BIM with VR for architectural simulations
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Abstract—This paper discusses the possibilities of architectural representation models in new media such as virtual reality, seen in the context of perception, and neurology. The discussion takes starting point in the findings of a study of the similarities between the perception of architectural space experienced in physical space conditions and in virtual reality. This research intents to clarify to what extend subjective and objective attributes of architectural space can be conveyed through a direct use of BIM (Building Information Models) in Virtual Reality. Sixty test subjects experienced the same architectural space, as either a physical environment or a virtual environment, while data from their experiences was collected through a quantitative/qualitative questionnaire and through collecting the eye tracking data from their experience. This paper deals with an extended analysis of the eye tracking data from the research. Neurology studies indicate that virtual reality three-dimensional representation models are less demanding on the cognitive load of the brain than three-dimensional models seen on flat two-dimensional computer screens. This research suggests that the correct use of virtual reality architectural BIM models can meaningfully improve architectural representation.

Architectural representation; Building Information Modelling; virtual reality; architectural preception; neurology

I. INTRODUCTION

This paper introduces a study of the similarities between the perception of architectural space experienced in a physical space condition and experienced using the Virtual Reality (VR) Head Mounted Display (HMD) technology Oculus Rift. The study intents to clarify to what extend subjective and objective attributes of architectural space can be conveyed through a direct use of VR BIM (Building Information Modeling) models.

Since it is not possible to build architecture without having some sort of representation, of at least the idea of the building, architecture and its forms of representation have always been inseparable. The representation is that it is not in itself the final product, but nevertheless an essential means of achieving the realization of the full-scale architectural idea. It might be possible to extend the understanding of that representational hierarchy by suggesting, like Pallasmaa, that even the final architecture is not the final product, but a framing of the human interaction taking place within it:

‘Architectural space is lived space rather than physical space, and lived space always transcends geometry and measurability.’[1].

With this potential inherent immeasurability, how do we then approach the architectural space and its representation through a meaningful measurement? There are obviously contents of architecture that can and must be measured. The rational organization of matter such as slabs and walls, roofs and foundations must be calculated with some precision in order to create architecture. But what Pallasmaa addresses is all that transcends the geometry and measurement. The research presented in this paper is directed towards establishing a measurement of the similarity between the architecture itself and its representation in virtual reality. In this way it is possible to measure the overlap between the real and the virtual experience, while not directly addressing the quality of the architecture. While the measure of the test subjects’ eye movements and answers to the qualitative questions to a certain degree can be said to deal with their behavioral response to the specific architecture, it has not been the main focus to analyze the architectural quality. However, this will be further elaborated in the discussion part of this paper. By focusing on the value of the architectural representation in virtual reality, it is the intent to raise a discussion about the interesting means of communicating and interacting with the architectural representation also through the layers of experience addressed by Pallasmaa.

II. EXPERIMENT SETUP AND RESEARCH METHODS

This paper adds to the study of perception of architectural space in virtual reality which has been presented in previous scientific research [2] and [3] with a focus on the new recently extracted dataset from the study and a new analysis of the eye tracking data itself in relation to two specifically selected situations. A short explanation of the research methods and experiment set up will be provided in the following sections and is considered necessary in order to disseminate the findings from this latest part of the study.

A. Setup

The study was established using a specific medium sized auditorium at the Royal Danish Academy of Fine Arts School of Architecture as the physical location Situation A and a BIM model of the same auditorium as the location in virtual reality

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Architectural Representation IBD // Institute of Architecture and Design

Anders Hermund; Lars Simon Klint; Ture Slot Bundgaard

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This paper discusses the possibilities of architectural representation models in new media such as virtual reality, seen in the context of perception, and neurology. The discussion takes starting point in the findings of a study of the similarities between the perception of architectural space experienced in physical space conditions and in virtual reality. This research intents to clarify to what extend subjective and objective attributes of architectural space can be conveyed through a direct use of BIM (Building Information Models) in Virtual Reality. Sixty test subjects experienced the same architectural space, as either a physical environment or a virtual environment, while data from their experiences was collected through a quantitative/qualitative questionnaire and through collecting the eye tracking data from their experience. This paper deals with an extended analysis of the eye tracking data from the research. Neurology studies indicate that virtual reality three-dimensional representation models are less demanding on the cognitive load of the brain than three-dimensional models seen on flat two-dimensional computer screens. This research suggests that the correct use of virtual reality architectural BIM models can meaningfully improve architectural representation.

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A. Setup

The study was established using a specific medium sized auditorium at the Royal Danish Academy of Fine Arts School of Architecture as the physical location Situation A and a BIM model of the same auditorium as the location in virtual reality.
In the situation A, a test person is experiencing a specified existing physical architectural space while wearing eye tracking glasses, to track his eye movements and fixations.

