How Virtual Reality is used when involving healthcare staff in the design process

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Abstract

The design process of a new hospital is often recognized as a complex task involving a diverse group of actors. The most common information media used today are project related documents and drawings. Hospital users´ ability to interpret information through these varies. This affects the design feedback from users. However, an increasing use of Virtual Reality (VR) support possibilities to facilitate better understanding. This paper presents six case studies of hospital design projects, where VR has been used with the purpose of involving end-users, investigating how and when VR has been implemented and which effects and experiences that could be noted.

The findings show different levels of involvement, engagement, collaboration, and interactivity. Using VR contributes throughout the design process but is dependent on purpose and setup. Furthermore, there is a strong connection between engagement and the interactivity of the VR model.

Keywords: Virtual Reality, VR, Design process, Case study, Healthcare facility, User involvement

1 Introduction

During the design process of a hospital project, many actors are involved. Given the complexity of the project, there must be a certain level of communication and collaboration between the involved actors. This is to ensure a common envision for how the project will take shape, reducing the number of reconstruction changes done close after commissioning as well as maintaining cross-border cooperation between the involved actors.

Currently, review of hospital premises is done in 2D drawings and 3D models. These drawings and models do not always provide sufficient understanding on the healthcare staff's part, leading to a gap of understanding of what is being built between the end-users and the actors in the project team who carry out the project.

Virtual Reality (VR) technology has in these occasions become a tool that provide and support a sufficient understanding on the healthcare staff's part and bridging the above-mentioned gap. For the other involved actors, it has also shown to be a way of communicating across disciplines and facilitate communication. Factors, such as immature technology, client-contractor dynamics, requirements for implementation and structure and an overall lack of experience have prevented VR from being fully established (Delgado et al 2020).

The healthcare sector facilities providers and real estate organizations has made strides to implement said new technology which has showed potential to translate into a shift towards a more effective working environment and consequently the patient care improving as well (Lapaó 2018). Furthermore, VR has proven to be an effective way of facilitating design related knowledge and understanding to those involved in a project, especially end-users, who might lack the technical experience. Several studies show that VR effectively facilitates the coordination and communication between involved actors in a project, and causes increased spatial understanding of the room, consequently leading to a better decision basis (Roupé et al 2016, 2019, 2020).

This understanding of spatial conditions and connection to layout are especially important for a productive feedback loop and validation of requirements from the user side (Dunston et al 2010; Yu-Cheng et al 2018). The same understanding has proven to be more difficult to facilitate via traditional 2D illustrations or full-scale physical mock-ups, (Dunston et al 2011; Johansson 2012). Increased spatial understanding has to some extent bridged the knowledge gap between typically design related actors such as architects and those working with BIM implementation and those that are not involved in said domains such as end-users and facility managers (Calderon-Hernandez et al 2019).

So far, VR has mainly been used during early design phases, where it has helped facilitate collaboration between design teams and healthcare staff and facility managers (Yu-Cheng et al 2018; Roupé et al 2020). Although there has been much VR related research in general addressing technical implementation, there has not been enough research done on how VR acts as communication facilitator and its implications for the healthcare staff and stakeholders pertaining to healthcare design. Moreover, there is a lack of research describing when in the design process VR usage is most efficient. Therefore, this paper will present how medical staff and design teams can enhance their understanding of the implementation knowledge and in what phases of the design process. Specifically, this paper will address questions such as when in the design process VR is feasible and the value of such a process and reducing the information communication gap among the healthcare staff, stakeholders, and design teams.

2 Existing theories & previous work

Current available work on VR implementation and usage in the AEC industry mainly covers what benefits its usage entails and the factors preventing VR from being fully adopted in the industry (Delago et al 2020). Findings show how the technology currently is regarded as expensive and immature although there are cases that showcase how these limiting factors can be mitigated by studying the benefits VR provide in earlier phases of a building project and in cases where spatial understanding is especially important (Balzerkiewitz & Stechert, 2020; Coroado et al 2015).

