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Citation for the original published paper (version of record):
Sateei, S., Roupé, M., Johansson, M. (2023). Transitioning from 2D to VR in design-review - Resistance to engagement. Proceedings of the 23rd International Conference on Construction Applications of Virtual Reality, CONVR 2023, 23: 85-96.
http://dx.doi.org/10.36253/979-12-215-0289-3

TRANSITIONING FROM 2D TO VR IN DESIGN REVIEW – RESISTANCE TO ENGAGEMENT

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ABSTRACT: *Although immersive virtual reality (VR) has been shown to facilitate collaborative understanding of a design, many users remain resistant to its use. Moreover, there is currently a lack of real-world studies investigating why certain users (e.g., architects) are resistant to use VR during design reviews. The aim of this study is to understand the resistance that influence client representatives' and architects' interaction with a VR-system that supports both fully- and non-immersive experiences of the virtual environment. Data were gathered from three VR-workshops, which were part of 3 design review sessions of a new elementary school. Additional data were gathered from four semi-structured interviews with both the architects and client representatives participating in all workshop sessions, the interior architect involved in the project as well as an additional six semi-structured interviews. These additional six interviews involved exterior architects from different firms, who had previously used VR for both informative and design review purposes. The findings suggest that client representatives and the architects had initially been resistant to use VR during the design reviews, but their attitudes changed progressively during the three workshops, in particular that of the architects. The findings also indicate that interactive features in VR (e.g., object manipulation, multi-user) help end users negotiate design requests more efficiently and make informed decision-making. This paper highlights how immersive VR could improve the design review process.*

KEYWORDS: *Virtual Reality, HMD VR, design process, design review, spatial understanding, end-users.*

1. INTRODUCTION AND RELATED WORK

Fully immersive Virtual Reality (VR) has emerged as a potential alternative to traditional information and visualization media (e.g., 2D drawings, 3D models) where users are surrounded by a virtual environment of the building design. This experience of users "stepping into the design" is referred to as an immersive experience (Castronovo et al., 2013; Johansson, 2016). When fully immersed, users can experience the design from a user-centric viewpoint, i.e., an ego-centric frame of reference (Paes et al., 2023), which provides clearer visual cues (e.g., size, shape, location) (Hermund et al., 2017). Enhanced visual cues not only help users better perceive volumetric qualities of the building design than when 2D drawings and 3D models are used (Chowdhury & Schnabel, 2020), but also help users gain a more representative understanding of the final building design (Nikolić & Whyte, 2021). It is important to note here that 3D models viewed on a traditional screen are considered non-immersive VR (Castronovo et al., 2013), e.g., when 3D models are displayed on a computer monitor, projector screen or a multitouch table (Dorta et al., 2016), the users are not immersed even though they do view a virtual environment. In contrast, immersive VR-systems provide either a semi-immersive experience (i.e., experiencing the virtual environment through stereoscopic displays) or a fully-immersive experience (i.e., with head mount display (HMD) and motion-tracking). Studies have also explored how hybrid design environments, (i.e., combining traditional design techniques such as sketching by hand with immersive ones like VR), influence users' understanding of the design. For instance, Okeil (2010) showed how design team members, interacting with available 3D computerized sketching feature combined with a visual understanding enabled by a semi-immersive CAVE system, were able to efficiently explore and iterate on different design ideas. More specifically, by viewing the design that had been drawn in the non-immersive environment, design team members could immediately see the outcome of their design decisions in the semi-immersive environment, resulting in a more rapid cycle of testing and validating of different designs.

In the context of users' interacting with different VR-systems, interactive features in fully-immersive VR such as object manipulation (Wolfartsberger, 2019), multi-user (Truong et al., 2021) and multi-scale (Sateei et al., 2022) have shown to facilitate a mutual understanding of the design between end-users and design team members. For example, the ability to combine multi-user and object manipulation to use task-based scenarios during design review has shown to accelerate decision-making when resolving design issues. Specifically, by enabling furnishment and collaborative review of the virtual environment in real-time, end-users can better understand which layouts support building occupants' work tasks whilst also reducing the overall lead-time of the design process (Roupé et al., 2020). Accordingly, task-based scenarios in VR shift design review from interpreting the design to understanding building occupants' daily work tasks (Nikolić & Whyte, 2021). This understanding of building occupants' daily work tasks is then more likely to result in collaborative practices such as Co-design where the end-users become part of the design team (Caixeta et al., 2019; Roupé et al., 2020).