Situation B (Figure 1). In the situation A, the same architectural space, is presented to the test person through the head mounted display (HMD) virtual reality Oculus Rift fitted with eye tracking equipment from The Eye Tribe, using a 3D digital architectural building information model. A total of sixty students were used for the study. Thirty students for each situation, respectively the real life physical situation and the virtual reality situation.

B. Methods

In combination with a quantitative/qualitative interview matrix, eye tracking in both situations were used to assess to what extend the perception of space through virtual reality technology is experienced similar to the physical situation. In each situation were used the same two specific locations. The simulation of the test subjects correct eye height was used in the virtual reality situation. In both situations we used the same two specific locations (Figure 2). The first location just inside the entrance to the space (a), and the second location approximately in the middle of the room (b). In addition to a silent ten-seconds-long logging of eye movement at the beginning of each location (in the study referred to as Instances 1 & 2), a series of questions were asked to the test subjects, and the answers, along with eye tracking data, were logged. The questions addressed the subjects’ perception of the space they were in, either physically or virtually. At the beginning they were asked to describe their experience of the atmosphere of the room with three freely chosen words, and the experience of the height of the room with one word. Afterwards they were asked 17 questions answerable on a scale from 1-7, and three questions about estimation of depth, width, and height of the room.

Figure 1. Situation A and B respectively the physical virtual auditorium

Figure 2. Auditorium plan with locations a and b

1) The questionnaire

The creation of the questionnaire matrix is inspired by Melhuish’s thoughts and definition of corporethics [4] and Zeki’s neurological work and definitions of micro-/macro-consciousness [5]. The questions of the questionnaire addressed four different areas of architectural perception: The space itself, lighting, sensation & estimation, and materials.

2) Eye Tracking

By using eye tracking it is possible to track where the test subjects are actually looking, in both a real and a virtual situation. The results can be compared and it can be estimated how similar the eye movement behavior is in the two situations. Once the equipment is set, the eye tracking data is being collected automatically into computer software. However, a subsequent analysis proves to be a quite time-consuming process requiring the development of a consistent way of screening out and picking the right ranges for analysis. An eye tracking time sequence of 10 seconds at the first ten seconds at each location and after each question, was logged for both situations A & B.

3) Reflective and immediate perception

The interview matrix data contains data of a conscious reflection about perception of space. The collected eye tracking data in relation to each question, points to a layer of behavioral perception at a less conscious level. Answering the question about the architectural space involves thus both a conscious reflection and a less conscious eye movement behavior. In the study this is termed as the immediate perception results from eye
tracking and the verbal reflective perception from the answers to the questions.

C. Summary of findings

A summary of the findings from the previous stages of the research are considered necessary to facilitate an understanding of the full study. For a more thorough explanation, please refer to the previous publications mentioned.

1) The questionnaire

The results, of the questionnaire part of the study, as disseminated earlier [3] shows high similarity between the two scenarios with a difference of less than 1% in 11 of the 20 questions and instances, 1-2% in 4 of the questions, 2-3% in 2 of the questions. Only three questions had a difference higher than 3%: respectively 3.4%, 4.1%, and 5.2%. The latter, highest difference, relates to a question about perception of the quality of the materials in the room. The results related to both lighting and feeling well and safe in the room hold, a bit more surprisingly, a difference below 1%, even though the virtual model did not provide accurate light or any shadows. The results from open questions about the experience of the atmosphere in the room are surprisingly close when compared. The top three of completely freely chosen words describing the atmosphere in the two scenarios, out of 90 words describing each scenario, were respectively: Bright (67%), Open (27%), Quiet (33%) in the physical and Bright (50%), Open (30%), Empty (17%) in the virtual. The overall conclusion, from that phase of the study, is that even a simple BIM model through HMD VR can convey rather precise information about both subjective and objective experiences of architectural space, ambience and atmosphere.

2) The eye tracking opacity mapping

The results from this phase of the eye tracking study, as disseminated earlier [2], show a higher correlation of eye fixations between virtual reality and its corresponding real life counterpart when asked a specific question, than between an average of non-corresponding situations. Figure 3 shows an example of the visualization of eye tracking data in respectively an aggregated heat map (A) and an opacity map (B). It is this way possible to measure the average intensity value in the image (C) to measure the balance between the number of black and white pixels in the grayscale image. Combining the opacity map feature with the Adobe Photoshop histogram and difference filters provides a precise and relatively fast way of comparing the overall areas of interest (AOIs) in the eye tracking data. This gives a general indication of the differences of eye fixations between the real and virtual situation (Figure 4). Cross-referencing the AOIs of all the eye tracking images from the questions and instances showed a clear divergence that could be further sustained when screening out the fuzzier datasets. The resulting divergence between same instances/questions and mixed instances/questions amounted to 38.78%. That indicated that there is indeed a correlation between eye fixations in the experience of architectural space in respectively real life and in virtual reality.

