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EXPLORING DIFFERENT DESIGN SPACES – VR AS A TOOL DURING BUILDING DESIGN

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ABSTRACT: *During the design process of a building different medias are often used to depict the design. Traditional media, especially 2D requires high spatial skill and cognitive demand on the designers. For inexperienced designers, this process can be demanding, be difficult and can cause potential biased design perceptions that are significantly different from the reality. However, studies have also shown that different media and representation facilitates different cognitive reasoning processes about the design. Immersive Virtual Reality (VR) is assumed to give another level of understanding and perception of design space from an egocentric perception than 2D plan drawings or bird-eye views, which have been argued to provide opportunities for better pattern and object recognition that is suitable when studying spatial organization in an allocentric reasoning process. This paper investigates, the different design medias and spatial space explorations further, by studying how students used the different representations and medias (e.g. sketches, 3d-models and VR) during their design process. By combining and using both of these two design space representations, (e.g. egocentric and allocentric) in the design process, it gives a possibility to achieve a more developed design outcome. The methods used in this study were observations and un-structured interviews during the design process and a follow up questionnaire at the end of the design project. The result show, by combining and using both VR and traditional design sketching tools that it is possible to support the two design space representations together and give the designer the possibilities to explore, understand, discuss and work with the design in a more elaborate way from both an egocentric and allocentric perspective. The paper also presents in what way VR can contribute to the Evidence Based Design (EBD) criteria and how the students used different design spaces representations for design and spatial reasoning about the healthcare design of the psychiatric facility they were designing.*

KEYWORDS: *Virtual Reality, VR, Evidence Based Design (EBD), Design process, Design Space*

1. INTRODUTION

The design process of a new building is often recognized as a complex and creative process where different artifacts, requirements, and functions are established and then designed, reviewed, analyzed and decided upon during the process (Chan, 1990). For inexperienced architectural students, this process can be demanding and the ability to interpret information and interpolate it into the spatial reasoning about the design could be challenging (Granath et al., 1996). The most common representations in these processes are documents, descriptions, sketches, 2D-drawings, pictures, 3D-models and physical scale models. However, these representations can be difficult to interpret and understand and place high cognitive demands on the designers' ability to transform the information into a self-made mental image of the project. The self-made mental image could also be misinterpreted and differ depending on the individual's background education, experience, and interest. Studies have shown that different representations facilitate different reasoning processes about the design (Coburn, 2017). For instance, flat 2D plan drawings or bird-eye views have been argued to provide opportunities for pattern and object recognition, which is suitable when studying spatial organization, relationship between space and objects, and orientation of different objects e.g. allocentric reference (Coburn, 2017). In addition, other studies have shown that 2D representations, such as floor plans or engineering drawings, are less intuitive for laymen (Granath, 1991; Hardie, 1988; Ingram, 1984; Lawrence, 1982). Ingram (1984) further argues that designers require lot of training and practice before they can efficiently use 2D drawing techniques as a primary design tool. During this process the designer must have the cognitive ability to mentally transform two-dimensional objects into a 3D-view to understand the design space e.g. called *Spatial visualization*. Another cognitive process related to the design process is the *Spatial orientation,* which is the ability to imagine an object or scene from other perspectives. These two parallel cognitive processes are a very demanding and can influence understanding and discussion about the design, as the different individual's could interpret design artifact differently. Bertel et al. (2008), argued that this type of mental design representation significantly differs from the reality i.e. the actual built building. In this context, studies have showed that immersive Virtual Reality (VR) can provide another level of understanding and perception of space, which is hard to experience using other type of visualizations and medias (Coburn, 2017; Roupé et al., 2016). To understand how information is decoded and interpreted it is necessary to explain how the human brain processes visual information into mental imagery and spatial perceptions. During this process the mind tries to create an understanding of the visual space within two parallel systems: the self-centered egocentric reference frame and an environment-centered allocentric reference frame (Burgess, 2006; Klatzky, 1998). Both systems interact during this processing and retrieval of spatial knowledge (Plank et al., 2010). In the egocentric reference frame, the viewer compares him/herself with the object in 3D space. During this self-to-object process, the distance and bearing to the object are processed independently of the global environment. As the viewer navigates through the environment, egocentric parameters have to be constantly processed and updated with each view change in 3D space and therefore it is seen as a viewpoint dependent reference frame. By contrast, the allocentric reference frame is built up by comparing object-to-object or environment-object relationships and is a global reference frame associated with the visual environment. Furthermore, Immersive VR gives the user the opportunity to compare themselves and their bodies with the environment in a view-dependent process i.e. egocentric reference. Research also suggests that using the physical-human rotation and movement Immersive VR provides a better understanding and spatial perception (Paes et al., 2017; Riecke et al. 2010; Roupé et al., 2014; Ruddle and Lessels 2009). In recent years, new Head Mounted Display (HMDs) technology released help support better stereoscopy, higher resolution of the display, wider Field-of-view, physical-human rotation and movement. Recent studies have shown that space perception in the HTC-Vive start to be comparable to real world space and distance perception, but still the virtual environment feels compressed (Buck et al., 2018; Kelly et al. 2017; Paes et al. 2017).

