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Bridging the Gap between Actors and Digital tools in a Furnishing Design Process

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Abstract

The high level of complexity in today's building design requires a high level of interdisciplinary collaboration, which historically is an uncommon working method in the building industry. To support the interdisciplinary collaboration, new digital tools such as Building Information Models (BIM) and Virtual Reality (VR) can be implemented in various phases of the building project. The implementation of BIM is expected to support the designers and improve the collaboration among multiple actors, but the social aspects related to the use of BIM in the design process needs further investigation and development. Knotworking is one solution that seeks to improve the interdisciplinary collaboration during the design process involving tools to solve specific themes, or "knots", of the design. In this study, we investigate the use of Knotworking in a small-scale project – a furnishing design process of a new building at Aalborg University in Denmark. Two design workshops of one day each were held with two weeks in between aiming to furnish 5000 square meters. 20 actors were gathered for the workshop where BIM was used as a real-time 3D visualization tool, in the form of a touchscreen where the actors were able to furnish the floor plans along with VR glasses supporting the actors' experiences of the furnished spaces. Using participant observation and written feedback on post-its, data was collected from the design workshops. Activity systems have been used to analyze the contradictions of the activities derived from the evaluations. Based on the analysis, improvements for future furnishing design processes using Knotworking, BIM and VR are suggested. The contributions of this paper lie in the practical example of how Knotworking can be applied in a furnishing design project with the use of BIM and VR, and suggested improvements for future Knotworking furnishing design workshops using digital tools.

1 Introduction

The level of complexity in a building design process is high; multiple decisions have to be made throughout the design process, and with multiple experts involved (Bougrain et al. 2010; Chiocchio et al. 2011). For this reason, interdisciplinary collaboration among different experts during the building design process is necessary, but studies have shown that individual experts often commit to their own tasks and, for this reason, are not interested in the overall design (Kerosuo et al. 2013b; Kymmell 2008). To support the interdisciplinary collaboration, digital tools such as Building Information Models (BIM) and Virtual Reality (VR) technology have been implemented in various phases of the building design process (see e.g. Niu et al. 2016; Roupé et al. 2016). In addition to the digital tools, various methods for structuring and improving interdisciplinary collaboration exist, such as Big Room (Alhava et al. 2015), Six Sigma (Schroeder et al. 2008), and Knotworking (Engeström 2008). However, the methods for structuring the collaboration and using digital tools are often not connected in practice. This underlines the importance of investigating the social aspects related to the use of BIM and VR in the building design process, to ensure successful integration of technology. The Knotworking method has previously been applied in BIM-based building projects to improve the building design process at a school community center in Finland (Kerosuo et al. 2013a) and a lifeboat station in Denmark (Buhl et al. 2014). The successful implementation of Knotworking has inspired the implementation of Knotworking in this study. The furnishing design is often separated from the building design project because the budgets are separate. Thus, the furnishing has a significant impact on the identity of the finished building (Elsbach 2003), why it is important to address the furnishing design process as well as the building design process.

In this study, we have applied Knotworking along with BIM and VR in a furnishing design process of a new building at Aalborg University in Denmark. The involvement of users was crucial, to accommodate their needs, and to improve the

furnishing of this building compared to other buildings at Aalborg University. Two design workshops were held with two weeks in between aiming to furnish 5000 square meters. BIM was used as a real-time 3D visualization tool, in the form of a touchscreen to support the participants' ability to furnish the floor plans along with VR glasses supporting the experience of the furnished spaces. Based on evaluation feedback from the participants, and participant observation, nine main categories were identified, one of them being "use of technology." The technology-related challenges were subsequently analyzed using activity systems (Quek & Shah 2004; Engeström 2000), to identify improvements of furnishing designs in the future, in relation to the use of technology.