Research also shows how interactive VR models support a collaborative environment for all involved project actors, which in turn reduced the time required for healthcare staff to understand and test design options in a more efficient way, compared to traditional methods (Prabhakaran et al 2020).

The spatial understanding, enhanced collaborative environment as well as the facilitation of improved communication between involved actors has also been observed in studies where VR has been used in hospital projects (Lin et al 2018; Dunston et al 2021). Research has shown how the usage of VR enable owner or client for healthcare facility projects a clearer way of comprehending proposed designs and especially so during the early phases of the building cycle. Additionally, VR not only improves and facilitates the efficiency of communication between the design team and healthcare staff, but also assists design teams and healthcare staff in the decision-making process (Roupé et al 2020).

When involving those affected by a change in the built environment several processes are at play. User's influence on design outcome could be described as having several levels (Castell 2013); just information, when information is shared, but no real influence; consultation, when the user-group give feedback on a proposal or a specific problem; and dialogue, when there is a mutual exchange of knowledge and a discussion mitigating new shared knowledge (Eriksson 2013).

3 Methods

This paper is based on six cases (see table 1 for details). Five of these are based in Sweden and one in the US. The study was conducted using a qualitative methods approach using interviews and observations connected to the case studies. The aim was to investigate how VR was used, to what extent it was used and what level of interactivity the VR supported. Furthermore, the study aimed to investigate the different cases related to the use of VR in different settings and phases in the design process.

The interviewed participants were stakeholders and specialists from healthcare and construction projects, e.g., healthcare staff (HS), architects (arch), BIM coordinator (BC) and project managers (PM) connected to the different cases. In total 32 participants were interviewed; i.e. Uppsala University hospital – ICU (PL=2, FM=2, Arch=1, HS=3), Skaraborg hospital - Psychiatric clinic (Arch=1, PL=1, HS=1), Skåne University hospital (PL=2, FM=1, HS=3, Arch=2, BC=1), Sahlgrenska University hospital – Children's clinic (BC=1), Sahlgrenska University hospital – Robot assisted surgical room - ViCoDE (PL=2, FM=1 HS=6) and Kaiser Permanente – radiology room (BC=1, PL=1)

The semi-structured interview consisted of questions ranging from exactly what phase of the design process VR implementation was conducted and to what extent as well as how and why VR was used in the project. The feedback the interviewee provided gave increased insight into important issues pertaining to VR that have not been addressed, these insights are elaborated in this paper. Furthermore, the feedback also provided insight into what value healthcare staff can gain from VR implementation in a project.

Four of the six cases consisted of static VR-models while two were interactive and collaborative (Figure 1, were picture E and F refers to the interactive cases). As seen in figure 1, the level of detail in each respective case differs. The purpose of showcasing the screenshots of the VR-models from each case next to each other, is to emphasize the point of how this paper will investigate similarities independent of parameters such as level of detail (LOD). Consequently, this will help accentuate how and when in the design process VR can be used. Furthermore, the cases were spread throughout different phases of the design process. Also, the different cases had slightly different purpose and scope, ranging from pure informative sessions to more concrete design review and creative sessions (see table 1).

Figure 1, picture E, shows virtual collaborative design environment (ViCoDE) being used. ViCoDE features seamless integration of several immersive VR systems in the form of VR-headsets and a multitouch table that facilitates collaborative and interactive design work with immediate, real-time feedback. The multitouch table client uses a top view to visualize the facility. Users can pan and zoom in this view using the same standard multitouch interaction features found in most smart phones. Different BIM-based components (static avatars, furniture, and medical equipment) coming from the Swedish national healthcare database, PTS (program for technical standard) can then be added to the scene by drag-and-drop. Once added, a component can be repositioned, rotated, or removed, using the multitouch interface. The component is then instantly updated in all the other connected clients.

Case F differed from case A-D with its interactive VR-models, enabling the participants to add, reposition or remove components, much like the ViCoDE based system in case E. Additionally, the models enabled multiple participants in the same model in order to review and validate the set design requirements.

