the workshops started with a short presentation round of respective subcontractors, their role in the project and activities assigned to the subcontractor. After introductions, the coordinated and combined BIM model was presented in Solibri Model Checker (SMC), where each of the zones were examined in a predefined order. Navigation through the SMC model was difficult due to the managements choice to review along a pre-defined path through the building. There was also a need for a special model-pilot to manage the walkthrough of the model as none of the participants felt secure enough to use Solibri by themselves, this was the only people related problem identified. Process-related problems: The division into zones and the order of the zones was primarily decided upon by the project planner. Boundaries between zones were hard to visualise and understand due to the fact that the order of the zones was pre-defined.

4.2.2 Plan zone phase

In the plan zone phase, the middle phase, all dimensions of people, process and tools were addressed (see Table 1). The observations identified concerning the people dimension showed that the parallel individual work was highly repetitive and somewhat tedious. This coupled with the fact that competences differed widely between different subcontractors and thus the need for interaction, information gathering, and reconciliation varied. In the process dimension the individual work surfaces again, the individual work and especially the creation of activities are time-consuming and recurring in some zones creating repetition. Added to this is the fact that boundaries between zones and different contractors can become fluid and thus are not particularly clear. The technology dimension in this phase is also related to individual work and focused on missing information from the input of participants and a lack of follow-ups on if all information needed was available. This led to identified extensive requests for information between parties.

4.2.3 Schedule zone phase

The last phase, the schedule zone phase also shows problems in all three dimensions. The people-dimension suffers from the fragmentation of practices and knowledge in the construction industry which creates boundaries between the specific trades. This is especially true when the group is trying to virtually build the project by sequencing each zone. The process related issues that arise during this phase are mostly centred around the group activity of placing the sticky-notes and identifying and visualizing the dependencies between the activities. Issues related to the technology dimension range from falling sticky-notes, dependencies missed due to misunderstanding, activities missed due to orientation issues in the project and a difficulty to update sequences without impairing legibility of the schedule.

4.2.4 Overall drawbacks

A number of problems are identified in several phases and are therefore grouped under this overall label. Problems identified in the people dimension, are the need for physical presence during the workshop as well as understanding the need for participating in a collaborative planning workshop. Problems in the process-dimension relate mostly to the editing, updating and adjusting of the work that is performed. Another problem related to the fact that not all were familiar with the process and that few had a full picture of the extent of the zones. On the technology side, some problems related to the information and the model, such as difficulty in knowing what version of the model is being used. Another problem is the lack of physical and visual space in the room to show the printed and plotted information. The final problem is the output of these workshops consisting of several large sheets of sequenced zones of the project. Processing this output is time consuming and leads to long lead times between workshops. In Table 1 below, the problems are categorized by phases by row and dimensions by column, each unique problem is index with W for workshop problem and is followed by a number.

TABLE 1: Summary of problems observed in the different phases of the workshops.

Phases	People	Processes	Non-digital Technology	Digital Technology
Review Zone: Visualisation and Orientation of the project (group activity)	W1. 3D-model/program demanded special "pilot".	W2. Division of zones hard to interpret. W3. Boundaries between zones hard to visualize. W4. Order of reviewing zones confusing.	W1. Division of zones hard to interpret.	W1. 3D-model/program demanded special "pilot". W5. Mostly used the BIM to walkthrough model/zones. W6. Hard to quickly navigate to appropriate position.
Plan Zone: Activity Planning (individual work)	W7. Individual work time-consuming W8. Separated areas of practice and knowledge. W9. No check if all info is placed on sticky note.	W1. Division of zones hard to interpret. W7. Individual work time-consuming.	W9. No check if all info is placed on sticky note.	W10. Did not utilize possibility to use coordination views in model.
Schedule Zone: Phase Scheduling (group activity)	W8. Separated areas of practice and knowledge.	W11. Order of placing sticky-notes not clear. W12. Discussion about dependencies hard to understand. W13. Scheduling the most collaborative part, hard to keep focus.	W14. Sticky notes not sticky enough. W15. Connections missed due to misunderstanding. W16. Activities missed due to orientation issues. W17. Hard to add new activities/connections without affecting legibility	
General	W18. Not all participants present. W19. Everybody couldn't participate on location. W20. Need and benefit unclear initially.	W20. Need and benefit unclear initially. W21. Need to update the schedule/sequence. W22. Need amend resources and duration. W23. All not familiar with the process. W24. Poor "full picture" of zones.	W25. Lots of information, physical lack of space	W26. Version of model unclear/unreliable. W27. Need for manual input into scheduling software. W28. Long lead times between workshops (input of schedule).