However, although several studies have shown the benefits of using VR in the design process, few have explored end-users' and design team members' engagement in using VR for design review purposes (Maftei et al., 2018). For example, questions remain as to how a collaborative understanding for the design may be facilitated with VR when VR as an information and visualization medium, whether semi- or fully-immersive, is primarily used as a presentation tool by architects (Achten, 2021; Scheer, 2014). One explanation might be the lack of knowledge on how to use VR in workflows where 2D drawings and 3D models are used (Zaker & Coloma, 2018). Another explanation highlighted by the literature is that due to the lack of real-case studies, stakeholders such as architects are resistant to using VR due to not knowing when in the building process to use it. Specifically, there is an initial resistance to using VR in a project setting, and its value in understanding end-users' design preference is often realized too late in the project when time constraints arise (Belek Fialho Teixeira et al., 2021). Therefore, the focus of this study is twofold: 1) to understand client representatives' and architects' resistance to engage with VR-systems with support for both fully- and non-immersive experiences of the building design and 2) how architects and client representatives collaborate to resolve design issues when VR is used in a design review context.

1.1 Clients' and architects' use of VR for design review

Studies have explored the advantages of using VR in the context of design review and from a client perspective. One example is that end-users such as client representatives seem to become less reliant on the design team for their interpretation of the design (Kim et al., 2016), which could help reduce decision-making time during design review (Liu et al., 2020). Another example is a study by Liu et al. (2020) where they found that semi-immersive VR did not only help those who have difficulties interpretating 2D drawings but also helped project members who had not yet seen the design to better understand it. Similarly, in an experimental study, Umair et al. (2022) observed that participants' task completion time was shorter in fully immersive VR compared to 2D drawings when identifying design issues. Studies have also investigated challenges to wider adoption of VR. Examples of these challenges are clients' lack of knowledge of how VR-based practices should be adopted (Zaker & Coloma, 2018) and the lack of real-life case studies that explore how decision-making that is typically done in later phases of the building process, could be made already in earlier design phases (e.g., concept design phase) (Nikolić & Whyte, 2021).

From an architect perspective, VR is seen as one of many available information and visualization mediums (Kim et al., 2016). Whilst drawing has been the traditional communication tool of architects (Scheer, 2014), recent years have seen a continuous increase in use of a 3D model-based approach when building information modelling (BIM) is used in project, whether it is throughout the entire construction process (Disney et al., 2022) or only limited to the design process (Smith, 2016). In this context of using 3D models in the design process, VR models have been used when extracting them from the BIM model (Johansson, 2016), resulting in architects able to showcase the building design in VR. Still, the literature shows that architects maintain control over decision-making in the design process when using VR as they have when 2D drawings are used (Scheer, 2014). An example is the use of pre-defined viewpoints in the VR model during architectural walkthroughs of the building design. The argument for using pre-defined viewpoints is that it prevents end-users from being overwhelmed with too much detail in the virtual environment, which ensures that end-users maintain focus on resolving intended issues during design review (Castronovo et al., 2013). Additionally, previous work highlights how VR challenges the hierarchical position of architects, who are used to predictable and controlled working methods, such as when 2D drawings are used (Cruickshank et al., 2013; Scheer, 2014).

Beyond these challenges relating to both client and architects, there is a lack of studies on how use of VR can affect stakeholders' acceptance of VR over time and how the interactions between architects and clients may be affected. While many research efforts have explored the use of VR-based design review in real-life cases, most of these have primarily concentrated on using VR in one-time sessions or semi-immersive use (e.g., power wall) rather than fully-immersive (e.g., HMD) VR-systems (Liu et al., 2020). Few have explored how the use of VR over several design review sessions, with the same stakeholders, influences their receptiveness or reluctance to use the VR-system. However, these studies do not delve into the impact of the shifting conventional roles between architects as "experts" and clients as "non-experts" on the design when using a VR system that supports both fully -immersive experiences (e.g., HMD) and non-immersive experiences (e.g., projector screen), combined with hand sketching.

2. STUDY DESIGN

In order to better understand how client representatives and architects interpret the impact of fully immersive VR and how it influences them towards becoming more receptive or reluctant towards using it, two (2) real-world projects were evaluated. The study follows a qualitative approach with data collected by means of observations, video recordings and semi-structured interviews.

2.1 Case study

The case study was based on the design of a new elementary school in the municipality of Gothenburg, Sweden, which was ongoing in different phases of the design process (e.g., spatial coordination phase, technical design) (Ostime, 2022). The project primarily used 2D drawings and incentive to use VR came from the clients when it was recognized that 2D drawings and illustrated rendered still images used by the architect could not provide a sufficient level of spatial understanding in the client group. Background information regarding the case study have been analyzed based on the following criteria: 1) purpose of using VR for design review, 2) participants' expectations prior and after each workshop as well as 3) outcome from having used VR in each of the workshops and how this influenced clients' and architects' stance on using VR. The case consisted of three workshop sessions in the following phases of the design process: preparation and brief, conceptual design stage and spatial coordination phase (Ostime, 2022).

2.2 Participants

To achieve sample representativeness, interviewees were selected based on the following criteria: 1) role in the design process, 2) prior experience of design reviews with traditional visual and information medias (e.g., 2D drawings, 3D models, physical mock-up rooms), and 3) involvement in ongoing projects for design of schools.