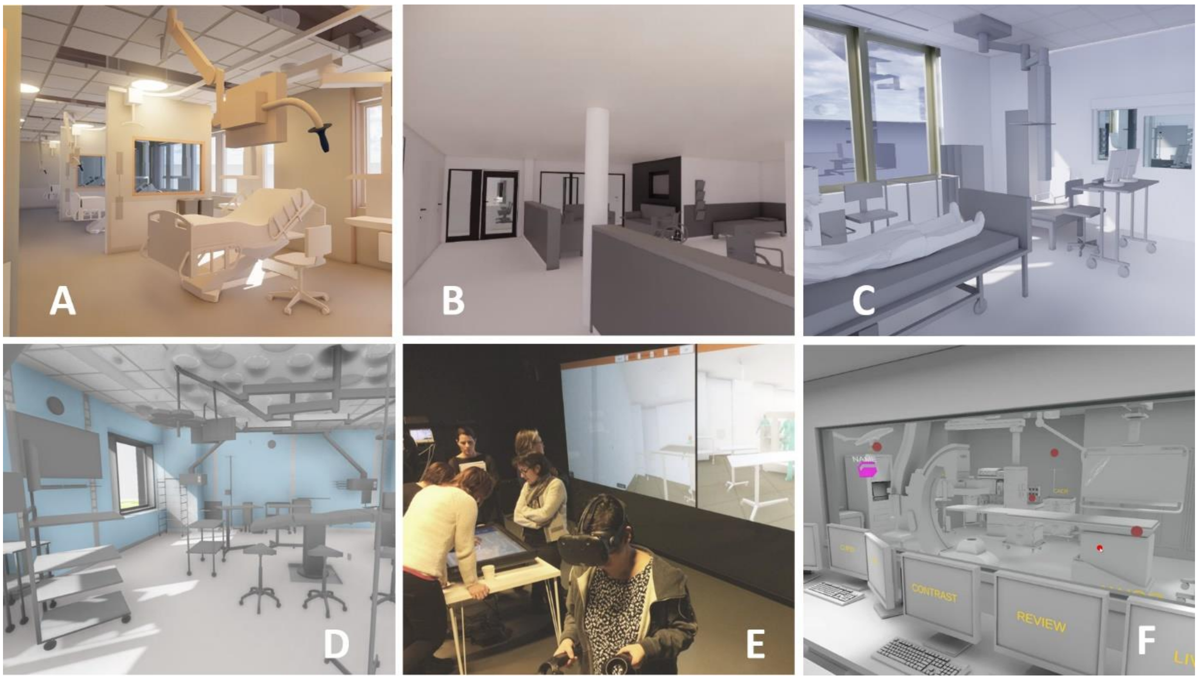

Figure 1. Screenshots from inside the VR-models as well as the set-up for case E with the multi-touch table together with the VR googles.

4 Results and discussion
4.1 Presentation of cases

Figure 1 and table 1 below shows a selection of the data collected, compiled, and categorized based on when in the building process VR has been used, with what purpose, in what context and the level of interactivity of the model. Timeline phases are based on RIBA Plan of work (RIBA 2020) and depicted here below in figure 2.