The paper is structured as follows. In the methods section, we describe the research methods applied in the study, and the case study is elaborated. In the results section, the workshop evaluation results are presented, followed by suggestions for improvement of the design process in relation to the challenges. Further, it is discussed how VR and BIM in the Knotworking workshops bridge the gap between the actors and the digital tools. We conclude by summing up the findings of the study. Throughout the paper, the workshop participants are referred to as actors.

2 Methodology

In this study, Knotworking has been applied for structuring the furnishing design workshops and supporting the interdisciplinary collaboration. Data has been collected in the form of evaluation notes on post-its from the actors at the end of each workshop, along with participant observation undertaken by the authors; one as facilitator and the other two as users. The evaluation notes were divided into nine main categories, one of them concerning the use of technology during the workshops, which is the focus of this paper. The evaluation notes were further elaborated using participant observations. Activity systems (Quek & Shah 2004; Engeström 2000) have been applied to analyze the challenges derived from the data, in order to identify contradictions and suggest improvements for each challenge.

2.1 Case Description

The furnishing design process of the university building was divided into three phases: Pre-phase, design workshops, and refinements. The duration of the pre-phase was one and a half month to prepare the set-up of the two workshops. The design workshops had the duration of one and a half day altogether covering the furnishing design process of the floor plans. Subsequently, the refinement phase lasted two months, refining the furnishing plans, deciding colors, textiles and ordering the furniture. The workshops were held with two weeks in between; day 1 from 8:00 AM to 3:15 PM and day 2 from 8.00 AM to 12.00 noon. The two weeks in between allowed time for the actors to reflect on the furnishing design proposals generated at the first workshop. The aim of the first workshop was to furnish the non-laboratory spaces covering 5000 square meters, while the second workshop aimed to refine the furnished plans from the first workshop. The design workshops involved 20 representing users of the building such as students, staff, janitors, cleaning staff, internal interior designers at the university, along with furniture manufacturers. For both workshops, the 20 actors were divided into two groups – "Group students" and "Group staff" – involving at least one actor from each profession such as student/staff, janitor, cleaning, internal interior designer and furniture manufacturer in each group. The aim of the groups was to furnish specific rooms predefined as "knots" (the terminology of Knotworking (Engeström 2008)) by the facilitator. The facilitator managed the furnishing design process, which was elaborated on the basis of the Knotworking method. The tools used for furnishing the spaces were both a touchscreen mediating the movements of 3D furniture representing the future furniture of the building within a BIM model of the building, and VR glasses mediating the spaciousness of the predefined rooms. The physical set-up is illustrated at floor plans in figure 2 indicating where the touchscreen and VR glasses were situated and how the room for the workshop was furnished. The groups had 30 minutes to furnish the floor plans for each predefined room, 15 minutes for evaluating the furnished floor plans followed by 20 minutes to present and discuss the evaluated furnished floor plans for the opponent group. To evaluate the workshops, post-its were handed out in the beginning and in the end of each day. At the beginning of the day, the participants had to write 1-3 post-its expressing their expectations of the workshop, and at the end of the day, they had to write 1-3 of the most important aspects and 1-3 of the most difficult aspects experienced during the workshop. The focus in this paper is the evaluation feedback concerning the most difficult aspects experienced during the workshops. The evaluation notes concerning the most difficult aspects were divided into the following nine categories: "use of technology", "structuring comments", "variety of needs", "size of the groups", "program", "comments", "enormous" and "budget". The results of this paper focus on the evaluation notes concerning the "use of technology". In the following, the evaluation results are analysed, in order to suggest improvements for future Knotworking processes, with emphasis on the use of technology

3 Findings

3.1 Evaluation Results day 1

Figure 1 Pictures visualising four statements concerning difficult aspects of digital tools