4.3 Current limitations concerning existing software

The planning and scheduling process illustrated the observed and current process in Fig. 2 in shows that there is a mix of individual and collaborative work in the studied approach. While some work is done by each subcontractor individually, the main work is done in a collaborative manner around the former mentioned big sheets of paper with the sequenced schedule. Examples of problems identified in Table 1 are e.g.W13. Scheduling the most collaborative part, W17. Hard to add new activities/connections without effecting legibility as well as W28. Long lead times between workshops. This shows indications of the need to support collaborative interaction, as well as a reason to look at the possibilities to digitize the process.

While a scheduling software such as the Vico Office package or the Synchro Pro package could address some concerns, it stills is software aimed at professional planners. Simpler software geared more towards coordination and visualisation of the model like Autodesk Navisworks Manage have somewhat limited scheduling capabilities and is more geared towards coupling an existing model with an existing schedule, even though the possibility to create activities directly in the software exists. Furthermore, these software's still fail to address requirements of CVE found in section 2.1, such as C2 – Enable co-creation, C5 – Shared context/Shared understanding, as well as the collaborative needs identified in the workshops.

Looking outside the field of traditional construction management software there are some collaborative tools that organises the project into boards and simulates sticky notes. Examples of these are Trello and Yolean to name a few, both in which entries or activities could be compared to sticky notes. However, these tools lack a direct connection to the model and more or less moves from physical to digital sticky notes, but with some added managerial possibilities.

This description of commercially available solutions are by no means exhaustive, but represent the tools seen typically seen in a Swedish context As described above, existing tools in general caters to some of the problem identified in Table 1, but no tool solves enough of these to create a collaborative planning and scheduling environment with the model in the centre of communication and interaction. To address these needs system which enhances the current analogue method rather than replaces it with another way of working is needed. This calls for the development of a new tool.

5. THE VISUAL PROJECT PLANNER APPLICATION

As seen in the CVE literature, there is a general call for a more collaborative interface and tool that is friendlier to new or inexperienced users, another important aspect according to the literature is the low adoption rate of new technology due to new processes, high thresholds of learning and a general fallback to previously known and tried methods. This is the main argument for developing a new application, the Visual Project planner (VPP). In this subsection the application is outlined as well as the requirements. Starting with section 5.1, a general overview of the developed application is given with the 3 main subprocesses and their correlation to the original approach shown in Fig. 2 in section 4. Section 5.2 highlights the problems from observations as well as the literature. The last subsection then gives a more in-depth technical overview coupled with the description of the application in relation to the requirements.

5.1 Application process overview

The full application supports the phases illustrated in the process in Fig. 2. Each of these stages have been further mapped in Fig. 6, Fig. 7 and Fig. 8. Fig. 6 shows the review phase, if the review zone phase is repeated for each zone in the project the phase become a project review phase. As seen in Fig. 6, the logged-on user selects project, then zone and then does the review, this is repeated for a zone but the team could also agree to move on to the next phase and perform the planning of the zone, which is shown in Fig. 7.

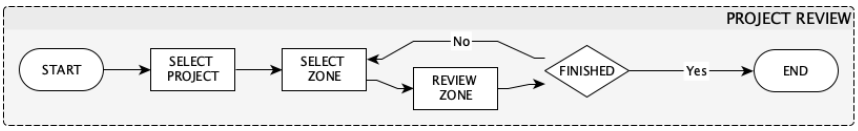

FIG. 6: Process map of review zone/project phase.

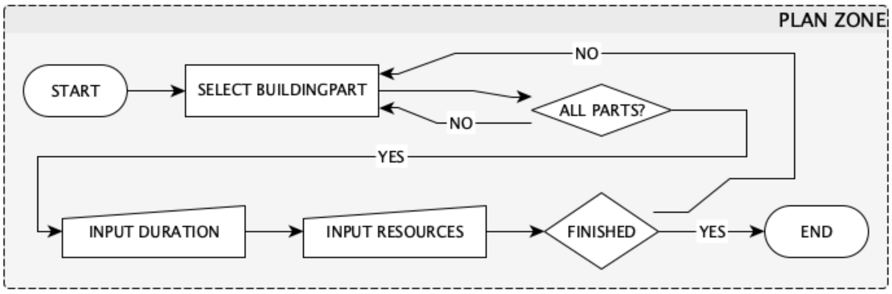

FIG. 7: Process map of plan zone phase.

The plan zone phase in the application mirrors the approach seen in the workshops but utilizes the BIM model directly for the creation of the schedule. This is shown in Fig. 7, where the user selects parts that make up the activity, then inputs duration and resources (workers) into the newly created activity, this process is repeated for all parts in the selected zone, until all activities needed have been identified and created for the current user and its discipline. This process is either repeated for the next zone or the team can choose to schedule the zone, a process which is shown in more detail in Fig. 8.