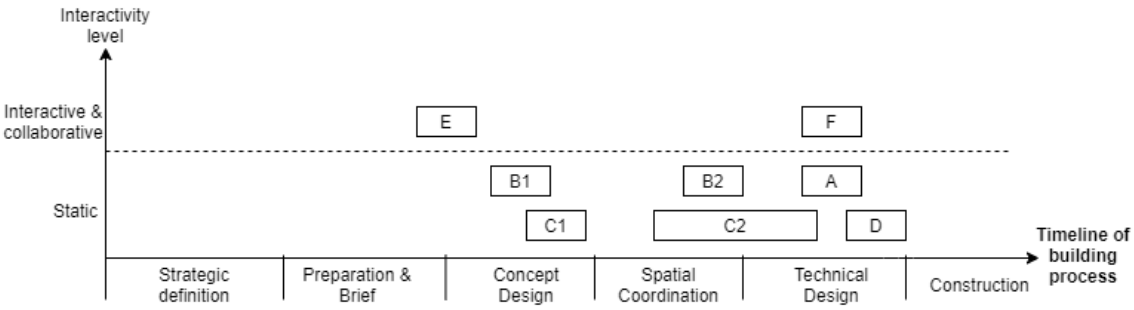

Figure 2. Graph illustrating how the observed cases map onto the various phases of the design process.

Case and VR-scope	Purpose	When and how
A. Uppsala University Hospital – ICU The ICU unit for a whole hospital floor	• Better understanding for future workplace • Access tacit knowledge • Validate design requirements • Information and consultation	*Technical design phase* • Static VR models (HMD) – dedicated reviewing sessions via VR using 2D blueprints as complement

B1-B2. Skaraborg Hospital– Psychiatric clinic The psychiatric ward, including patient rooms, administrative area and dining area	• Inform healthcare staff of the design of the new facility • Gain better insight in future workplace • Information	*Concept design & Technical design phase* • Static VR models (HMD) – VR being one tool of many during "staff-day"
C1-C2. Skåne University Hospital – NSM project (various facilities) Rooms pertaining to various types of operations and common areas independent of a particular operation	• Provide understanding for the hospital staff • Create a more collaborative environment for all involved actors • Information and consultation	*Regularly held sessions during Concept design phase*. • As one of several tools during technical design phase. • Static VR models (HMD) – dedicated VR reviewing sessions (*Technical design*), using 2D blueprints as complement
D. Sahlgrenska University Hospital – Children clinic ICU unit and hyperbaric chamber	• Using VR as one tool of many to achieve the goal of building "*world's best children hospital*" • Final design review, before construction document. • Mitigating any surprises in terms of costly reconstruction close to commissioning • Consultation	*Technical design phase* • A whole day • Static VR models (HMD) together with 2D blueprints and 3D models
E. Sahlgrenska University Hospital (ViCoDE) – Unit of obstretics and gynaecology - Robot assisted surgical room	• Provide a more engaging and collaborative environment for the healthcare staff • Improve feedback loop • Increase the knowledge dispersion from the healthcare staff • Consultation and dialogue	*Concept design phase* • ViCoDE (interactive VR-models) together with 2D blueprints and 3D models • Dedicated VR-workshop
F. Kaiser permanente (US) – Radiology room A single radiology room with adjacent corridor and common area	• Spatial understanding of whether new radiology operation will fit in existing space • Consulting and dialogue	*Technical design phase* • Dedicated VR-workshop together with 2D drawings as complement • Interactive VR models (HMD) where healthcare staff interacted in various interactive scenarios

Table 1. A table demonstrating the observed case studies

4.2 Reflection on differences and similarities

As seen above most of the VR-sessions used static VR-models from the design process. In these settings the users reviewed the design of a static model and gave input on the design. In case E and F a more collaborative and interactive approach was used were the user had the possibility to design and investigate whether the equipment, furniture and activities could fit in the given space of the room. In case E, VR was also used together with a multi-touch table where the user could seamlessly interact with the model both in VR and at the multi-touch table, see figure 1E. In this case the multi-touch table supported better communication, knowledge sharing, and negotiation possibilities around the multi-touch table setting (Roupé et al 2020).

To use interactive VR, late in the process, like in case F, is often considered too expensive. However, in case F it led to validation that the new operations could fit in the existing space and avoiding costs because of this. The background to this was the client in this case had resources to enable this due to size of consortium.