Figure 3. (A) The heatmap on a gradient scale from red to green showing eye tracking data related to a set of answers to a specific question. (B) An opacity map of the same data without the colours but with a gradient intensity. (C) The Histogram used to calculate the average intensity value in the image.

Figure 4. Grayscale intensity and difference filters used to measuring the difference (C) in eye fixations between real life (A) and virtual reality (B).
III. COMPARATIVE ANALYSIS OF TWO SITUATIONS

This paper further adds to the findings of the study by focusing on the specific areas of interests in the data obtained from the eye tracking of one of the instances and one of the questions. Instance 1 and Question 7 have been selected, since those two represents the range from a very open nonverbal eye tracking i.e. the first 10 seconds of observation in the architectural space at the beginning of the eye tracking session, before any questions were posed, and the more definite and task based eye tracking in relation to answering the question “What row would you like to sit for a lecture?”. The latter 10 seconds eye tracking was captured immediately after the question had been posed. The name Instance 1 was chosen for the simple reason of distinguishing this eye tracking segment from the eye tracking segments made in relation to actual questions.

A. Instance 1

The Instance 1 is, as mentioned, the period from when the test person opens his/her eyes in the architectural space and begins to look around. There is no task or question at this phase, so the eye movements are expected to be more different between the 60 test subjects. Based on the heat maps from the study it is possible to suggest areas of interest, AOIs, in relation to what parts of the architectural space are actually being watched and could be interesting to measure more precisely. The space has accordingly been divided into AOIs (Diagram A) and exact data from these different areas can be extracted.

In many cases, when eye tracking research is applied, the focus of the measurement is on a particular product or brand located on a specific place in space. Since our research area is the experience of the full architectural space, it is not enough to concentrate on a single particular object. Therefore, it has been necessary to divide the whole architectural space into 29 different AOIs based on the findings from an analysis of the heat maps produced by the eye tracking in the first place. From the large amount of data extracted through these AOIs we have decided to focus on the time spent on fixations in order to compare that correlation between the virtual and the real situation. The time spent on fixations is measured in milliseconds.

The eye tracking AOI data has been calculated from all the test subjects to an average (Table 1) with a calculation of the difference between the virtual and the real situation in percent. Absolute values, permits a general overview of the AOIs with the highest difference of fixations between the virtual and the real situation. It is noteworthy that the differences span from 0% to a maximum of 6%, while the average of difference between the two situations is only 1.5%.

![Diagram A. Instance 1 with the defined AOIs within red lines.](attachment:image.png)
The seven highest ranking differences, i.e. above 2% of difference, is thus measured on: 1. Wall side (without acoustic wall), 2. Wall around screen, 3. Screen, 4. Large window side, 5. Rear wall (without window or door), 6. Acoustic wall 1, and 7. Wooden floor, corresponding to the locations marked (Diagram A). If the differences are sorted between the virtual and the real according to which situation receives the highest fixation time, we find that the top scorers in each situation are for the virtual situation: 1. Large window side, 2. Rear wall (without window or door), and 3. Wooden floor. And for the real situation: 1. Wall side (without acoustic wall), 2. Wall around screen, 3. Screen, and 4. Acoustic wall 1.