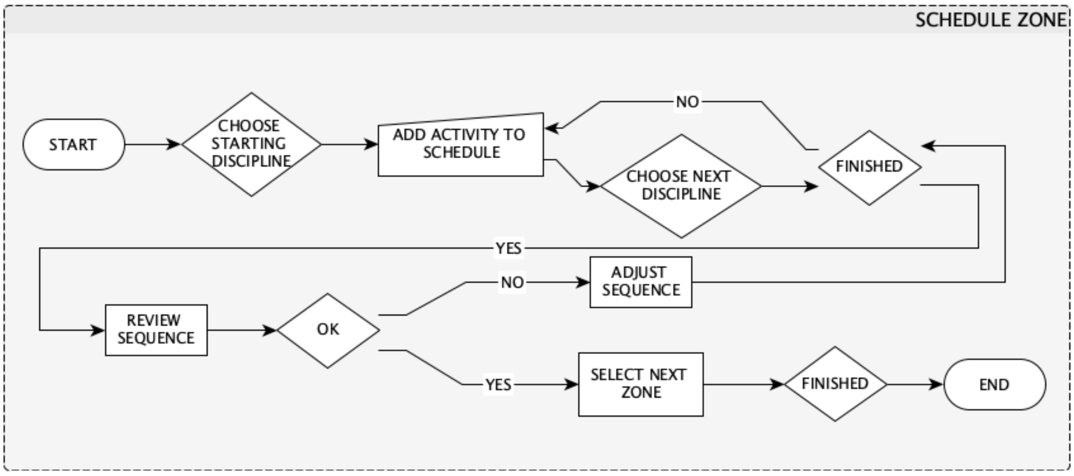

FIG. 8: Process map of schedule zone phase.

The scheduling of the zone in the application also mimics the original schedule zone approach shown in Fig. 2. All the users agree upon which discipline should go first, the selected discipline and puts its first activity into the schedule, the process is then repeated until all activities of all disciplines for the selected zone has been put into the schedule. This is followed by a review of the sequence logic of the actual zone, if needed the schedule is adjusted. The process is then again repeated for each zone in the project until the project is fully scheduled.

5.2 Requirements

Along with findings from the literature, and the drawbacks observed in the workshops, four core requirements are defined that are the foundation for the development and evaluation of the prototype VPP (see Table 2). These requirements are expressed as functionalities and are listed below.

TABLE 2: Requirements related to problems from literature and from workshops as well as related CVE aspects.

REQUIREMENT	PROBLEMS FROM PLANNING LITERATURE (Lx)	PROBLEMS FROM WORKSHOP (Wx)	CVE LITERATURE (Cx) (SNOWDON, CHURCHILL AND MUNRO, 1998; FISCHER *ET AL.*, 2005)
1. HELP USERS GAIN OVERVIEW OF PROJECT AND DISCIPLINES	L1 Overview (Löfgren, 2007; Christiansen, 2012) L2 Visualising the problem (Dvir, Raz and Shenhar, 2003) L3 Reduce the complexity (Crowther and Ajayi, 2019) L4 Breakdown of the project (Kenley and Seppänen, 2009)	W1, W2, W3, W4, W5, W6, W7, W10, W11, W24, W25, W26.	C1, C4, C5, C7, C8
2. SUPPORT INDIVIDUAL AND GROUP WORK	L5 Early involvement is hard to achieve (Friblick and Nordlund, 2013) L6 Workers should plan (Winch and Kelsey, 2005; Crowther and Ajayi, 2019) L7 Involvement creates ownership of work (Dainty, Bryman and Price, 2002; Liker, 2005) L8 Support processes (Hartmann *et al.*, 2012)	W4, W5, W6, W7, W8, W9, W10, W11, W12, W13, W15, W16, W17, W18, W19, W20, W21, W22, W23, W25, W27, W28.	C1, C2, C3, C4, C7, C8
3. SUPPORT INFORMATION GATHERING WHILE CREATING ACTIVITIES	L3 Reduce the complexity (Kenley and Seppänen, 2006) L4 Breakdown of the project (Kenley and Seppänen, 2009) L6 Workers should plan (Winch and Kelsey, 2005; Crowther and Ajayi, 2019) L9 Utilize tacit knowledge (Brito and Ferreira, 2015)	W7, W8, W9, W10, W21, W22, W25, W26.	C1, C2, C3, C4, C5, C6, C8
4. SUPPORT COLLABORATIVE CREATION OF THE SCHEDULE	L7 Involvement creates ownership of work Dainty, Bryman and Price, 2002; Liker, 2005) L9 Utilize tacit knowledge (Brito and Ferreira, 2015) L10 Early involvement is hard to achieve (Friblick and Nordlund, 2013) L11 4D scheduling (Eastman *et al.*, 2011; Boton, Kubicki and Halin, 2013; Trebbe, Hartmann and Dorée, 2015; Crowther and Ajayi, 2019)	W8, W11, W12, W14, W15, W16, W17, W18, W19, W20, W21, W22, W23, W24, W25, W27, W28.	C1, C2, C3, C5, C6, C7, C8