5 Analysis of findings

5.1 Value of using VR

Based on the observations and interviews done in the studies (Case A-F) it emerges that VR provides a more developed understanding of project and design conditions and supports development of a spatial understanding better when compared to 2D drawings and 3D models, in all phases during the design process. VR provides an egocentric immersive experience in scale 1:1, which is not possible with drawings or in scale models. In this context, VR offers users the possibility to better understand and experience their future workplace, which give them possibility to review and give feedback and influence their future workplace in a more tangible way. During this process, observation from the cases A-F shows, that end-user knowledge and experience about work activities can be identified and proved important feedback connected to the design. In this context, design feedback connected to workflow (Case E, F), visibility and sightline (Case A, B), distances (Case A, B) and logistics movement of medical equipment and patients (Case C, E, F) was addressed during the VR usage.

Based on what has been observed in the cases, where the level of detail (LOD) has differed, it appears that having a detailed model is more useful and important rather than having a photorealistic model. Moreover, the details in the VR-models affect what aspects the user focused on during the VR review sessions. Also, the higher the interactivity level is in the models (Case E and F), the higher the chances of understanding, identifying underlying drivers related to workflow and logistics movement of medical equipment and patients during work activities. Therefor it could be argued that the details and interactivity level in the models tend to facilitate which direction the reviewing process will take and how these are set up accordingly.

In the early phases of the design process spatial understanding, expressing, and testing requirements is emphasized more as no boundary conditions of the design yet is set, such as floorplan, layout and building structure. Furthermore, in the later phases of the process these spatial boundary conditions are set and often could not be changed due to costs. The focus therefore shifts from macro changes towards micro changes e.g., spatial room changes towards details and medical equipment placement in the design, see Figure 2. In this context, there was a better understanding regarding floor layout connected to logistic workflow, movement of staff, sightline, distances towards room size and layout with focus on visibility, workflow, logistics (of equipment and patients) and placement of medical equipment. In this context, VR can be argued to facilitate understanding and extraction of experience and practice related knowledge from healthcare staff, such as knowledge related to work activities and workflow. It could be concluded, that by finding and changing these structural or detailed changes early in the design process, rather than going via the mockup route, there is a possibility for cost savings. This would be supported mainly because VR can facilitate spatial understanding, which provides a "real mock-up experiences" based on discoverable tacit knowledge mentioned above (Dunston et al 2012). VR could then act as the main way of validating set up requirements pertaining to room and floor plan layout where usage of mock-up rooms, 2D drawings and 3D models would act as complementary tools.

Case F had, when studied, no longer the possibility of changing boundary conditions, the discussion focused instead on what could be done within the given conditions, compared to case E, where there was still a flexibility in terms of changing layout and structural elements.

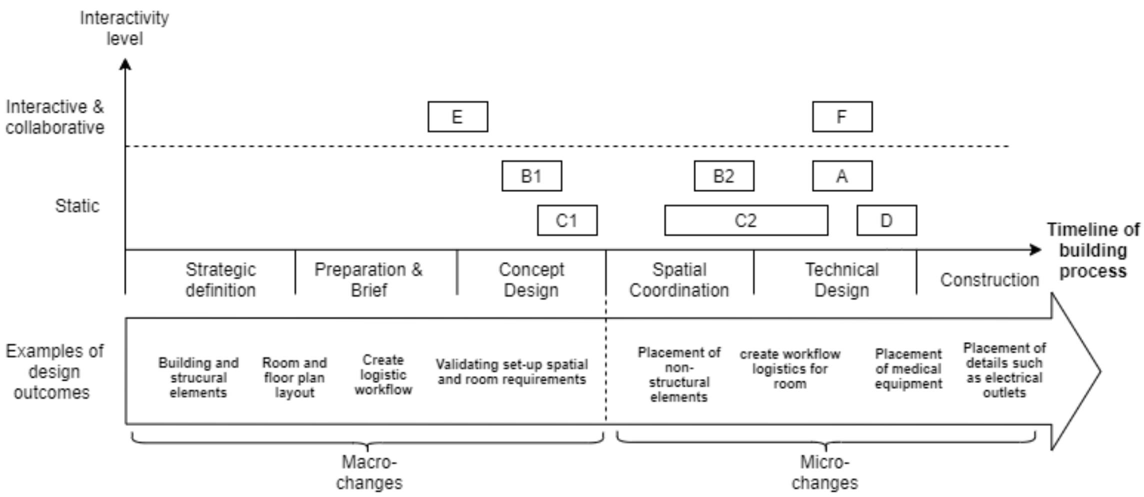

Figure 3. The figure illustrates the cases and the possibility and focus of influence the design outcomes when using VR. The spatial boundary conditions are determined in early part of the design process and are difficult to change in the later part of the design process.