Whilst the focus of this study was on the same 2 client representatives and 2 architects who participated in all three VR workshops, a total of 7 other participants were also interviewed. These were the interior architect connected to the case study as well as 6 exterior architects who all had participated in separate school projects together with the client representatives interviewed in this study. The projects in which these 6 exterior architects had been involved in, involved using HMD VR for both informative- (i.e., feedback from client not incorporated into the design) and design review purposes.

It is also important to note that all participants in the studied case had prior experience of design review with 2D drawings. Moreover, all the client representatives in the studied case had experience of design review with 3D models whilst the architects had limited experience of design review with 3D models. Lastly, architects (exterior and interior) who had experience with VR had only used it for informative purposes (e.g., presenting the design to clients without incorporating any feedback).

2.3 VR-system

The Virtual Collaborative Design Environment (ViCoDE), a VR-system with support for fully- and non-immersive user-interfaces was used. It consists of several VR-headsets (e.g., Oculus Rift S kits), a multitouch table that facilitates collaborative design work with immediate, real-time feedback (i.e., object manipulation) (see fig 3) as well as a projector screen that mirrors the HMD users' view inside the virtual environment. The multitouch table 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 smartphones.

BIM-based components (e.g., loose and fixed furniture) are available via an asset library that is accessible on user-interface on the multitouch table, which can be added to the scene by drag-and-drop. Once added, a component can be repositioned, rotated, or removed, using the multitouch interface. The changes made on the multitouch table are then instantly updated in all the other connected user-interfaces (e.g., projector screen, HMD VR).

Fig. 3: ViCoDE set up with multitouch table and projector screen (left). Client representatives and architects design review via ViCoDE during the first workshop for project B (right).

Moreover, the HMD VR user-interface allows users access to interactive features such as measurement and dimensioning with snapping, filtering and color-coding, 3D-markups, object information (BIM-properties) and 3D-labels, section planes, miniature model (1:40 scale of the building design), multi-user and associated functionality (e.g., gather, goto), and BCF snapshots. During the three workshops, at least one person from the research team was available for supervision and providing help such as showing how to navigate with the HMD VR user-interface and how to use the various available interactive features.

2.4 Data collection and analysis

2.4.1 Interviews

The 2 client representatives and 2 exterior architects who attended all three VR workshops were interviewed as well as the interior architect of the project who participated in only the first workshop session. The focus of the interview questions were based on assessing the interior and exterior architects' and client representatives' views on 1) expectations before each respective workshop, 2) how VR influenced the dialogue of design review and how different interactive features were used to resolve design issues and 3) reflection after each workshop session.

Beyond the five interviews conducted with the 2 exterior architects, 1 interior architect and 2 client representatives involved in the project, an additional eight semi-structured interviews were also conducted with architects and client representatives who were not part of the case study but had collaborated with the same client representatives of the case study, on different projects. The purpose of these additional interviews was to gain a broader perspective on the client representatives' preferences and working dynamics between architects and client representatives when HMD VR is used for design review purposes. The assumption was that insights from individuals who had collaborated with the same client representatives on different projects could offer valuable comparative insights into preferences for information and visualization medium as well as decision-making processes when VR is used for design review.

These additional interviewees consisted of 6 exterior architects and 2 client representatives. The architects' experience of using HMD VR were mostly limited to informative purposes (i.e., presenting the building design without incorporating any feedback) and using HMD VR for design review purposes only during single VR workshop sessions. These architects were asked about 1) their expectation before and after the single VR-workshop session and 2) what challenges they consider as necessary to address in order to increase the use of VR for design review purposes. The 2 client representatives had used HMD VR for both informative and design review purposes were also interviewed and were asked about 1) their expectation before and after the single VR-workshop session and 2) how use of HMD VR helped them assess design issues and provide feedback to architects during design review.

2.4.2 Video recordings

The case with its three workshops were video recorded, with a GoPro 360 camera for a total of 3h, with 45 minutes from each workshop being selected. The two stationary GoPro 360 cameras were placed in elevated positions to capture the participants' collaboration, movement, and use of the different user-interfaces (e.g., multitouch-table, HMD VR) in the workshop room. The collected corpus of video data was transcribed for further analysis and later compared with the field notes and interview data.

The video data were analyzed by looking at the interactions between client representatives and the architects when resolving design issues as well as how both client representatives and architects each respectively interacted with the fully- (HMD VR) and non-immersive (i.e., projector screen and multitouch table) user-interfaces of ViCoDE. The verbal interaction between the participants was transcribed by one of the researchers. Segments of recording were selected based on when the greatest number of interactions took place between participants and the different user-interfaces of the VR-system in order to achieve sample representatives of captured data.

2.4.3 Analysis of interaction pattern

From the selected 45 min of video recordings of each workshop, 15 min were selected to analyze the interaction patterns between architects and client representatives and how both these type of stakeholders interacted with the fully- and non-immersive user-interfaces of ViCoDE. The selected time period for analysis of interaction patterns was based on 1) identifying parts of the selected video recordings where the architects and client representatives interacted the most with each other to resolve design issues, 2) interacted the most with the different user-interfaces, 3) specific moments where key design decisions were made (e.g., reaching consensus on design issues based on the design review agenda) and 4) number of user-interfaces that were used to resolve specific design issues (e.g., revising different room layouts on the multitouch table and validating these via HMD VR and projector screen).