5.3 The developed VPP-application

In this section of the paper the development as well as the artefact itself is described. Starting with a general description of the artefact, the description of the development process as well as an initial testing of the artefact. The artefact, VPP application, was chosen to be a web application to be less dependent on specific hardware and computers. Thus, enabling a bring your own device approach, supporting requirement 2. The web application approach was also chosen to easier enable the collaborative aspects of requirement 4 and address some of the shortcomings found in other software solutions. The VPP application is a server/client-based web-application that connects disciplines and the BIM model through the scheduling work. Here the approach differs from how traditional scheduling is done. Activities are created by grouping of model elements rather than through the traditional approach of 4D-systems to connect an existing schedule to an existing model. Thus, the activities are created directly from the model rather than in parallell with the model but disconnect until mapped togheter. The general layout is presented in Fig. 9. The backend is based on two microservices, one serving the three.JS based application and the models, and one serving the NoSQL-MongoDB database with the project specific planning and scheduling data. The schedule is stored in the database as a separate schedule for each zone, containing both activities and connections. The BIM-model data is currently uploaded from a BIM system such as Revit to a JSON object 4.3 format, useable for the three.JS based webGL application. Thus, both native Revit models as well as IFC models can be used as input to the application. With regard to requirement 3, the VPP-application filters the project by discipline depending on the user logged on. From here the user can review levels and zones and create activities and participate in the collaborative scheduling workshop, which covers all four general requirements in Table 2.

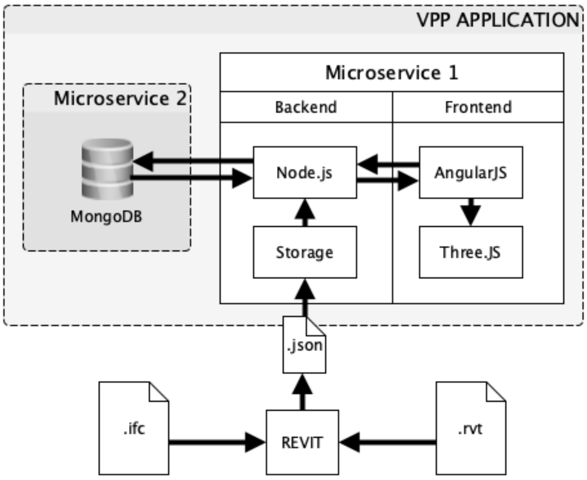

FIG. 9: Main setup and frameworks of the VPP application.

In Fig. 10, the selected project is presented, here the user can select a level to work on by clicking in the appropriate position. Fig. 11 represents the selected level and displays available zones in this level. This is an example of how requirements 2 and 3 come into play. The focus here is to enable both individual and groupwork, people within the same disciplines will have changes reflected in each other's models. The information is also presented as needed, when objects are selected. The navigation through the model to the zone ensures that the user understands the location of the zone. The users go from selecting the project, then the floor and the specific zone on a floor, thus navigating through the model and gaining context and an overview of where the zone is located. This part of the application can be used during the walkthrough of the project to gain an overview and is designed with this requirement in mind. In Fig. 12, the activity planning is shown in more detail; a wall is selected and shown in

FIG. 10: Project screen, select level.

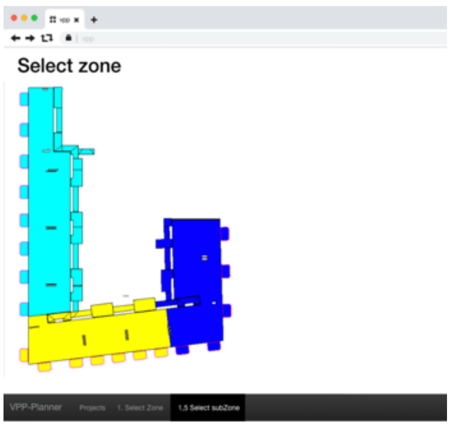

FIG. 11: Level screen, select zone.

