4D MODELS TO SUPPORT SAFE PLANNING OF HOSPITAL RENOVATIONS

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ABSTRACT

During hospital renovations, medical processes are, oftentimes, in progress at the same time as construction processes are. As a result, construction work may interfere with ongoing medical work. These conflicts often have undesirable effects on the vulnerable medical processes, in particular in relation to patient safety. Hence, during hospital renovation planning activities medical and construction experts have to work closely together to devise sound construction plans that align these two processes. To support such planning activities, this paper presents a method to model hospital renovation activities using 4D models that link a virtual representation of the hospital and several temporary objects, such as dust barriers, with planned construction sequences. We developed the method in an action research effort working closely together with architectural and medical practitioners on a hospital renovation project in the Netherlands. Throughout this action research we iteratively generated 4D models of the project and applied these models by supporting decision and communication tasks of practitioners in the ongoing project planning process. Next to the method itself, the paper also reports about some these first applications of the model that we were able to observe. These applications show that the method allows construction managers and medical specialists to develop 4D models that help to mutually evaluate the effects of a chosen construction sequence on ongoing medical processes.

Keywords: Hospital renovation, safety planning, 4D modelling, action research, modelling process.

1. INTRODUCTION

Renovation activities in hospitals often result in infections, fires, budget overruns, and construction delays. Therefore, construction and renovation activities in health-care facilities require substantial planning and coordination to minimize the risks both during projects, and after their completion (Sehulster, et al., 2003). During these planning and coordination activities. project teams have to carefully consider, which impacts construction activities have on hospital operations and safety.

Therefore, planning hospital renovation projects requires an integrated project planning approach that involves construction and medical specialists. Problematic is that such an integrated planning approach demands that all members of the integrated team are able to communicate their domain specific knowledge to all other members. Only then, all project team members are able to actively take part in the design and planning process. In practice, the communication of knowledge across disciplines remains one of the major barriers to a truly integrated project planning practice. To overcome some of these problems, 4D modelling seems an adequate tool. 4D modelling are computerized methods to represent construction plans that add the temporal dimension to 3D CAD models. In this way, 4D models integrate the logical, temporal and spatial aspects of construction planning information, thereby reducing the need for individual conceptualizations of the construction schedule (Koo & Fischer, 2000). In recent years more and more construction practitioners used three-dimensional/four-dimensional (3D/4D) models to support management tasks (Hartmannet al., 2008). Researchers described various task specific applications of 4D models, for instance: site management (Akinci et al, 2002; Chau et al., 2004; Coles & Reinschmidt, 1994), multi-stakeholder input (Eastman, Teicholz et al., 2008; Hartmann & Fischer 2007; Fischer & Kunz, 2004), communication of the construction schedule (Eastman, et al., 2008; Hartmann & Fischer 2007; Koo & Fischer, 2000; McKinney & Fischer, 1998), evaluating schedule alternatives (Chau et al., 2005; McKinney & Fischer, 1998), and tracking construction progress (Ma et al. 2005; Webb & Haupt, 2003).

Based on these applications, researchers identified several advantages of 4D models over traditional methods. So do 4D models, for example, allow for the more effective evaluation of construction schedules (Koo & Fischer, 2000) or for identification of problems that might occur later during construction (McKinney et al., 1996). Researchers also showed the benefit of 4D models in communication activities of multi-disciplinary project teams. Unfortunately, little knowledge still exists in the area of 4D modelling to specifically support hospital renovation projects. Researchers studied the use of 4D modeling on hospital construction cases and other researchers on construction worker safety (Chantawit et al., 2005), but without specifically focusing on patient safety.

To further knowledge in how to apply 4D models to support hospital renovation planning under consideration of patient safety, this paper presents a formal method to generate 4D model to allow multi-stakeholder safety planning exercises for hospital projects. We developed this method in an action-research effort (Hartmann et al. 2009) working in close collaboration with construction and medical professionals on a hospital renovation project in the Netherlands. The modelling method describes how the important safety information can be visualized in 4D models next to the standard construction sequencing information that current 4D technology already offers by default. To illustrate the practical utility of the method the paper also summarizes some of the practical applications of 4D models that we were able to observe during our action research approach.