These interactions are divided into three different groups:

- Group: statements, callouts and interactions not directed to a specific individual, but more to the whole group.
- Incoming: interactions directed to the person in question, such as a direct question and a request on the design
- Initiated: interaction initiated by the person in question. This includes questions directed to other person initiated by this particular person.

From the 15 min of each workshop that was video recorded, analysis was performed to count how many times the available user-interfaces – HMD, multitouch table, projector screen – were used by the different participants. These transcribed interactions were used to generate interaction graphs per workshop session with the different types of interaction documented in Microsoft Excel. The transcribed interactions were then imported to create a social network matrix using Gephi 0.10.1 to visualize these patterns emerging between users and the user-interface that they used (Bastian et al., 2009). The network comprises of nodes, representing participants in the different workshop as well as the available user-interface. The edges connecting the nodes are interactions between participants or participants and user-interfaces. Moreover, these edges are weighted by the amount of interaction occurring between the nodes, with distance and a bolder type of line indicating a stronger connection. Strong interconnection between participants/user-interfaces can be viewed in a cluster of nodes close to each other in the network as well. Lastly, the graphical layout algorithm selected for the social network is Fruchterman & Reingold layout algorithm (Fruchterman & Reingold, 1991), due to how it presents a good visualization of the interaction distribution.

3. RESULT

Based on the data analysis, six different visual interaction network graphs are presented, with two from each workshop showing the interaction between participants as well as the interaction participants had with the different user-interfaces of the VR-system. These graphs are presented together with the data captured in the semi-structured interviews as well as the video recordings. This was done to better understand how the use of the different user-interfaces of the ViCoDE system, used by the architects and client representatives, changed over the three VR workshop sessions.

3.1 Case study

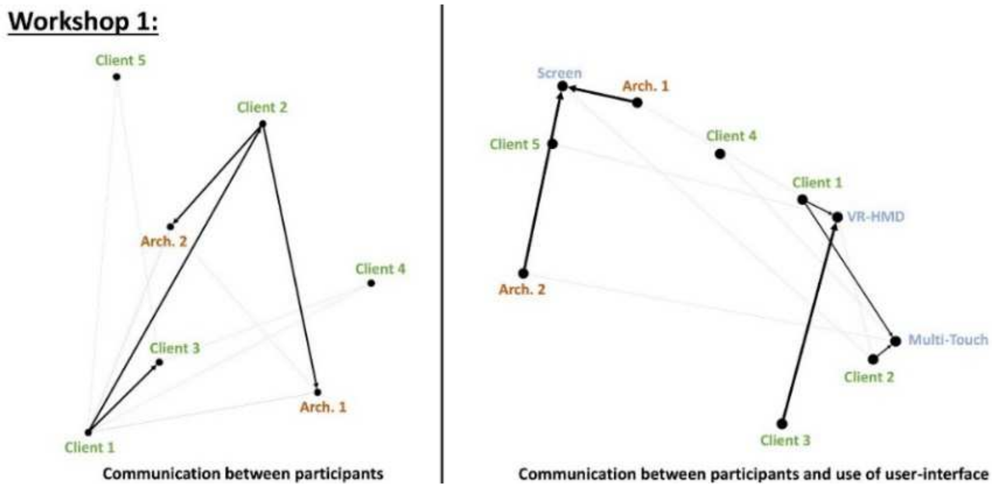

Fig. 4: Architects were noticeably receiving questions about the design from client representatives. Conversely, client representatives coordinated decision-making among themselves and used the HMD and multitouch table.

As illustrated by the edges of the nodes above the architects only used HMD VR once and instead used the non-immersive projector screen when viewing the virtual environment. Still, interesting to note is that when wearing HMD VR, design issues identified by client representatives were reviewed by architect 1 using the mark-up feature to assess the questions client 1 and 2 were asking. Rather than using HMD VR, both architects opted to view the projector screen, which displayed the perspective of HMD VR users, i.e., the virtual environment. Additionally, for a few minutes they used the multitouch table for discussing ideas and thoughts about the design. By seeing client representatives' view from inside the virtual environment, architects directed the client representatives to different points in the building design. The architects' non-immersive experience of the virtual environment via the projector screen was similarly observed in workshop 2 as well, with their fully-immersive (i.e., use of HMD VR) experience being limited to a few minutes during workshop 1.