The work presented in this paper investigate the different design media and spaces further, by studying how masters level architectural students used the different representations (e.g. sketches, 3d-models and VR) during their design process. During this process the students/designer elaborate on various alternative solutions to a given task in the *architectural design problem space* (Chan, 1990; Goel and Pirolli 1992). Within the scope of this paper we define this problem space as a rational search process that elaborate on various alternative design solutions to a given problem through spatial reasoning and problem exploration of the design in 2D and 3D space. This spatial reasoning and problem exploration process is done both in egocentric and allocentric frame of reference. As mentioned, the allocentric theory suggests that flat 2D plan representation such as drawings/sketches or bird-eye views support better reasoning about the design when it comes to studying spatial organization, studying relationship between spaces and objects and orientation of different objects and functions (e.g. allocentric spatial reasoning). In comparison, VR supports another level of understanding and perception of space from a self-centered view-dependent process i.e. egocentric perception where the user can experience the design in scale 1:1. By combining and using both of these two design space representations in the design process, it gives a new possibility to achieve a more appropriate project outcome. To explore this design method and process, we have implemented it in the masters course Healthcare Architecture Studio. One of the key course objectives was to actively incorporate Evidence Based Design (EBD) principles in the architectural design process (Ulrich, Zimring, and Zhu 2008). Founded in research, EBD within building design for healthcare demonstrates processes for how the built environment can provide optimal conditions that support health, productivity and healing process. Furthermore, VR gives the student/architect/designer the possibility to analyze the design from a patients and nurses point of view (e.g. egocentric spatial reasoning), which could facilitate the EBD process. In this context, the aim of this research is to explore and describe in what way VR can contribute to the above mentioned design criteria and how the students used different design space representations for design and spatial reasoning about the design of the psychiatric facility that was the case in the course.

2. METHOD

The study was conducted with masters level architectural students (i.e. 4 year) students (n=24) at Chalmers University of Technology, 2018. The respondent groups were part of Healthcare Architecture Studio with the assignment of designing a 15 000 sqm psychiatric facility. An EBD approach was one of the key course objectives and was used during the design process (Ulrich, Zimring, and Zhu 2008). In this context, EBD bases the design decisions concerning the built environment on validated research to achieve the best possible outcomes of the design regarding health, productivity and healing process. Additionally, health promotion, reduced treatment time, decreased medication, and stress reduction are some examples of studied outcomes related to design based on the EDB approach.

Clear functional objectives connected to the architectural program for psychiatry are as follows:

- ***Clear and visible sightlines*** between staff and patients. Facilitate unobtrusive observation of patients. Visible and central placement of staff team stations. No hidden corners where patients can hide.
- ***Protect patient privacy***. Orientate and place windows so that patient rooms and communal areas are not exposed to overlooking.
- ***Views and connection to nature***. Avoid long narrow corridors and create breaks in the facade to allow in daylight and views.