The paper is structured as follow: It starts with a brief introduction of the action-research method we used to develop the method. We then derive the requirements for the method by theoretically discussing hospital renovation planning activities and general 4D modelling techniques. Afterwards, the paper describes the modelling method. The paper continuous with summarizing the limitations of the research and its theoretical contributions. It finally, closes with discussing some practical implications of the presented work and with developing a number of suggestions for future research activities.

2. RESEARCH METHOD

To develop the method, we used ethnographic action research (Hartmann et al. 2009) on an exploratory case study (Yin, 2002). The basic philosophy of ethnographic action research is it to develop new information systems in close collaboration with practitioners within their real work setting. The method prescribes to develop a system in small iterative steps of close observation of work practices, the development IT functionality with the aim to quickly and directly improve these work practices, and the direct implementation of the small iterative improvements in the work practice. In this way, the method is specifically well suited to develop extensions for already existing systems, such as the extension of existing 4D systems to support decision making about hospital procedures during renovation planning activities.

We conducted the action research on a case study with an architectural design firm in the Netherlands. Being one of the biggest architectural firms in the Netherlands, the firm gained experience in delivering a variety of projects, including hospital renovations. In this specific case, the firm was engaged to plan the renovation of a surgical department of a middle sized hospital (€12-17 million). The realization of the project was scheduled to start in the summer of 2010. The renovation was necessary, because equipment and architectural features were outdated and did not longer meet today's requirements.

The task of the firm on this project was to deliver a renovation plan for the hospital that fulfils all client requirements, is feasible to build, and will allow the renovation of the hospital within budget. During the time of our action research based fieldwork, the architectural design company had settled on a conceptual design alternative and was concerned with the preparation of an initial construction sequencing plan. To develop a feasible and, in particular, safe renovation sequence, the firm collaborated with advisors of the construction office of the hospital. Due to this collaborative activity, the case presented a formidable chance to introduce 4D modelling as a tool to support the decision making activities using action-research.

While the research we conducted was very iterative, the rest of this paper will describe the final findings from these iterative efforts in a sequential manner. To this end, the next section first describes the requirements for the 4D system that shaped during our ethnographic observation of practice. We then continue with a section that summarizes the final method to develop 4D models that allow for hospital safety planning. Afterwards, we describe a number of instances of how practitioners on the project used the evolving 4D models to make better decisions to illustrate the applicability of the 4D models that we created with the evolving method.

3. REQUIREMENTS OF 4D MODELS TO SUPPORT HOSPITAL RENOVATION SAFETY PLANNING

Overall, there are a number of issues that occur during hospital renovations that planners need to account for during their decision making tasks. First of all and probably most importantly, construction activities can indirectly cause hospital acquired infections, because construction dust and soil almost always contains pathogenic spores. Construction dust is transported on shoes and clothes, or is spread by means of gravity and air flows in the building (Bartley & Bjerke, 2001; Werkgroep Infectie Preventie, 2007). To prevent spreading of harmful dust, planners have to isolate areas with construction activity from the rest of the hospital (Wischer & Riethmuller, 2008). Therefore, contact of construction workers and material with patients, medical staff, and medical equipment has to be avoided. In practice, this isolation is achieved by installing dust barriers and by planning dedicated routes for patients, material, medical staff, and construction workers. Planners have to devise plan that can ensure this separation.

Next to the problem of hospital infections, construction activities in hospitals also increase the risk for the outbreak of fires. Hospitals are full of dangerous materials. Anaesthesia equipment, for example, contains medical gasses, such as oxygen, carbon dioxide, medical air, and nitrous (Inspectie voor de Gezondheidszorg, 2008). Hospitals have to control the storage and transport of these gasses to prevent the outbreak fires which is complicated through parallel construction activities. Further, to reduce the harmful effects in case the outbreak of fires cannot be avoided, hospitals must have an adequate evacuation plan. These evacuation plans must account for immobile patients and, hence, consist of complicated emergency escape routes and protocols for the treatment of patients. Hence, planners do not only need to account for the possibility that hospital staff can transport all flammable materials safely during construction, but must also devise emergency protocols to ensure safety during construction activities.