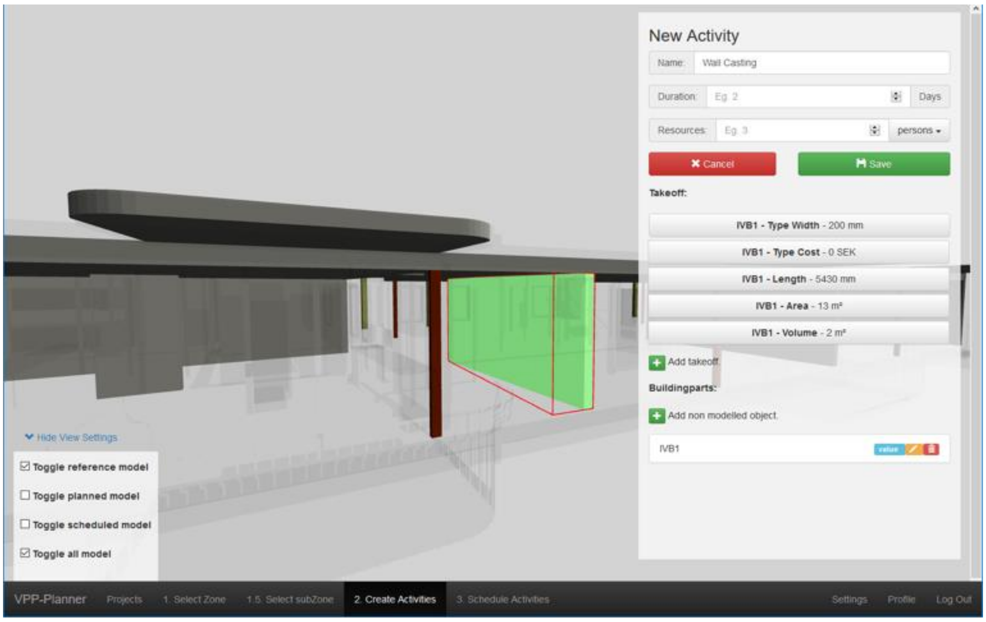

FIG. 12: The VPP-application in action, a wall selected (white with red boundary) while creating activity.

white with red edges in the figure. On the right side in the figure, is the beginning of a new activity. Information is kept to a bare minimum; name of the activity, duration and resources/manpower needed to perform the activity, and then a list of all building parts that is part of the activity, along with the quantity take-off for each part (not shown in figure). In the lower left part of the view the user can switch between different views and turn the reference model on and off.

For several disciplines the architectural model is shown slightly transparent as a reference, to help the user orient oneself. Fig. 13 shows the view for HVAC, with the architectural model slightly transparent on top of the piping elements, this addresses for example the problem W10 in Table 1. As elements are planned in activities and activities are saved, the corresponding elements are hidden, thus gradually giving the user input of what is left to plan, once again related to requirement 1. This visual feedback is a typical example of outcomes from the DS development loops, where feedback during one evaluation led to the development of this feature. Scheduling activities represent the majority of the collaborative part of the original workshop and are related to the fourth requirement. Fig. 14 presents the view of the schedule after some activities have been scheduled. The view represents the screen one discipline would see. Each instance of the VPP-application is filtered by the respective discipline logged in. The activities list (right part of Fig. 14), is filtered according to the currently logged on discipline while the left part of Fig. 14 shows the schedule with blocks from all disciplines. Each discipline can thus only see their activities (the left part containing the list), but once activities are placed in the schedule all participants can see and interact with them. This gives a full overview of all disciplines once the activities are

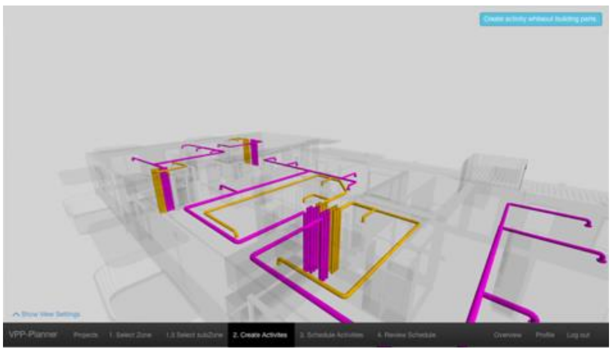

FIG. 13: HVAC discipline showing transparent architecture model as reference.

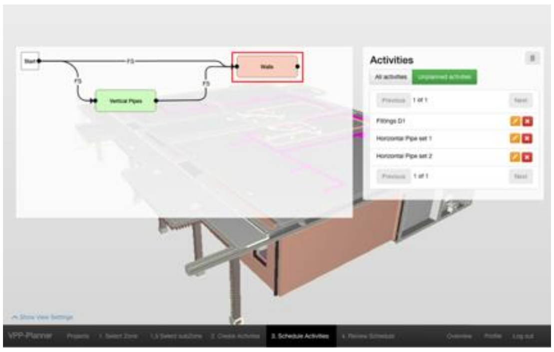

FIG.14: Scheduling phase of the workshop. Different coloured boxes for different disciplines.