The students were introduced to VR and how they could use it as a tool during their design process in the fourth week of their design project. By then they hade had done the pre-design of the Psychiatric Facility, where the students had done sketches and 2D-drawings of the layout and studied relationship between functions and spaces. In the following week five and six the students worked with more detailed design and room layout. It was in week 5-6 the students had VR workshops, where they used VR for group discussion and design review meetings, see Fig 1. During these design review meetings, at least one teacher was present for observation, tutoring and feedback. The VR system that was used was HTC Vive together with the software BIMXplorer (Johansson, 2016). The creation of the 3D-models was done in Rhino, Autodesk Revit, or SketchUp and imported directly into BIMXplorer through the 3ds-file format or as a plugin in Revit. During the design review meetings/group discussions, the groups used the HTC-Vive together with a big screen display, see Fig 1.

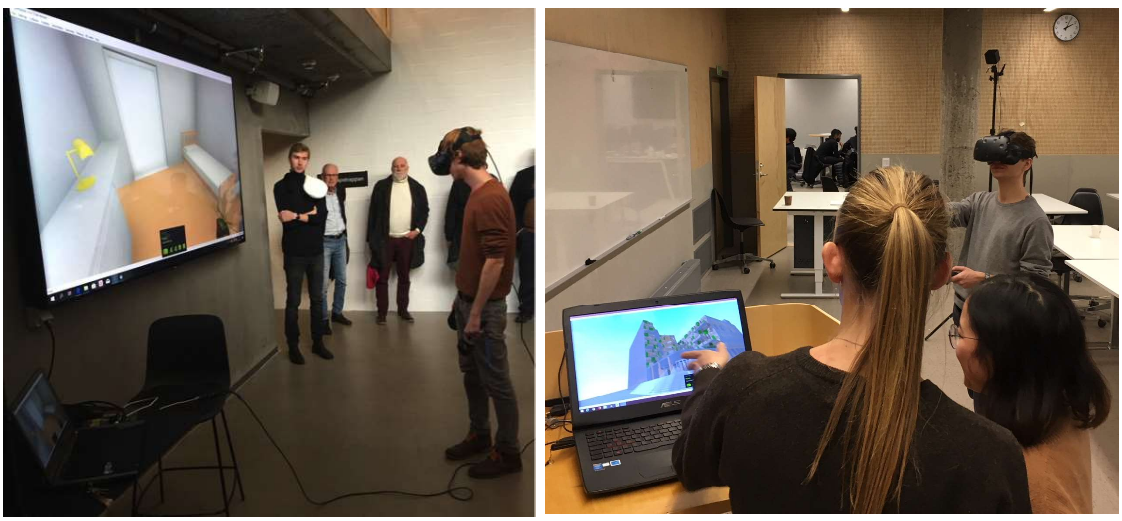

Fig 1: Design review meetings the groups used the HTC Vive together with a big screen display during their group discussions.

The methods used in this study were observations and un-structured interviews during the design review meetings and the design process. The main focus during the observations and un-structured interviews was to explore and to investigate how the students explored and used VR during the design process. From these observations and interviews a follow-up questionnaire was created, which was conducted by the students at the end of the project/course. The questionnaire included in total 22 variables and questions. The questionnaires contained questions that were answered by marking five-step scales and some questions were open-ended. The open-ended questions results were analyzed and categorized. The questions was related to; *-design changes due to VR and what type of changes, -new insights about the design space using VR, - were there any advantages of using VR during the design process, - what the individual student thought about work with VR in design process in comparison to work with for example physical models, drawings and sketches.*

3. RESULT

The following result section presents the results from the open-ended questions, which has been analyzed and categorized. Some of the citations from the open-ended questions are also used to highlight the essence and meaning of the different categories. In the end of the result section the quantitative questionnaire results are presented.

3.1 Design changes due to VR design review

In table 1, we present the results from the question related to if the students made any design changes due to experience the design in VR and what type of changes they made.