20 % of the evaluation notes stated that one of the most difficult aspects of the workshop was the use of the digital tools. One statement was "Limitations of the technology" referring to both the non-realistic visualisations of the spaces at the screen, because of graphical limitations when converting from the 3D modelling software to the software used on the touchscreen, and the low variety of furniture in the BIM model compared to the assortment of the furniture manufacturer. Furthermore, the software was not developed to either save or print a new furnishing plan after the design activity on the touchscreen, why the participants manually had to press the button "Print Screen" to save a picture of the furnishing plan for later evaluation. Another statement was "Use of 3D" referring to the participants having difficulties to understand the opportunities and the purpose of the digital tools, and how to use the VR glasses properly (Figure 1). The VR glasses automatically disconnected from the IT-system when not being used for a while, why the VR glasses were not functional when the participants wanted to use the VR glasses. A third statement was "Difficult to get a sense of the space on the screen" referring to a too small display in the corner of the touch screen representing the view of the VR glasses (Figure 1). A fourth statement was "Generation gap in the use of technology" referring to some actors being reluctant to use the touchscreen and the VR glasses (Figure 1). An example was an actor having an idea about a specific furnishing design, but the other actors did not understand her explanation. They asked her to show it on the touchscreen, and she replied: "Oh no, I'm not going to touch that!". Some actors were reluctant of trying the digital tools, especially the VR glasses because jokes were made about other people getting nausea using the VR glasses. The fifth and final statement was "People are afraid to use something new – VR!" referring to the fact that almost half of the actors were reluctant to use the digital tools (Figure 1).

3.2 Evaluation Results day 2

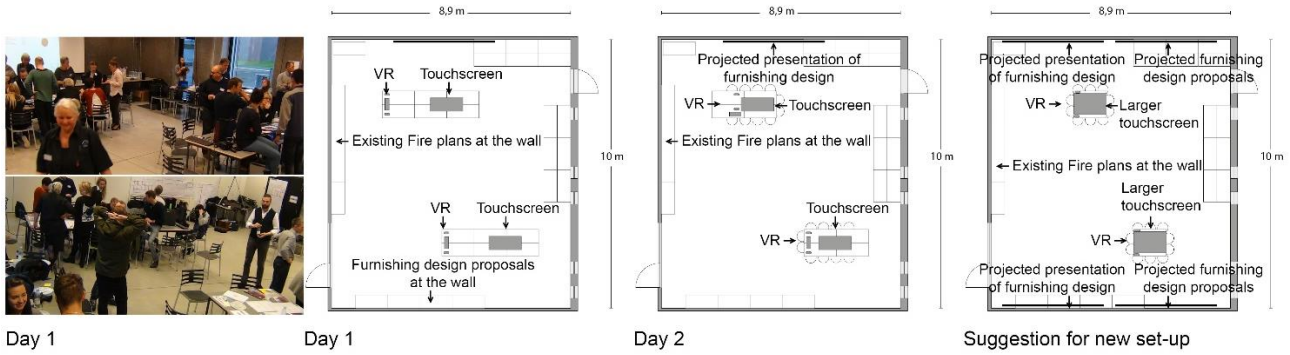

Figure 2 Floor plans of physical set-up of the workshops day 1, day 2 and our suggestion for future workshops in this room

Based on the findings from day 1, adjustments were made for day 2 to improve the workshop according to the usability of the digital tools. An adjustment of the physical set-up was a smaller table for the touchscreen making the participants physically closer to the touchscreen, which invited a larger amount of people to touch the screen (Figure 2). Moreover, the VR set-up was moved closer to the touchscreen to make the VR set-up a natural part of the entire set-up for the actors to use the VR glasses more intensively than day 1 (Figure 2). To encourage the use of VR, the division of roles for day 2 included an internal predefined VR responsible among the actors of the groups, and moreover, during the introduction of day 2, the facilitator emphasized the gain of using VR glasses. The actors in the groups were the same as day 1, why they were more comfortable with the digital tools at day 2. The evaluation notes from day 2 indicate the

confidence of the digital tools by several evaluation notes on the use of technology within the pile of the most important aspects compared to the pile of the most difficult aspect, which was the result of day 1. Only 7% (two out of 28) of the evaluation notes on the most difficult aspects focused on the use of technology. The first comment was "Limitations of the VR-system" referring to the limited furnishing assortment, and that it was not possible to save the new layouts. The second comment was "The IT was difficult to operate" referring to a small delay on the touchscreen when moving the furniture. Contrary, 20% (4 out of 20) comments on the most important aspects were focused on the use of technology such as "More use of VR", "Feel at home in the technology", "People got an eye-opener when they put on the (VR) glasses" and "Wearing the (VR) glasses while furnishing by slightly lifting the glasses from the head".