From the client representative perspective, the multitouch table was the main user-interface used during the first workshop. This was done to resolve design issues in spaces such as classrooms to identify design issues related to hidden sightlines and furnishment. Specifically, by using interactive features such as object manipulation on the multitouch table and multi-scale in the HMD, client representatives used these different user-interfaces of the ViCoDE system to implement a scenario-based approach during design review. For instance, when changing the furnishment layout and placement of walls and windows on the multitouch table, client 1 and 2 viewed in real-time via the HMDs that there were insufficient space which would prevent teachers from performing their daily work tasks (see fig 5).

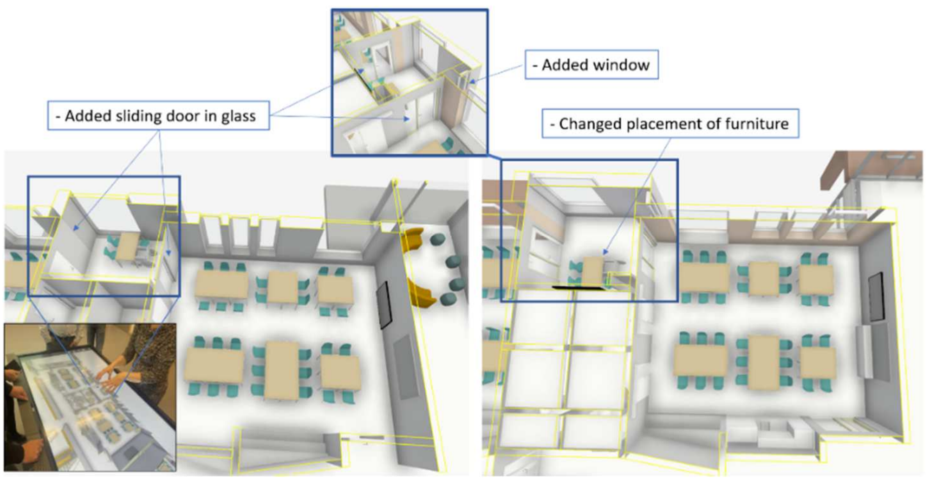

Fig. 5: Design issues identified and resolved in the first workshop via the multitouch table and HMD user-interface (left), which then were incorporated into the second workshop (right).

In the context of identifying design issues such as a lack of sufficient space, client representatives 1 and 2 who had experience interpretating 2D drawings, highlighted the difficulties with correctly assessing the design via 2D drawings. Explaining in the interview after the third workshop how "*regardless of our experience, there is a tendency for us to miss design issues when using 2D drawings [Client representative 1]"* but also *"difficulties with understanding the volume of object, such as loose furnishment, the room space itself or window elevation [Client representative 2]"*. This statement by the client representatives, however, contrasts those of the architects who shared in the interviews that they believed that *"client representatives experienced with interpretation of 2D drawings have sufficient understanding for assessing the building design correctly [Architect 1]"*. This belief among the architects could be explained by their previous experience of having worked with the same client representative when 2D drawings were used.

From the architects' perspective, the multitouch table was increasingly used in all three workshops. Even though HMD VR was not worn for more than a few minutes by either architect, with one of them explaining the reason being that *"that we already know how to visualize the virtual environment in our heads by spatial reasoning, as we have been trained by practice… [architect 1]"*, the multitouch table was the user-interface the architects interacted the most with. For example, whilst client representatives used all the different ViCoDE user-interfaces to identify and resolve design issues in the first workshop, the architects instead viewed the projector screen to discuss design issues with the client representatives. Then in the second workshop, both architects started to use the multitouch table more, as a result of helping client representatives who were unable to resolve design issues by themselves. Lastly, during the third workshop, they took the initiative to use the multitouch table and actively started to lead the discussions and in particular design issues related to building code requirements (see fig 6).

Fig. 6: Workshop 1-3. Architects directing client representatives (left) and discussing ideas with them whilst sketching (center), to directly using and reviewing the design via the multitouch table (right).

With none of the architects having used VR for design review purposes and only for informative purposes, the progressive interaction with the multitouch table indicated a certain acceptance among the architects. They used it for task-based scenarios, which could be shown and explored in VR (see fig 5 and 6).

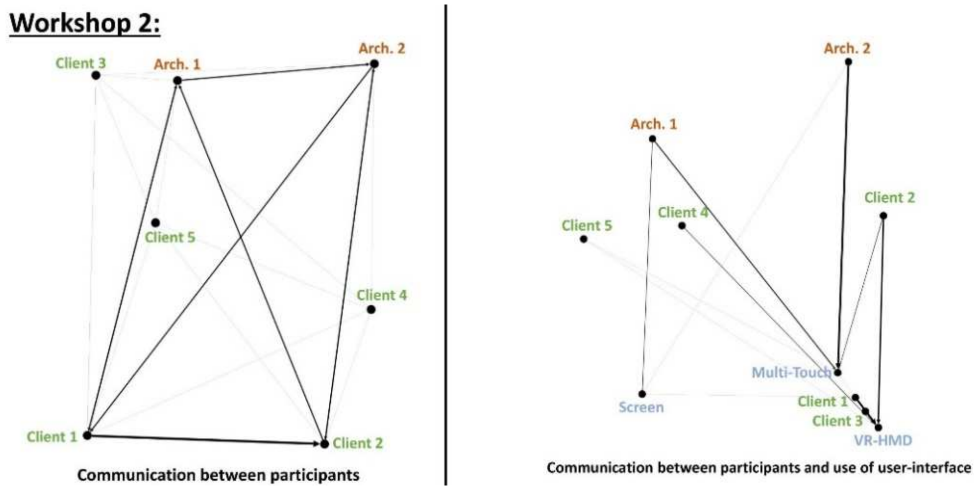

Fig. 7: Client representative 1 and 2 who participated in all three workshops had frequent interaction with each other (left). Both architects also became more involved via their use of the multitouch table (right).