Table 1. Reported comments relating to: *Did you make any design changes due to the VR design review? If so, what type of changes?*

Category	**Number of responses (n=21)**
Changes related to perception of room size and space	13 (61.9%)
Too large space/rooms	12
Widths of the corridors	9
Height of the ceiling	2
Changes related to floor plan	4 (19.0%)
Size of rooms and spaces	4
Wayfinding	2
Changes related to sightlines	5 (23.8%)
Sill-height and placements off windows	5
Corridors and rooms	2
Changes related to design errors, such as stairs, windows etc.	3 (14.3%)

As can be seen in table 1 and also observed during design reviews in VR, most of the discussions and design changes were related to the size of rooms and corridors (e.g. width and height) in the building due to the better understanding and perception of the designed space. Other changes were related to the floor plan due to; -recognized difficulty during wayfinding and navigation in the building, -the ambition to accomplish clear and visible sightlines between staff and patients in corridors and rooms and the visibility and central placement of staff team stations. Furthermore, some students recognized more general design errors and some groups used VR for evaluating different sizes and placements of windows and views connected to the experience of nature in the patient rooms.

3.2 New insights about the design space using VR

Table 2. Reported comments relating to: *Can you give one (or several) example(s) where VR gave you new insights about the design (that you weren't fully aware of before doing the VR review).*

Category	**Number of responses** (n=21)
Another understanding and perception of room size and space	13 (61.9%)
Walk around and analyzing orientation and wayfinding in the building	3 (19.0%)
Materials	2 (19.0%)

As can be seen in table 2, the students also here mention that they got another understanding and perception of room size and space of their design compared to the other traditional design medias. Also, by having the possibility to walk around and analyzing orientation and wayfinding in the building it also gave an insight about their design. One student mentioned that: *"It´s hard to see the dimensions in just a 3D model or drawing, it is way easier to see and feel it in VR"* another student comment was: *"VR helped to better grasp how the spaces that we draw in plan view would feel like"*. Another mentioned, *"I felt that the scale of the patient rooms wasn't as big as I feared, that was good. Also we saw that the corridors could be smaller."* One student comment related to analyzing orientation and wayfinding was: *"One example is the wayfinding. On paper and in 2D it seemed to work but when we walked* *around in the building we figured out that it was really hard to find the right places. We got lost."*

3.3 Advantages of using VR during the design process

In table 3, the result from the question related to what the advantages of using VR during the design process was.

Table 3. Reported comments relating to: *What were the advantages of using VR during the design process?*

Category	**Number of responses** (n=21)
Better understanding of the design	19 (90.5%)
Better understanding of spaces and the scale	18 (85.7%)
Experience of being in the building/designed project	10 (47.6%)
Discussion about the design	5 (8.3%)

The result in table 3 indicates that the participant's thought that the biggest advantages in using VR during the design process was related to better understanding of the design and that they got an better understanding of space and scale compared to other media and tools. They also mentioned that VR gave them another experience of being in the building/designed project. Some student mentioned that VR helped them during discussion about different design opinions and concepts. One student mentioned that: *"Easier to understand the design of the project than just plan- and section-view or even 3D model. It is also exciting to see how our ideas turned out in 'reality '"* another student comment was: *"that it is hard to see the dimensions in just a 3D model or drawing, it is way easier to see and feel it in VR"* Another student mentioned: "*We realized that the space was too large and not giving the feelings we wanted to provide. So VR is good for understanding the spatial qualities you want to achieve in your design and VR could really work as a design tool"*. Furthermore another student highlighted that VR helped the design process during the experience and analysis of architectural design problem space, e.g. *"How big the patient room look like in 'reality' and what effect our curved bathroom wall gave to the room, how good overview the staff would have of the patient."* One student mentioned that VR helped during discussion and analysis about the design, e.g. *"To see it together with your team you find both the positive and negative things of our design, and create a common frame of reference for discussion."*

1.4 Working with VR during the design process in comparison to physical models, drawings and sketches

In table 4, the result from the question related to: What the student thought about working with VR during the design process in comparison to working with, for example, physical models, drawings and sketches.