3.3 Suggestions for Improvements

Based on the evaluation results it is clear that improvements are needed for future similar design workshops. The limitations of the technology are based on the software used for the workshop, why the software has to be improved by for example implementing a "save" button in the program, making it possible to refine existing furnishing plans, and a "print" button to print directly from the touchscreen. To present the project, suggestions for improvements are using a projector for presentations in plenum, making it possible for all participants to see details, and, moreover, make a virtual walkthrough of the room to visualise the spaciousness of the room. This suggestion influences the furnishing of the room for the workshop, which is illustrated in figure 2. Regarding the non-realistic visualisation, it is suggested to use rendering programs such as Enscape[1] or Lumion[2] in a future furnishing design process, to render the 3D model. For the workshop, a script for 3ds max[3] was used. To render the furniture in Enscape or Lumion requires the furniture manufacturer to develop 3D models of their entire furniture assortment. The furniture manufacturers involved in this workshop were interested in developing the 3D models if the customers made a request because he identified the potential of working in 3D. To improve the process of using 3D in the furnishing design process, it is suggested to spend more time on introducing the IT equipment to the actors, making the users comfortable using the IT equipment. Jokes about VR glasses are not preferable because of diversity in humour and jokes having the potential of the actors getting reluctant. Moreover, the equipment has to be fully functional, why it is suggested to test the IT equipment multiple times before the workshop. Another suggestion is to make both the floor plans and the walkthrough obtainable by a larger window showing the walkthrough by for example projecting the view in a larger scale (Figure 2). The larger projection improves the visualisation of the details on the screen because of the size. To sum up, the challenges based on evaluation notes and suggestions for improvements are collected in Table 1.

	CHALLENGES BASED ON EVALUATION RESULTS	SUGGESTIONS FOR IMPROVEMENTS
Limitations of the technology	Non-realistic visualization of the spaces	Utilization of better rendering programs such as Enscape or Lumion
	Lack of variety of furniture to furnish the rooms	3D models of all furniture from the specific furniture manufacturer
	Impossible to print directly from the software, why the printing process was time consuming	Project the furnishing plans and the view of the VR glasses on the walls
	Impossible to save the furnish design in the software	Implement a save button in the software
Use of 3D	Challenges of using 3D	Better introduction to the IT equipment before initiating the first Knotworking session
	VR glasses disconnected from the IT system when turning on stand-by	Test the IT equipment multiple times before introducing it for the participants
Difficult to get sense of the space on the screen	Jokes about VR glasses made some actors reluctant to use the VR glasses	Introduce the new aspects in a positive way without jokes
	The display representing the view of the VR glasses was too small	Project the view of the VR glasses on a large screen allowing everybody to get sense of the space
People are afraid to use something new – VR	Less than half of the actors were uncomfortable to use the IT-equipment	Better introduction to make the majority of the actors positive about the IT equipment

Table 1 Challenges related to the use of technology during the first design workshop, and specific suggestions for improvements.

[1] https://enscape3d.com/
[2] https://lumion3d.com/
[3] http://www.autodesk.dk/products/3ds-max/overview

3.4 Discussion

In this section, we discuss the advantages of Knotworking in this study as a method for structuring interdisciplinary work compared to common practice in furnishing design processes, where users are not necessarily involved in the design process. Further, we discuss the contribution of using VR in a Knotworking session compared to previous Knotworking sessions in the building industry implementing BIM, but not VR. Lastly, we discuss how the implementation of VR in a Knotworking session bridges the gap between the actor and digital tools.