As shown by the node cluster in Fig. 7 (right), client representatives continued using the multitouch table in combination with the HMD VR to rapidly review design revisions via task-based scenarios. Moreover, as indicated by Fig. 7 (left), both architects started to interact more with the rest of the participants as well as starting to primarily use the multitouch table instead of observing the virtual environment via the projector screen. In this context, video recordings show how both architects first sketched ideas on how certain room design layouts for different classrooms could be arranged (see fig 5 and 6). Following this sketching procedure, the object manipulation feature of the multitouch table would be used to validate the feasibility of the design based on these sketches. Lastly, after having decided upon different layouts, the architects would view the projector screen in combination with client representatives using HMD VR to discuss thoughts and ideas about the design together with the client representatives.

In workshop 2, the architects began using multitouch table and became more engaged in the design review process. Similarly to workshop 1, client representatives worked independently during design reviews, separate from the architects. In the context of resolved design issues, video recordings show how the first and second workshop focused on spatial zone relationships, hidden sightlines and furnishment of classrooms and different spaces. Once these design issues had been identified and resolved, 2D drawings were used alongside the multitouch table by both client representatives and architects. With the use of 2D drawings, the architects took a more active role during the design review and specifically the decision-making related to review of building code requirements.

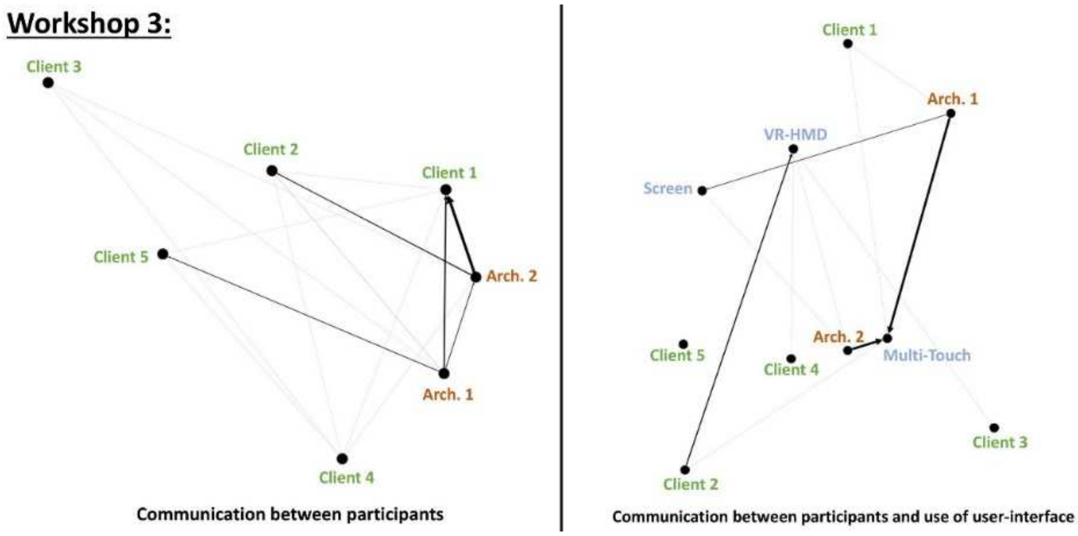

Fig. 8: Contrasting the first workshop, architects initiated more interactions with client representatives (left) as well as interacted more with the multitouch table (right). Clients had similar trend in their interactions as before.

As illustrated by Fig. 8, workshop 3 resulted in a shift in interactions from workshop 1. Specifically, during workshop 1, client representatives led the decision-making regarding the design and during this process used both the non-immersive (i.e., projector screen) and fully-immersive (i.e., HMD VR) user-interfaces of the ViCoDE system. This lead of the decision-making process by the client representatives differed from the 3rd workshop. Instead of being on the receiving end of decision-making, architects now initiated interactions with the different client representatives.