Table 4. Reported comments relating to: *Make a short reflection of how it was to work with VR during the design process in comparison to working with for example physical models, drawings and sketches?*

Category	**Number of responses** (n=21)
New experience of the design space by "brining it to life"	14 (66.7%)
Better understanding of space and the scale	7 (33.3%)
More accurate feeling of scale	6 (28.6%)
Simulate the movement and wayfinding in the design/building	2 (9.5%)

As can be seen in table 4, the students mention better understanding of space and scale as one of the most positive effects of using VR compered to physical models, drawings and sketches. But the most positive effect was that they felt that VR gave them a new experience of the architectural design problem space by "*bringing it to life*". Related to this, one student mentioned that: *"Exciting to see the result of analogue and 3D work, ideas coming live almost"* Another student mentioned: *"The VR offers a reality to the project, brining it to life and making it feel big, important and realistic and the virtual perspective can't be compared to smaller physical models, drawings etc. VR offers a new important dimension to the design process"*. Furthermore another student's reflection was: *"When* *working with VR you can get a very realistic feeling. When working with physical models, plan and sketches everything seems smaller than it is".* Another student mentioned: *"Physical models and drawings don't take you inside of the building. Physical models are better for understanding the volume from above."*

Observations during the VR design reviews also identifies the above-mentioned categories. Some groups used VR to analyse the design from the patients and nurses point of view by trying to sit on the chair or lie on the bed in the patient room and experience how the future patients would experience the room. One group analyzed their designed *curved bathroom wall* from the staff security point of view, e.g. if the staff could enter the patient room by seeing the whole room from the window in the door which is vital for psychiatric patients rooms for safety and assault reasons.

Fig. 2 displays the frequency and rating from the last quantitative questions related to how the students used and perceived VR during their design process.