5.2 Level of detail (LOD)

Based on the observations made, the level of detail (LOD) in interactive models (case E, F) is a non-decisive factor when it comes to the participants reviewing set design requirements or having an informative based session (case B). One could argue that this is mainly driven by the fact that the interactive models provide scenario-based sessions which is not possible in static VR-models. Although the observed interactive cases differ phase-wise in the design process, and both differ in LOD-levels, the focus in these VR-sessions have been the interactivity and multiple participants in the same VR-models. Furthermore, the issues set out to be addressed in both these cases were similar; using VR to know how to optimize either new (case E) or existing space for new medical operations (case F).

Regarding static models, there appears to be a higher degree of emphasis put on LOD in the VR-models due to above mentioned functions. Therefore, the focus shifts from interactivity to what the participants can see in the VR-models which in turn depends on what phase of the design process VR is used; models used in earlier phases are less prone to use higher degree of LOD in the models whereas later phases tend to put a higher importance on LOD-level (case D in particular). Though it is important to highlight how the observed cases in the later phases (case B2, C2, A, D) are not only dictated by the LOD-level but also on the actual set-up of the VR-sessions. Regardless of the models being photo-realistic (case A) or being models of low LOD-level (case B), the framework (or lack of) is what appears to dictate whether the higher LOD-level models can be a contributing factor when reviewing design requirements; a lack of set-up can lead to participants focusing on details that are not relevant to review. This is especially important in the very late phases of the design process (case D) where details and functions are the main things to review.

5.3 Interactivity and collaboration

The spatial understanding VR provides in comparison to 2D drawings and 3D models is mainly due to the egocentric immersive experience, e.g., identifying sightlines.
Interactivity and collaboration have been observed in case E and F and when VR models provided that functionality, it was noted that more new knowledge was articulated and discussed due to the ability to test workflow, e.g., moving around equipment and consequently influence the design outcome (see figure 3).

As seen in figure 3, examples of what aspects of the building, rooms and activities that were studied during the VR sessions, it is shown that the early phases had an emphasis on structural elements and floorplans, whereas later VR sessions put focus on non-structural elements, details, and equipment. Aspects of workflow and logistics were present in all phases. The interactivity level the end-users experienced in the cases of E and F meant that, in comparison to other cases where the models were static, the participants could add and move elements, such as furniture and equipment to create VR-based scenarios where the logistic workflow for certain rooms could be tested. Furthermore, it has been observed that the influence of larger, structural changes via VR is more prominent in the earlier phases of the project whereas the smaller, micro-changes, takes place in the later stages of the project. The ViCoDE system (case E) which was implemented in a much earlier design phase compared to the interactive VR models used in the later stages (case F), showcase how although both cases provided an interactive and collaborative environment for the participants, that the degree by which the end-users can influence the facility design, differs.

The difference mainly lies in whether it is a matter of influencing the structural or non-structural elements, such as the room and floor plan layout in early design phases compared to placement of medical equipment in later phases. Another example is creating a general logistic workflow in early phases which later instead shifts to creating workflow logistics for designated rooms.