One explanation for the shift in decision-making could be based on the architects being unfamiliar with how to use VR-systems such as ViCoDE for design review, but slowly during three workshops grew more accustomed to the different user-interfaces. Another explanation is that after addressing design issues concerning spatial understanding of the building design, the architects took the lead in interactions and decision-making when reviewing the building code requirements, similar to a traditional design process involving 2D drawings. Connected to the last explanation, another possibility for the shift in decision-making could be that initially when client representatives were using the different user-interfaces of the VR-system, the architects were unsure on their "role" during design review with a VR-system such as ViCoDE. Specifically, whilst the video recordings show how the architects initiated interaction and discussions during the last workshop, the design review were mainly facilitated by the client representatives themselves. With client representatives doing design review mostly independent from the architect in the first two workshops, the role of the architects in these sessions was questioned, as evident by the incoming interactions shown in Fig. 4 but also as the video recordings show when the client representatives questioned design issues they previously were unable to identify during design review with 2D drawings. Moreover, this challenge of the architects' role in the design process was also pointed out in the interview with the interior architect involved in the project:

"When using VR for design review purposes, I sense that end-users such as client representatives identify design issues before we (architects) do and following this, ask questions about the design that we usually are the first to ask whenever 2D drawings and 3D models are used. [interior architect]"

Whilst the architects' lack of experience in using VR for design review purposes explains this statement, it could also explain client representatives' receptiveness towards using the VR-system from the very first workshop. For example, whilst the architects were initially reluctant to interact with the multitouch table, client representatives actively and continuously used all user-interfaces of the VR-system and in particular, the different interactive features of both the multitouch and HMD VR.

In general, results for all the three workshops showed client representatives and architects being receptive towards using many of the same user-interfaces of the VR-system. Whilst similarities in interaction towards using the multitouch table were apparent, equally apparent was the contrast in reluctance and receptiveness in using the HMD VR. From the architects perspective, they became more receptive towards use of interactive features such as object manipulation throughout the three workshop sessions. Specifically, by first sketching with pen and paper and then testing these different layouts on the screen showed how the architect initially started with directing client representatives via the projector screen to later in the second and third workshop actively being part of the discussions that took place. From the client representative perspective, receptiveness to both the non-immersive user-interfaces (i.e., multitouch table and projector screen) and the fully-immersive one (i.e., HMD VR) led to a decision-making process mostly independent of the architect. Moreover, this independence shifted in the second and in particular the third session when design issues related to building code requirements (e.g., daylight, distance between spatial zones) were reviewed. When reviewing these requirements, the architect was more receptive than the client representatives in using the multitouch table and with both type of participants showing reluctance towards using the HMD VR when reviewing building code requirements.

4. DISCUSSION

4.1 Participants' interaction with user-interfaces of a VR-system

Findings show that the different user-interfaces of the ViCoDE VR-system were used to varying degrees during the three workshops. On the one hand, client representatives from the first workshop all through the third session, interacted mainly with the HMD VR and multitouch table as well as the projector screen. On the other hand, the architects' reluctance to use HMD VR for design review persisted throughout all three sessions. Yet, both client representatives and architects frequently used the multitouch table.

From the client representatives' perspective, different interpretations can be made as to why their interactions with the different user-interfaces were consistent. Firstly, with mainly HMD VR increasing their spatial understanding compared to 2D drawings (Chowdhury & Schnabel, 2020) client representatives were able from the first workshop to identify and resolve design issues that they previously unaware of. This unawareness of design issues, regardless of previous experience with interpretation of 2D drawings, could also be interpreted as the client representatives being more receptive towards using the different user-interfaces of the ViCoDE system and in particular HMD VR. This could be due to HMD being perceived as a more engaging information and visualization medium than 2D drawings (Johansson, 2016) with the ego-centric frame of reference client representatives had via HMD VR (Paes et al., 2023), helped them better assess different furnished layouts in workshop 1 and 2. Moreover, the design changes made in the 1st workshop with HMD VR and multitouch table and later incorporated in the 2nd workshop, can be interpreted as client representatives being provided with clearer visual cues (e.g., size of room, placement of windows) (Hermund et al., 2017) when perceiving volumetric qualities of the building design better in fully-immersed virtual environment (Chowdhury & Schnabel, 2020). Secondly, it could be argued that by identifying design issues such as hidden sightlines, furnishment and design of different spaces (i.e., workshop 1 and 2) via HMD VR, client representatives grew more receptive towards continued interaction with HMD VR but also the multitouch table. Thirdly, by adopting task-based scenarios during design review (i.e., workshop 1 and 2), it can be argued that collaborative practices such as Co-design further helped facilitate their interaction with HMD VR and the ViCoDE system at large (Roupé et al., 2020). Also, as observed during workshop 1 and 2, client representatives made design changes such as furnishment and revision to layout of different spaces independently from the architects. This independence is further acknowledged by the project's interior architect when she explains how clients tend to identify and ask questions about the design in HMD VR before the architects do. This suggests that Co-design is more likely to emerge when VR-systems with support for both HMD VR and object manipulation are used during design review, as client representatives become part of the design team (Caixeta et al., 2019).