scheduled. The collaborative scheduling is done similarly to how the observed current process was conducted with sticky notes. The difference in the scheduling is that instead of sheets of papers on the walls, a digital whiteboard is used where the participants drag and drop their activities and connect them with links, as seen in the left part of Fig. 14. This is aimed at the fourth requirement, enabling the collaborative creation of the schedule. As VPP was design with the DS approach, it has undergone several design cycles with rigor and relevance cycles iterated throughout. The first design cycle was initiated after a relevance and rigor cycle done in parallel. The design cycle started with a rough prototype sketching using the four base requirements found in the starting relevance cycle in the initially observed three workshops along with the nine requirements from the rigor cycle regarding collaborative environments and processes found in the literature. The observations from the workshops are firmly rooted in the contextual environment and its application domain of Fig. 1, while the literature provides the connection to the foundations of the more general knowledge base. By using an iterative approach with design cycles with connected relevance and rigor cycles, the development achieves anchoring back and forth into the application domain and foundations. The VPP-tool was built iteratively with evaluations towards both general planning as well as the specific workshop practice observed. The requirements derived from both the knowledge base and the contextual environment helped focus the problem on the people in the process. Thus, keeping the design of the application as technology to support the people in the use of the process rather than letting the process dictate the design. The evaluations of the tool are described in the following section.

6. EVALUATION OF THE VPP-APPLICATION

This section describes the findings from the evaluation sessions and their impact on the continuous development from the requirements. The methods of how the evaluations were performed, who participated in the evaluations and how data was collected are discussed in section 3. The first evaluations focused more on the technology aspects of the VPP-application, while the later evaluations also focused on the user and the support of the current process. The evaluations were based on the four requirements listed in Table 2. Table 3 summarizes how the VPP-application addresses the different requirements. This is further explained in more detail in the following sub-sections showing how the requirements of the VPP are met in the design and the outcome of the evaluations.

6.1 Overview of project and participating disciplines

The ability to gain an overview of the project and the participating disciplines was one of the main reasons for developing the artefact rather than relying on adapting currently available solutions. While currently available BIM-tools support filtering and grouping to various extent, these BIM tools did not support the collaborative aspects needed for the workshops to work. The workshops highlighted the need for a lightweight collaborative tool. As seen in the observations, the mix of current tools and otherwise available information in the form of drawings and documents, to some extent confused the users more than helped them, thus, the tools did not suit their needs.

During the evaluations of the VPP-application, the general observations showed that the discussions shifted from questions around location and orientation to more specific coordination questions regarding the activities and their order as the activities was being scheduled. The discussion became more focused on the sequencing of activities rather than trying to interpret position, orient oneself in the documents or models and identify what was seen here. Further, the evaluations showed that the navigation through the model, stepwise through full model to level down to the isolated specific zone, helped the user understand and remember the location of the current zone. This helped the evaluators staying focused on the task when they discussed certain specific problems while reviewing the model or scheduling for example. The evaluations also confirmed that the choice to reduce the complexity of the model by limiting what is visible to the current disciplines' building objects, supported by a translucent version of the architectural model, again helped focus the evaluators on the task at hand. The possibility to hide/show specific models, such as the translucent architecture model helped de-clutter the view. This shows a clear example of how requirement for the flexible and multiple viewpoints demanded in the CVE literature have been addressed. The evaluation showed that the evaluators found the interaction with the model intuitive and helped them understand the current zone. During the evaluations, several areas of improvements were suggested and fed into the design cycles, one such improvement from the first evaluation was the ability to easily select similar elements in the model, which later became a filter feature in of the VPP-application. During the last evaluation during discussions, several of the evaluators individually compared and contrasted the VPP-application to the current process and stressed the improved legibility as well as overview of the task at hand.

TABLE 3: How the VPP application addresses the requirements.

REQUIREMENT	HOW REQUIREMENTS ARE ADDRESSED IN THE VPP APPLICATION
1. HELP USERS GAIN OVERVIEW OF PROJECT AND DISCIPLINES	- Break down model into smaller zones – L1, L3, L4, W2, W3, W6, C1, C4, C5, C8 - Navigation to specific zone – L1, L3, W2, W4, W6, C1, C4 - Limit visible information – L1, L2, L3, W2, W3, W4, W5, W24, W25, C8 - Possibility to show / hide other disciplines in specific zone – L1, L3, W2, W3, C1, C4, C8 - Possibility to interact with model in zone – L1, L2, W1, W2, W5, W6, W12, W24, C1, C8 - Creation of activities stored in database – W7, W10 - Model distributed from server – W26
2. SUPPORT INDIVIDUAL AND GROUP WORK	- Interactions with specific zone is individual and customized to user – L5, L6, L7, W1, W6, C4, C8 - Possibility for user to create activities from filtered zone view – L6, L7, L8, W7, W8, W9, W10, C1, C2, C3 - One discipline can work together on the same zone, sees all activities they've created – L6, L7, L8, W7, W10, C1, C2, C3, C4, C5 - Co-creation of schedule when sequencing activities – W8, W10, W11, W12, W13, W14, W15, W16, W17, W20, W21, W22, W23, W24, W25, W27, W28, C1, C2, C3, C4, C5, C6, C7, C8 - Distance participation possible – W18
3. SUPPORT INFORMATION GATHERING WHILE CREATING ACTIVITIES	- BIM model provides information – L3, W8, W10, W26, C3, C8 - Users can specify information shown by model – L3, L4, L6, W7, W8, W25, C2, C3, C8 - Information is hidden until hoover over element or click on element – L3, L4, L6, W8, W10, C3, C8 - Specified information acts as input in the activity, information is summarized as preliminary take-off quantities – L3, L4, L9, W8, W21, W22, C8 - Planned parts are hidden until scheduling starts or user override, gives visual feedback of what is planned – L3, W8, W25, C1, C2, C3, C4, C8 - Users able to interact and discuss around reference model as well as model – C1
4. SUPPORT COLLABORATIVE CREATION OF THE SCHEDULE	- Every user can see and interact with the full schedule – L7, L9, L11, W8, W11, W12, W14, W15, W16, W17, W18, W19, W20, W21, W24, W25, W27, W28, C1, C2, C3, C6, C8 - Several users can interact with the schedule simultaneously –L10, W11, W12, W19, W21, W22, W23, W24, W25, W27, W28, C1, C2, C3, C4, C5, C8 - Possibility to show / hide other disciplines in specific zone – L7, L9, L11, W21, W23, W24, C8 - Visual feedback from the model on what is scheduled – L11, W19, W24, W25, W27, W28, C1, C4, C8