The genuine character of Knotworking is described by Engeström as "pulsating movements of tying, untying and retying together otherwise separate threads of activity" (Engeström et al. 1999, p.346). In earlier furnishing design processes at Aalborg University, assumptions have been made about the end-user needs and wishes, instead of involving the users directly referring to separate threats of activity. This resulted in complaints from the end-users in the occupation phase regarding e.g. expensive furniture not used in practice. Common practice for including user needs in building design projects are either by developing a building brief stating the needs of the end-user, or by making assumptions without actually involving the end-users. Hereby, the designers receive information about the end-users in written format, which are to be transformed into a design of a building. Potentially, the information can be misinterpreted, why involving the end-users directly in the furnishing design process is preferable, in our opinion. The use of Knotworking aims to extract a large amount of information from actors with various disciplines within a short time (Kerosuo 2015), which is proven in this case, were 5000 square meters were furnished in 5.25 hours, which would normally take several months. The preparation of the two Knotworking workshops was time-consuming, but the output from the workshops made a great contribution to the final furnishing design. Moreover, Knotworking assisted both the collaboration among various actors by dividing them into groups working together and presenting ideas in plenum, and the structuring of themes to be discussed as predefined rooms to be furnished. The Knotworking workshops contributed to the efficiency of synergies of ideas for developing holistic furnishing solutions through interdisciplinary work.

Previously, BIM-models have been used as a tool for communicating ideas and final products, but VR glasses and touchscreens have not, to our knowledge, previously been used as mediators for ideas in a Knotworking context. The difference between previous work with BIM, and this work with VR, is the connection between the actor and the digital tools. Previously, a Knotworking workshop in Skagen used BIM as a mediator of the actors' ideas. A BIM-expert interpreted the ideas into components in the 3D modelling software Revit, while the actors followed the visualization at a projector (Buhl et al. 2014). By using VR glasses and touchscreens as digital tools, the actors are able to design by themselves eliminating a BIM-expert mediating the ideas of the actors. At the same time, the VR allows the actors to virtually walk around in the furnished rooms to get a sense of the spaces. Contrary, the VR software did not support the format of the existing 3D model of the building, why a new 3D model had to be made specifically for the VR setup. Using the existing 3D model would have saved time, and would have allowed the furnishing design solutions to be implemented directly in the 3D model for the subsequent design process refining the solutions. The benefit of using VR in a Knotworking workshop is the sense of space for the actors when developing the furnishing design. However, further studies on improvements of the details in the software are a necessity to advance the technology and improve the entire furnishing design process from the idea to the delivery of the physical furniture.

The results of this study indicate the potential of implementing digital tools in a Knotworking session, but improvements are needed to make it fully applicable. As multiple scholars have stated, there is a potential of improving building projects by using BIM (Kiviniemi 2005; Miettinen & Paavola 2014; Kerosuo et al. 2015), why the digital tools are now highly encouraged in building projects. The challenge is how to bridge the gap between the actors involved in the building project and the digital tools used for mediating and visualizing the ideas to improve the design. The high level of complexity in today's building design requires on one side interdisciplinary collaboration because multiple decisions have to be made throughout the building design process, and, on the other side, digital tools to support the collaboration and improve building projects by using BIM. The two sides have to be connected for the building project to reap synergy benefits from the involvement of both the interdisciplinary team and the digital tools. Knotworking is used as the bridge between the interdisciplinary collaboration and the digital tools (Figure 3), because of its two pillars of (1) assisting the collaboration of a project and (2) structuring the predefined themes. According to the pillar of (2) structuring the predefined themes, the digital tools support the visualization of the actors' ideas, while the interdisciplinary collaboration makes the actors use the tools to visualize their ideas. According to the pillar of (1) assisting collaboration, the digital tools oblige the interdisciplinary collaboration by being the mediator for communication, while the interdisciplinary collaboration accommodated by the actors using the tools to communicate.