While the main concern during hospital renovation should be with patient safety, financial considerations can never be completely disregarded. Renovations of hospitals are frequently more expensive and last longer than planned. Often renovations turn out to be more expensive than the construction of a complete new hospital would have been (Wagenaar, 2006). Cost and time overruns have several underlying causes, of which only one is the construction typical time-space conflicts between different contractors that work at the same time that cause budget overruns and delays. During hospital operations, the traditional costs caused by scheduling conflicts between construction parties are often minimal compared to the financial gains that hospitals can achieve if a sound renovation plan allows them to continue offering as many health services as possible during the construction time. Planners have, of course, to balance all this with the overall duration the renovation activities take. Financially, the earlier a hospital is completely operational again the better.

To mitigate the above described risks different regulations and measures exist that project planners and contractors should comply with. In current practice, it is hard for practitioners to gain sufficient insight to acknowledge these regulations and measures adequately. For instance, little support exists with planning how to best isolate construction areas with dust walls, how to maintain the required higher levels of air pressure in sterile areas, or how to devise separate routes for construction workers and medical staff. Additionally, supporting tools to plan for transitions between different construction phases are not available. Such transitions particular often cause problems and hence have to be planned in great detail. To allow for a safe and easy transition between two different stages that require a different separation between areas it is, for example, important to first create a new temporary access to be able to clean areas thoroughly before they are ready for use.

Due to all these complexities, planners often do not understand the necessary regulations and measures to ensure for patient safety enough to devise their construction plans accordingly. At the same time, hospital staff with an in depth knowledge about safety regulations and measures does not understand the specifics of the planned construction work to support the planners. Hence, hospital renovation planning activities seem to be a great area for the application of 4D models. The next section, describes the method to generate specific 4D models that allow for hospital renovations planning activities that we developed based on these requirements in detail.

4. THE PROPOSED METHOD TO GENERATE 4D MODELS

As described above, theoretically 4D models seem to be an appropriate tool to support the decision making of practitioners that wish to plan hospital renovations. To leverage this potential we developed a 4D modelling method to visualize hospital and construction processes, and safety measures (Figure 1). The method allows for generating 4D models that combine information about

- building design and planning,
- hospital safety guidelines,
- and ongoing hospital processes.

The method uses the general features of 4D modelling:

- linking activities in a construction schedule and 3D objects to visualize construction progress over time,
- colour coding to highlight certain construction, operational, or safety related information, and
- text overlay to further highlight important other aspects.

Two 3D models of the, to be renovated, hospital serve as basic input for the generated 4D models: One model of the building before the renovation and one model of the building after the renovation. Additionally a number of different sequencing alternatives for the renovation activities are required as initial input. Existing 2D construction sequence drawings provide a good starting point for the developing these initial alternatives. 2D drawings are a good medium to brainstorm several opinions before using the information as input to the 4D model. This is mainly because sketching in 2D is less time-consuming than directly creating complicated sequences using scheduling or 4D modelling programs. 2D drawings allow for the quick generation of multiple basic scheduling alternatives that later can then be converted to formal 4D models for more in depth discussions.

Finally, additional 3D model objects representing different safety measures are required as an input. To be able to visualize different sterile and construction zones flexibly, we suggest to add a separate surface at the floor of each room or hallway. Further, we propose to add additional 3D objects representing dust barriers, obstacles, and risks that might occur during the renovation activities. Finally, the method prescribes to visualize routes for people, material, and evacuation using textual annotations and symbols such as arrows (Chantawit et al. 2005)

Following general 4D modelling techniques, the method suggests then to collect several 3D objects that are subject of the same type of construction activity or that represent a specific area of a certain hospital operation to a group – often called selection set. 4D systems can then colour these groups of objects according to defined task types, such as installation, demolition, or safety measures. Finally, we suggest to insert a legend to help people to understand the colours of the model. Figure 2 provides an example screen shot of a 4D model we generated with the method that illustrates the above summarized techniques of the method.