6.2 Individual and group work.

The VPP-application fulfils the requirement to support both individual and group work was shown well. By observing the evaluators interactions with the application, it could be concluded that the evaluators rapidly became proficient in the use of the application, even with only a short introduction and regardless of their computer proficiency level. The screen recordings of the later evaluations also helped analyse and evaluate the efficiency of the implemented process. The evaluators commended the possibility to individually work by discipline, but still being able to build on others work if several users were active in one discipline, this was greatly supported by the filtering of the visible model per discipline. The sharing of the schedule view for the group work was specifically mentioned during the later evaluations as an improvement over the unenhanced planning and scheduling method. This sharing of the schedule view enabled a cleaner and more structured overview of the schedule than the result from the traditional manual sequencing and scheduling of sticky-note activities.

6.3 Information gathering while creating activities.

The evaluations showed that the increased use of the BIM-model, the navigation and twisting and turning of the model to explore building parts and identify activities, was a main source of information gathering. It was mentioned in the evaluations that the possibility to turn on and off as well as override planned, and scheduled state of the model helped in the understanding and information gathering while creating activities. The early evaluations also provided input to later design cycles and versions of the VPP-application that there was a need for certain information to become visible on hoover on elements. The evaluations also provided positive feedback on displaying take-off quantities as a possibility in the planning of activities. Further the use of visual feedback by hiding elements that are planned (and the same when scheduled) was specifically mentioned as a helpful ability of the tool to visually understand what was done. This also shows a direct relation to the identified benefit of the 4D visual simulations mentioned in the literature.

6.4 Collaborative creation of the schedule.

As collaborative creation was one of the core elements of the scheduling process and this collaborative planning and scheduling workshop, this was especially important to address in the evaluations. As mentioned earlier, the first evaluations were more focused on the activity creation, while the main emphasis in the last two evaluations were the actual comparison between the unenhanced paper/sticky note version and VPP -application enhanced method. One of the main features of the VPP-application was the removing of the use of sticky notes and substituting them with the virtual activities created in the VPP-application by each discipline. The evaluations showed that it was possible for all evaluators to collaboratively create the schedule. Furthermore, one evaluator joined online via the VPP-application together with skype from another location. This showed that the problem seen in Table 1 that originally all participants could not participate and the possibility to work remote could possibly address this. Thus, this exemplifies that the VPP-application enabled remote work as well co-located work. Furthermore, the evaluation showed that the users could interact with the schedule and saw updates in real time to the schedule made by other users in their respective schedule overview. Thus, they were able to build upon each other's work. During the last evaluation, several participants emphasised the improvement in gaining a better overview with the VPP-application compared to the traditional sequencing on paper method.

6.5 Summary of the evaluations

All in all, the developed VPP-application addresses the four requirements well. As seen in Table 2, each of the requirements of the system addresses several of the key collaborative social environment aspects that CVE literature mentions (Snowdon, Churchill and Munro, 1998; Fischer *et al.*, 2005). All of these aspects are addressed, but not in each requirement. The DS approach to the development of the VPP-application meant that findings during the evaluations could be fed into a new design-loop as adjusted requirements and thus acted as a mean to keep the design of the VPP-application closer to the users' needs rather than strict process adherence.