In other words, Knotworking, in this case, bridges the gap between the interdisciplinary collaboration anchored in social science and digital tools in the form of BIM and VR anchored in the technological world of BIM (Figure 3).

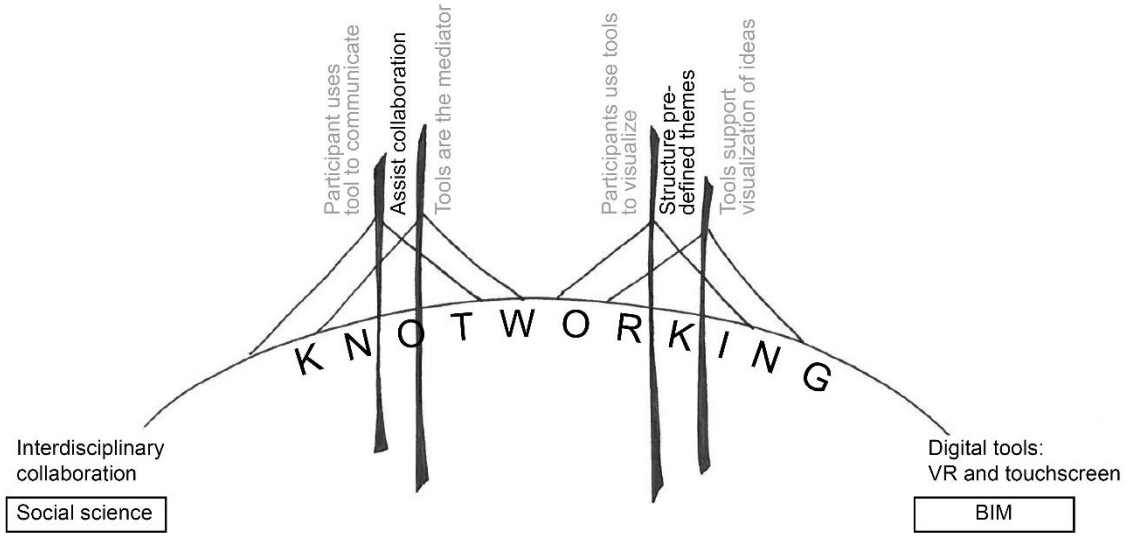

Figure 3 Bridging the gap between interdisciplinary collaboration and digital tools as VR and BIM.

4 Conclusion

The aim of this paper was to investigate the use of BIM and VR in a furnishing design process based on the Knotworking method. Applying Knotworking in combination with BIM and VR made the process highly efficient; 5000 square meters were furnished in 5.25 hours. The quality of the output was high, making it highly useful in the subsequent refinement process. Involving the end-users in the Knotworking workshops resulted in holistic furnishing solutions, and ensured a sense of ownership from the users. The evaluation feedback from the users was analysed, with emphasis on the most difficult aspects experienced at the two workshops. Nine categories challenges were found, one of them being "use of technology". In relation to the use of technology, ten challenges were identified (Table 1). The challenges were analysed using activity systems, and suggestions were made to improve the use of VR and BIM in future design workshops. The suggestions for improvements can be summed up in the following points:

- An introduction of the digital tools to the participants prior to the initiation of the workshop task would be of great benefit. In this way, all participants get "hands on" experience using the tools, and it might not be as intimidating to use the tools during the workshop tasks.
- Using projectors to present the results in a larger scale in plenum at the workshops, to evaluate the different design proposals.
- Updating the software used at the touchscreens to support saving and printing functionalities is recommended to ease the process of these functional tasks, and furthermore using rendering software for realistic visualisations.

In future research, there is a potential of integrating these improvements in further development of practical guidelines for designing and facilitating Knotworking workshops in the building industry, using digital tools as BIM and VR. This paper has contributed with a practical example of how Knotworking can be applied in a furnishing design project with the use of BIM and VR, along with suggestions for improvements for future Knotworking furnishing workshops using digital tools.

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