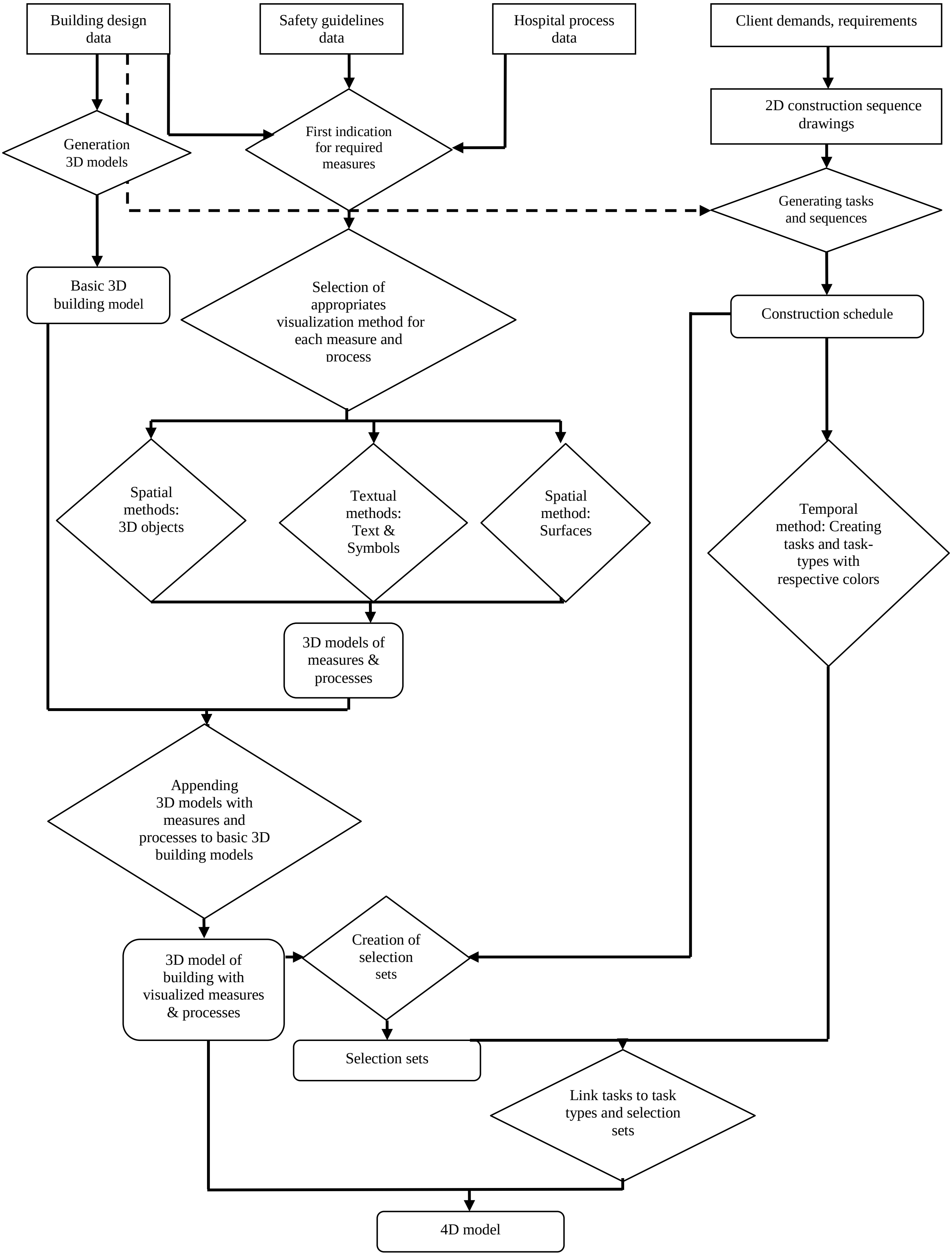

Figure 1: The method to extend 4D models with patient safety information.