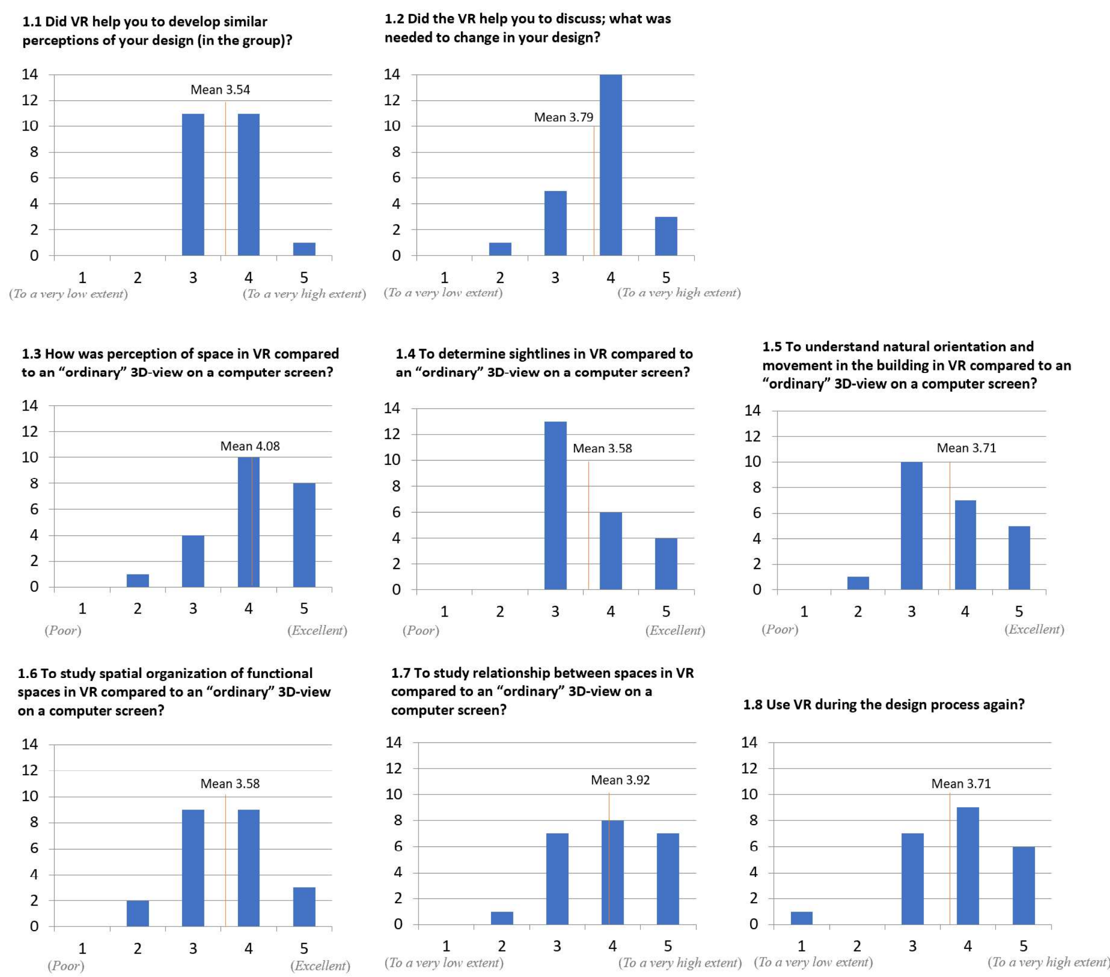

Fig 2. Frequency and rating for the last quantitative questions related to how the students used and perceived VR during their design process on a scale from 1 (*To a very low extent*) to 5 (*To a very high extent*). (n_{tot}=24)

As can be seen in Fig. 2, the results from the quantitative questions are aligned with the results from the qualitative questions in table 1-4 and the observations. The participants thought that VR helped them during discussion about what was needed to change in their design and that they wanted to use VR again during their design process. Furthermore, the participants perceived that VR gave them a better perception of space and some of them believed that VR gave them the ability to study relationship between spaces and natural orientation and movement in the building (i.e. how you would naturally navigate in the real building).