Moreover, the interactivity and collaborative factor enables the VR-participants to test out various design proposals via either scenario-based cases (case E, F) or themselves moving around non-structural and structural elements (case F) and thereby seeing how for example the logistics of a room works out. Furthermore, the advantage of an interactive and collaboratively based VR model is the possibility to make changes on the go, that is, the need to revise the VR models after each review session is no longer required, thereby shortening the overall design proposal process for all involved actors. This process of evaluating and testing ideas during sessions where VR is used in turn creates engagement among the participants to become more involved in the design process in comparison to design processes where 2D drawings and 3D models mainly are used. This engagement could then be said make VR a communicating facilitator between design teams and healthcare staff.

5.4 Engagement of end-users

Based on the observations made in the studies, the level of engagement of end-users, seem to be based on what purpose that was presented when the users were invited to the VR session. The purposes could be described as information-, consultation-, or dialogue-based. One session could involve one or more purposes.

The more it is stressed that the usage of VR in the project is to evaluate the set-up requirement and there is a task of feedback from the end-users, the higher the engagement. If the purpose of the VR-usage is primarily information based, there is a lower level of engagement. This can be observed in case C, where users were invited to take part in a VR session, mainly based on informing participants about what was going on.

Other levels of engagement are shown in case A, E and F, with smaller project scopes in the VR session, where users observed and evaluated a specific room, or set of rooms.

In case A, the nurses and doctors were given clear instructions on what to look for and discover any design related shortcomings. During the session, the spatial understanding became apparent when the participants highlighted how the windows between each patient rooms were set up too low and that certain medical equipment reduced the workflow logistics of the room. The workflow efficiency was also in focus in case E and F. The purpose of the VR session was to investigate whether the activities in question could fit in the given space, by adding, rearranging, and discussing the use of equipment and furniture. This provided the highest level of engagement.

These last two cases also indicate that when VR provides interactivity (possibility to move things around during session) how it correlates with the level of engagement end-users show. The high level of interactivity provided in the VR models would then facilitate engagement among the end-users, more so than static VR models. Furthermore, it is interesting to note that the two cases with the highest interactivity (E and F) was conducted in very different phases of the building process. The tasks were very similar, but in case E, there was still an opportunity to change the size of the room, whereas in case F, the room size was fixed, due to the late phase.

6 Conclusion

As the results from our study indicate, by using VR, it is possible to influence the design outcome of the building depending on which phase of the design process one uses VR. Earlier phases are associated with macro changes that covers building and structural elements whereas later phases cover micro changes that revolves around non-structural elements such as logistical workflow and placement of medical equipment. Thus, this study proves how influencing the design process via VR is not limited to earlier phases of the design process as previously thought, but that influencing the design process is possible in all phases. Furthermore, the case studies showcase how the role of VR varies from a mere technical solution towards being viewed as a more engaging and interactive, versatile tool throughout the design phases.

As concluded from previous research on VR usage, observations in this paper also show how the value of using VR lies in the understanding of project conditions and the spatial understanding it provides in comparison to 2D drawings and 3D models, in all the phases of the design process. Consequently, this spatial understanding leads the end-users to articulate tacit knowledge related to their operations and work activities. Especially a higher degree of interactivity in the model, testing scenarios, seem to support the identifications and articulation of new knowledge and requirements. This in turn enables VR to provide a “mockup experience” pertaining to insights similar to when doing design review via a physical mockup room.

Moreover, the character of user input that is fed into the process depends on when in the design process VR is used; early phases are associated with structural elements and floorplans and later phases with non-structural elements, such as details and equipment. Furthermore, the interactive models which provide the ability to make changes on the go, work as a facilitator for effective communication between the end-users and the design team. Consequently, this leads to a reduction in lead-time and an overall shorter design process.

Lastly, the level of engagement of end-users seem to correspond with what purpose the users were presented with, to engage in the VR session; to evaluate set-up requirements translates to a higher level of engagement and to partake in an information-based VR session results in a lower level of engagement.

6.1 Future Works

For future work it would be valuable to further investigate what key factors affect the value created when VR is implemented together with users. Further studies would investigate how to achieve engagement in different design phases and with the various actors involved in a project. Additional studies would look into how purpose-driven questions affect the validation of requirements via VR.

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