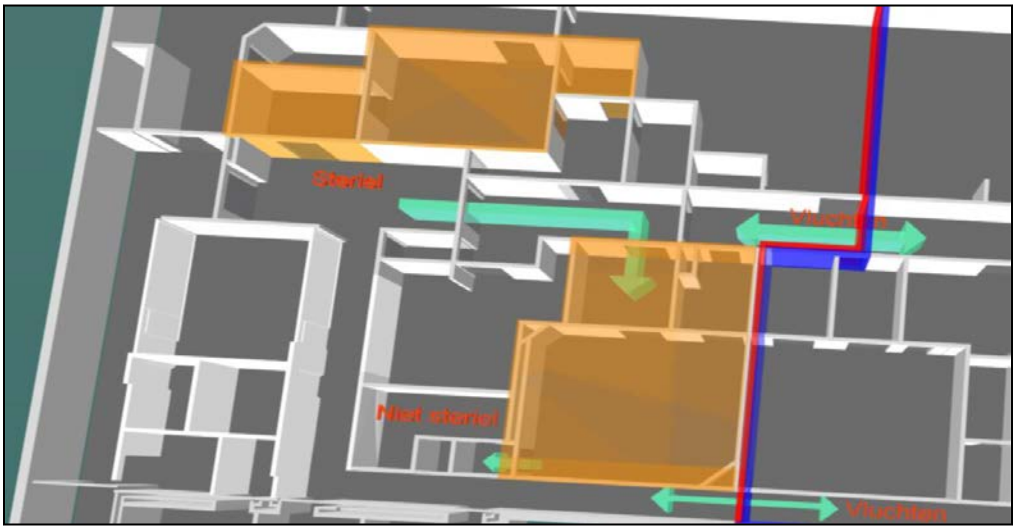

Figure 2: A 4D model generated with the method. Arrows visualize pathways for doctors, surfaces are used to signify areas of medical activity. Additional, elements show dust barriers. Finally, annotations provide additional information.

The model presented in the figure uses the following additional objects to convey patient safety related information:

- textual annotations to indicate sterile and non sterile working areas,
- arrows to indicate possible access routes for hospital staff,
- horizontally placed surfaces for spaces that indicate operative surgery arenas, and
- vertically placed surfaces to indicate dust barriers.

As discussed above, we used models similar to the one depicted in Figure 2 to support decision making tasks at an architectural company to learn how the models can support decision making tasks. The following section will describe this implementation effort to provide illustrative evidence for the working of the method.

5. VALIDATION OF THE METHOD

Throughout the action research effort, we asked a number of specialists to evaluate the benefits of the model. All of these specialists agreed upon the potential of the generated 4D models to support hospital renovation planning activities. Architectural specialists were especially interested in use of 4D models to support their external communication with hospital staff during project team meetings. One architect, stated that “we want to use 4D in the future to clarify plans to clients, to get them involved in the planning process.” One project manager also mentioned the advantage of 4D models, in understanding the lay-out of installations: “where 2D drawings provide a reasonable picture of buildings, 2D drawings of installations are very hard to understand for laymen.” The medical specialists involved with the project also saw the potential: “2D drawings are rather hard to understand for non-architects, 3D models already allow for a better understanding, and 4D models certainly do.” Finally, the project's contractor suggested that 2D drawings did not give as much insight in planning errors as 4D models do.

Additionally, we continuously asked the project specialists to evaluate the used visualization methods. The architect found ‘colour coding an effective way of visualizing the temporal dimension of project plans, and as very useful to put emphasis on a particular point of the plan’. However the communications advisor criticized the colour coding because ‘it contained too much different colours and text’. The architect & project manager also said this during the second meeting. The architect found that ‘it is important to find balance between the amount of information showed in the model, and the clarity of the model’. According to textual methods, the ICP stated ‘such method is useful when working with routing of various things, like construction workers, medical staff and patients’ because use of for instance arrows with multiple colours, confuses viewers. The duration and playing speed of the 4D visualization also lead to discussion. Both the communications advisor and architect found that the speed of the animation should be adapted to the presentation. 'When we want to use the 4D model, it must be integrated in the oral presentation of the architect, therefore it should be slow enough to do this'.