From the architects' perspective, it is interesting to notice, due to how VR being described primarily as a presentation tool used by architects (Achten, 2021; Scheer, 2014), that interaction with different user-interfaces in the different workshops, was mostly limited to the non-immersive experience, offered by the projector screen and the multitouch table. By viewing client representatives' HMD VR view of the virtual environment and using the projector screen to direct them in the building design, the architects' experience of the virtual environment was limited to a non-immersive one. In this context, when using sketching with pen and paper prior to testing the idea on the multitouch table, we saw that the architects are more receptive towards interacting with user-interfaces they perceive as familiar with their own traditional design tools (e.g., multitouch touch table with top-view similar to 2D drawings) (Scheer, 2014), rather than user-interfaces they do not have experience in using for design review purposes (i.e., HMD VR). This familiarity could be argued to be based on the top view perspective they are used to work with (e.g., 2D drawings) but also for how the use of interactive features such as object manipulation allowed them to seamlessly test and validate design proposals when swapping between sketching and multitouch table. This idea of familiarity could also explain why architect 1 in the first workshop, on their own accord, used the mark-up tool to better understand the client representatives' question on the design. To this point, it can be interesting for future studies to investigate whether architects design review in multi-user HMD VR, together with client representatives, would affect their resistance towards engagement with HMD VR. For instance, what interactive features would be needed in HMD VR to result in a shift for architects viewing HMD VR primarily as a presentation tool (Scheer, 2014), to one of their primarily chosen mediums used for design review?

4.2 Communication between participants when using VR-systems

Results from the three workshops suggest that VR-systems with support for multiple user-interfaces and available interactive features enable client representatives to have a Co-design approach to design review. With the architects being questioned on their decisions made earlier with 2D drawings (workshop 1 and 2), we could see that in conjunction with client representatives doing design review independently, that their role in the design review context came into question. With the third workshop instead consisting of architects initiating interactions with the client representatives as well as leading the design review when reviewing compliance with building code requirements via 2D drawings, the questioning of architects' hierarchical position is supported (Cruickshank et al., 2013; Scheer, 2014). Also, with the explanation provided by the interior architect on how design issues and questions on the design are now instead initiated by client representatives rather than the architect, it can be argued that the role of architects during design review with VR, needs to be further explored to address their resistance toward engaging with HMD VR.

Consequently, providing client representatives with the conditions to express their needs about the design (e.g., use of interactive features to enable design review via task-based scenarios) results in increased sense of ownership of decision-making. Nevertheless, with architects experiencing a loss of decision-making power (i.e., workshop 1 and 2) (Maftei et al., 2018), we saw that VR used for design review purposes would be useful in collaborative practices such as Co-design. In this context of Co-design, it is noteworthy how the architects in all three workshops started developing solutions to different design issues firstly via non-immersive design tools, i.e., sketching by hand, and then shifted over to the non-immersive user-interfaces of ViCoDE, i.e., multitouch table and projector screen. Whilst this hybrid design environment with both non-immersive and immersive user-interfaces can help involved participants to immediately validate their design decisions (Okeil, 2010), it could be argued that the design creation/feedback/revision cycle between architects and client representatives would be more efficient if alternation between non-immersive (i.e., projector screen and multitouch table) and fully-immersive (i.e., HMD VR) environments was not required. With architects developing and revising their design ideas in a fully-immersive environment, they would also likely face a loss of predictability in their working methods (Cruickshank et al., 2013) and decision-making on the design (Scheer, 2014). As such, the "loss" of predictability in working methods and decision-making power could make architects in the fully-immersive virtual environment susceptible to being wrong about certain design ideas, i.e., how the needs and wants of the building occupants are considered in the design.

Therefore, by immediately facing the consequences of their design ideas via use of task-based scenarios (Nikolić & Whyte, 2021; Roupé et al., 2020), it is more likely that the typical hierarchical position of the architect (Scheer, 2014) is questioned, due to client representatives identifying and resolving design issues independently from the architect, as evident by 1st and 2nd workshop. Although the setting of the workshops involved participants using both a non- and fully-immersive approach to design review, it could be argued that the questioning of the architects decisions of the design would be further reinforced when the design review with involved participants is mainly done in a fully-immersive environment. As a result, it is important to explore the conditions architects need, to design review in fully-immersive VR. For instance, how would availability of object manipulation in HMD VR influence collaboration between architects and client representatives? Would collaborative practices such as Co-design more likely be facilitated with everyone doing design review in the virtual environment? Connected to the last point and as evident by the video recordings from workshop 1 and 2, the VR-system tested in this study, i.e., ViCoDE, meant that 2 out of 3 design review sessions were observed to be an isolating experience for the architects. This isolating experience meant that the architect's typical role of a facilitator (Scheer, 2014), were not as apparent as in design processes involving traditional design medias (e.g., 2D drawings and 3D models). It would be of interest to further study what type of role, whether similar or a new one, architects need to take on when doing design review with fully-immersive VR (Maftei et al., 2018). Thus, these are just some of the questions worth exploring in future studies, to better understand the resistance to engagement with VR-systems.

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