7. DISCUSSION AND FUTURE WORK

This paper started out by arguing that management and especially scheduling in construction and especially pre-construction is an area that despite research still warrants continued attention. This is especially true with regards to how tools are developed. The increasing complexity of construction projects in general, both in terms of technical complexity as well as organisational complexity could be argued to call for a deeper involvement of subcontractors in pre-construction planning. The paper shows that the collaborative and empowerment approach taken in LPS and IP have inspired extended planning approaches in a positive direction. However, even though there has been a great deal of development in IT-tools with the rise of BIM during the last decades, the adoption of tools still lags behind, especially when it comes to possibilities to collaborate simultaneously. While some of the shortcomings of these tools trace back to the tools often being coupled with new processes, it is also traced to the site manager's lack of time to adopt new processes and rather sticking with known practices (Christiansen, 2012; AlNasseri and Aulin, 2015). This is especially true to lean construction and LPS, where the current process is discarded and replaced entirely by the LPS system. Thus, the main aim of the paper was to show how to develop an application from the user as well as process perspective, without the need to discard current processes but rather enhance them. The developed VPP-application focuses on collaborative aspects and utilises a user centric perspective in the development. By using DS as a framework for the research, the development and the evaluation as well as the connection to the original planning process was kept user-focused and interconnected. The DS approach helped form general requirements through the knowledge base in the form of connected literature and research. DS also helped specify the context-dependent requirements through the observations. Thereby creating a tool that could enhance the existing analogue collaborative planning and scheduling process.

The developed VPP application supports pre-construction planning and can be used regardless of the planning approach used. However, the VPP system has primarily been developed to support collaborative and visual planning. Thus, it is well suited for IP as well as LPS approaches. This paper serves as an example of how IT-supported systems in construction could and should be developed. A strong focus on enhancing current practice is needed to lessen the threshold to implement new tools that could provide benefits to the process. The DS approach to ensure relevance as well as rigor by both observing current context, e.g. practice, as well as surveying the research field's body of knowledge enables an artefact that provides actual usefulness as well as the possibility to add general knowledge to the field. An example of this is the documentation in this paper of the design process and approach, that allows for similar development to be adopted in design of tools in other parts of the construction process or with other goals.

The requirements for the VPP-application have been broadly inspired by the CVE-knowledge base (Snowdon, Churchill and Munro, 1998; Fischer *et al.*, 2005), which identify several aspects that promote the social processes a systems solution needs to support; e.g. Shared Context, Awareness of others, Transitions between shared and individual activities, Negotiation and communication, Flexible and multiple viewpoints. These aspects form the basis to enable a collaborative artefact. While part of the benefits of the system are positioned in the collaborative nature of the scheduling approach, the system addresses all of the CVE requirements in several different ways. One example of this is the creation of a shared understanding, this is enabled by overlaying different models on each other, which is possible in many BIM-tools, but the VPP-application differs in that it allows the users to interactively and collaboratively engage with the model. This enables the users to zoom in to interesting areas of the model and discuss between disciplines the specific solutions to a sequencing problem of the activities in this zone. Furthermore, the VPP application supported discussions concerning the problem at hand (reviewing, planning, sequencing or scheduling) rather than trying to interpret and understand what they are seeing, as seen in the original workshop observations. Also, the application encourages a more active role in creating the schedule, by actually placing the activities in the schedule promotes the feeling of ownership and commitment toward the created schedule, much more so than in the unenhanced IP workshops where sticky-notes often are handed to the specialist planner to put up on the zone-paper. The collaborative approach used with the VPP application, enhances involvement of the different subcontractors, possibilities to exchange their tacit knowledge during the planning, and visualising the different planning stages. As the evaluations show, it could be argued that the requirements derived from these aspects have a positive effect on the collaborative scheduling process and the VPP-application in general. In fact, there is a possibility that using the VPP-application in other planning approaches, such as a pull planning type of approach these positive effects on for example the schedule creation and understanding of the project could be seen as well.

Furthermore, the VPP application shows indications of having a positive impact on the time needed to finalize a pre-construction schedule. This is especially true since the time from creation of the structure of the schedule to actually reviewing the schedule could be decreased. However, some further development and more studies are needed.

A limitation of the work with regards to the DS approach is that the work presented here is not yet implemented and conducted on an on-site ongoing project and thus could be argued to not have closed a full development cycle in a DS perspective. While several small and iterative design cycles have been conducted, they have only been evaluated with specialist planners, middle managers, researchers and construction management students. While these different evaluation groups complimented each other with their respective knowledge they do not fully represent the aimed stakeholder group. The specialist planners and middle managers had specific construction and general project management knowledge, but limited knowledge in the observed planning approach. The construction management students were experienced in the actual planning approach but did not have as extensive general project management knowledge as the middle management group. Thus overall, it could be argued that the evaluations covered the general competences needed to evaluate the tool reliably against the requirements. This hints at possible positive results in a more on-going construction setting as well. However, future work will further explore and evaluate the VPP-application and the collaborative scheduling process in on-site ongoing projects and investigate how this new method effects scheduling and what type of behaviours and processes occur during VPP collaborative scheduling workshops.

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