Overall, due to the positive attitude of all participants, models generated with early version of the method were also already successfully used in project team meetings during our action research effort. This allowed us to observe the interaction of practitioners with 4D models in person. During one meeting we joined, for example, the participants started to use 2D drawings. Soon it became apparent that the participants experienced problems presenting schedule alternatives. The presentation of different scheduling alternatives on multiple sets of 2D drawings quickly lead to chaos and misunderstanding. The medical specialists that participated, for example, started to comment on drawings that they did not understand completely. To overcome this confusion the project manager showed the meeting participants the 4D models that visualized the different sequences. This increased the understanding of the medical specialists about the planned renovation work immediately. All meeting participants could then start to have meaningful discussions about how to best stage the construction work. The meeting participants agreed that such a discussion would not have been possible without the increased understanding that the 4D model allowed for.

6. CONCLUSION

This paper introduced a 4D modelling method for visualization of hospital and construction processes, and safety measures for hospital renovation projects. The method combines spatial, textual, and temporal aspects to visualize hospital & construction processes and safety measures. The paper also shows that 4D models generated with the method give practitioners insight in problems and hazards that might arise during hospital renovation projects. The combination of general 4D modelling techniques (Chantawit, et al., 2005; McKinney & Fischer, 1998) enables practitioners to choose an appropriate way of visualizing for several processes and measures.

The implementation of models generated with the method in architectural practice during our action research effort illustrate how the models can improve participatory decision making tasks in two broad areas. For one, the models proved to be valuable to support the discussion between architects and hospital staff. In the meetings that did not use 4D models, we observed hospital staff had problems to quickly understand traditional construction drawings. Hence, architects spent significant time to explain plans to hospital staff. The more visual representation of the construction sequences the 4D models offered, allowed hospital staff to understand specificities of sequence plans much quicker and easier. In the end, this helped to streamline the meetings towards evaluating the sequencing plans instead of merely communicating the details of a specific plan.

Moreover, the models also supported the architects with making decisions about how to best sequence the construction. Architects were able to make decisions about the appropriateness of single stages using their traditional approach to sketch safety information on construction drawings. However, due to the static nature of the drawings, architects lacked the ability to easily understand and plan how to best transition between phases. 4D models with their possibility to provide animations of construction sequences over time helped architects to better understand whether a transition between two stages was feasible and, if feasible, how to best transition between two stages.

Although the study is a representative sample for hospital renovations, and 4D models generated are complete, there are of course some limitations that should be addressed by future research. A first limitation is that we developed the method with a focus on supporting preliminary design activities. However, we expect that practitioners can also benefit from the use of 4D models in later stages. Further, 4D models generated following the method do not account for building systems. Building systems are a very important part of hospital construction projects because medical equipment is very sophisticated. Results of the study also showed that the required information in a 4D visualization differs by the specialist using the model, for instance architects are interested in the architectural features, where medical practitioners want to be informed about the routing of patients. Therefore project teams need several models to adopt 4D modelling successfully. Researchers need to identify the requirements of specific parties involved in the planning process in more detail.

Despite these limitations, the study contributed to several aspects of 4D modelling theory. If nothing more, this research explored the applicability of 4D modelling to support safety planning of hospital renovation projects. So far most research done on 4D modelling for hospitals did not focus on patient safety related issues, but only on construction planning (Garcia, et al., 2004; Heesom & Mahdjoubi, 2004; Kunz, et al., 2003; Webb & Haupt, 2003) and construction worker safety (Chantawit, et al., 2005). This research is, to the best of our knowledge, one of the first studies to give construction related practitioners insight in the risks and safety problems arising during hospital construction. The research views construction activities as hazardous for both medical staff, patients and construction workers.

Beside these theoretical contributions, we also expect that practitioners are able to effectively devise safety measures using the method. With the method 4D models that visualizing hospital and construction processes, and safety measures, are relatively easy to generate. This will allow for the widespread use of 4D visualizations to communicate plans to users and staff before the execution phase of the project. Also users that get aware of hazards and risks will likely handle accordingly safe. Another fact that argues for the use of the method is that practitioners suggest that they are willing to use the method in future projects. This is supported by the fact that the architect explained about problems he perceived during project team meetings.

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