4. DISCUSSION AND CONCLUSIONS

The design of a new building or healthcare environment is recognized as a creative and complex process, where different artifacts, requirements and functions are designed, reviewed, analyzed and decide upon. For inexperienced architectural students, this process can be demanding and the ability to interpret information and transform it into spatial reasoning about the design could be challenging. However, as the result of this study show, VR support the students/designers in understanding and how they perceive the designed spaces from a self-centered view-dependent process compared to other medias. Furthermore, VR gives the student/architect/designer the possibility to analyze the design from other stakeholder's perspectives, e.g. nurses and patients. Either by including them or by simulation of these users from a self-centered view-dependent process. This facilitate an EBD approach in building design as it complements the use of validated research with a tool to develop understanding of context and specific user requirements – all aspects of an EBD decision making process. As mentioned before, EBD within healthcare building design strives to accomplish a built environment that has a positive effect in the healing process and healthcare productivity. As this study shows, the students analyzed and tried to understand how the future patients would experience the patient room by sitting in the chair or lie on the bed and experience how the views connected to out door nature would be. Also the security point of view was tested e.g. if the staff could enter the patient room by seeing the whole room from the window in the door. Furthermore, analyses of unobtrusive observation of patients and natural orientation and movement in the building was also enabled by VR. In this study it is recognized by the participants that VR is a good tool to use during the design process as it gives a new experience of the architectural design problem space by "*bringing it to life*" and *"that it is hard to see the dimensions in just a 3D model or drawing, it is way easier to see and feel it in VR"*. In this context, VR could be argued to bring a pedagogic effect to the design process, as it gives the student the possibility to experience their design from an egocentric perspective in scale 1:1, which is not possible in other medias. Other media can be difficult to interpret and understand and place high cognitive demands on the designers' ability to transform the information into a self-made mental image of the project. Furthermore, the self-made mental image could also be misinterpreted and differ depending on the individual's cognitive spatial capabilities. Bertel et al. (2008) has also agued that this can cause potential design biases and that this type of mental design representation can significantly differ from the reality e.g. the actual built building environment. Furthermore, by using VR the designers' get a feedback loop that their cognitive spatial and mental image (e.g. *Spatial visualization and orientation)* of the design is accurate or not. As the result from this study showed, the students used VR as a tool for understanding space and to explore the design and analyze the design from the above-mentioned EBD design criteria's. They used VR for design review and to examine their design and if they had decoded and interpreted their design correctly during the sketching process. As the result show, most of the student groups implemented several design iterations after they used VR as they found design errors and misinterpretations of spaces and sightlines, which were hard to find using traditional design medias such as sketches, 2D-drawings, pictures, 3D-models. By combining and using both VR and traditional design sketching tools it is possible to support the two design spaces together and give the designer the possibilities to explore, understand, discuss and work with the design in a better way from both an egocentric and allocentric point of view. As the observations showed during the project, the student used sketches and 2D-drawings initially to create the first draft and studying relationship between spaces in 2D from bird-view perspectives. This type of reasoning process can also be seen in other studies related to the design process. For instance, Brösamle & Christoph (2007) found that during the pre-design analysis in 2D of pathways, navigation and orientation and visitor flows, the designers reason from an allocentric view about axis, flows and paths and missed to consider more location factors that are used during actual navigation and orientation in an building. It could be argued that these type of allocentric representation and design process support better reasoning about the design when it comes to studying relationship between spaces and objects and orientation of different objects and functions (e.g. allocentric spatial reasoning). However, as the results in this study show, VR supports another level of understanding and perception of space from a self-centered view-dependent process e.g. egocentric perception where the user could experience the design in scale 1:1. In this context the participants thought that VR gave them ability to study relationship between spaces and how the future patients and staffs would actually experience, orientate and navigate in the building. By combining and using both of these two design spaces in the design process, it gives a new possibility to achieve a better outcome of the building design when it comes to perception, orientation and navigation. Furthermore, the result from this study exemplifies that this type of analyses is most efficient in VR.

Additionally, the study also shows how the student used HMD-VR in their design process connected to EBD. As mentioned before, EBD principles in healthcare has very high focus on the patient's and nurse's perspective and experience of the self-centered view-dependent process, it could be agued that design review in HMD-VR is very suitable in this context. Besides, as the result shows, the designers analyzed and tried to understand how the future patients and staff would experience the healthcare facility from both a healing process and from a security and productivity point of view as mentioned above. In this context, VR could be argued to be a great EBD tool for design reviews and decision and to overcome potential design biases imposed, which is not as easy in other medias.

More importantly, VR require the designers to leave the traditional drawing board and become reflective and aware of their own practical experience of elaborating on various alternative solutions to a given task in the architectural design problem space. It could be argued that the immersive VR system facilitated a self-centered egocentric reference frame and reflection space and where the user had the opportunity to consider, reflect, validate and confirm the design. Traditional media, especially 2D, which modern day designers use most in design processes, are more static and designers might require greater cognitive spatial capability to work with it. VR has the possibility to provide much more dynamic visual-spatial feedback than traditional media does. This might lower the threshold of some cognitive spatial capabilities such as spatial orientation and spatial visualization for designers. It potentially shifts the attention from the creation of objects that define space to the creation of space itself and shifts the direction of the design process from outside-in perception (such as traditional design medias, sketches, 2D-drawings, physical models) to inside-out perception (such as 3D models/BIM together with VR). Looking forward, VR applications are likely to support even more integration and interaction thru sketching and editing directly in immersive VR. This will open up new possibilities where support for self-centered egocentric reference frame and reflection space will have more focus and possibly will change how the future design process will be conducted.

Additionally, many studies has claimed that VR should be used as an communication media between different stakeholder and specialists, but as this study show it is also important to use VR during the creative design process by the designers as an reflection space to get another level of understanding and perception of the architectural design problem space and the artifact.

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