### TABLE I. AMOUNT OF TIME OF FIXATIONS AT AOs AT INSTANCE 1

<table>
<thead>
<tr>
<th>Comparison of amount of time spent on fixations at AOs in relation to instance 1</th>
<th>Eye tracking data</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Virtual FIX ms</td>
<td>Real FIX ms</td>
<td>Difference in %</td>
<td></td>
</tr>
<tr>
<td>Wall side (without acoustic wall)</td>
<td>791,0</td>
<td>1332,0</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Wall with box</td>
<td>361,2</td>
<td>388,3</td>
<td>0,5</td>
<td></td>
</tr>
<tr>
<td>Screen</td>
<td>401,3</td>
<td>735,9</td>
<td>3,8</td>
<td></td>
</tr>
<tr>
<td>Artwork</td>
<td>519,7</td>
<td>368,7</td>
<td>1,3</td>
<td></td>
</tr>
<tr>
<td>End wall (without window)</td>
<td>295,5</td>
<td>448,1</td>
<td>1,6</td>
<td></td>
</tr>
<tr>
<td>Wooden floor</td>
<td>416,7</td>
<td>178,6</td>
<td>2,3</td>
<td></td>
</tr>
<tr>
<td>Wall with loudspeaker</td>
<td>290,0</td>
<td>339,2</td>
<td>0,7</td>
<td></td>
</tr>
<tr>
<td>Window (back wall)</td>
<td>376,6</td>
<td>299,9</td>
<td>0,7</td>
<td></td>
</tr>
<tr>
<td>Row 1</td>
<td>190,4</td>
<td>318,6</td>
<td>1,2</td>
<td></td>
</tr>
<tr>
<td>Row 2</td>
<td>202,0</td>
<td>71,7</td>
<td>1,3</td>
<td></td>
</tr>
<tr>
<td>Row 3</td>
<td>138,4</td>
<td>282,1</td>
<td>1,5</td>
<td></td>
</tr>
<tr>
<td>Row 4</td>
<td>82,5</td>
<td>155,8</td>
<td>0,7</td>
<td></td>
</tr>
<tr>
<td>Row 5</td>
<td>87,2</td>
<td>77,3</td>
<td>0,1</td>
<td></td>
</tr>
<tr>
<td>Row 6</td>
<td>37,5</td>
<td>79,3</td>
<td>0,4</td>
<td></td>
</tr>
<tr>
<td>Row 7</td>
<td>170,5</td>
<td>131,0</td>
<td>0,4</td>
<td></td>
</tr>
<tr>
<td>Rear wall (without window or door)</td>
<td>352,3</td>
<td>81,4</td>
<td>2,7</td>
<td></td>
</tr>
<tr>
<td>Ceiling (low part)</td>
<td>388,5</td>
<td>257,1</td>
<td>1,3</td>
<td></td>
</tr>
<tr>
<td>Tile floor</td>
<td>197,2</td>
<td>149,6</td>
<td>0,4</td>
<td></td>
</tr>
<tr>
<td>Projector</td>
<td>165,4</td>
<td>59,3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Acoustic wall 1</td>
<td>76,7</td>
<td>311,7</td>
<td>2,6</td>
<td></td>
</tr>
<tr>
<td>Acoustic wall 2</td>
<td>140,2</td>
<td>238,0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Acoustic wall 3</td>
<td>160,0</td>
<td>205,4</td>
<td>0,7</td>
<td></td>
</tr>
<tr>
<td>Acoustic wall 4</td>
<td>196,6</td>
<td>145,6</td>
<td>0,5</td>
<td></td>
</tr>
<tr>
<td>Ceiling (high part)</td>
<td>199,0</td>
<td>191,0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Large window side</td>
<td>345,8</td>
<td>0,0</td>
<td>3,5</td>
<td></td>
</tr>
<tr>
<td>Door</td>
<td>136,6</td>
<td>0,0</td>
<td>1,4</td>
<td></td>
</tr>
<tr>
<td>Tables</td>
<td>52,1</td>
<td>84,7</td>
<td>0,3</td>
<td></td>
</tr>
<tr>
<td>Wall around screen</td>
<td>448,5</td>
<td>927,2</td>
<td>4,8</td>
<td></td>
</tr>
<tr>
<td>Window wall (without window)</td>
<td>586,8</td>
<td>398,6</td>
<td>1,9</td>
<td></td>
</tr>
</tbody>
</table>

### B. Question 7: Where would you like to sit for a lecture?

The eye tracking time segment immediately following the abovementioned question, is of a presumably more predictive nature, since the question itself directs the test person’s attention towards something specific in the architectural space. The AOs for this part of the study has, like in the previous case, been defined using the heat maps generated in the first earlier stage of the study. From observing the heat maps (Figure 5) it can be observed how the fixations are centered in almost the same specific area in both situations.

In line with this observation, it makes sense to limit the definition of AOs to the area around the seven rows of chairs with an additional combined area defining the rest of the architectural space as presented (Diagram B).

In relation to the eye tracking about where to sit, it is noteworthy that in response to the questionnaire the majority in both the real situation and in virtual reality chose to sit on row 3 or 4. The eye tracking data from this part of the study is presented (Table 2) as milliseconds of fixations in respectively virtual reality and the real situation. The difference has been calculated in percent ranging from 0.5% up to 8.8%, but with an average of 3.85
This phase of the study sustains the findings from the previous phases in several ways. In *Instance 1* the measurements of differences between eye tracking in the architectural experience of the two situations, respectively virtual reality and the real situation span from 0% to a maximum of 6%, while the average of difference is only 1.5%. That is a very low difference between the two situations.

A closer examination of the numbers shows the top scorers in each situation according to the highest amount of difference in the eye fixations. Those are for the virtual reality situation:

1. **Large window side**
2. **Rear wall (without window or door)**
3. **Wooden floor**

And for the real situation:

1. **Wall side (without acoustic wall)**
2. **Wall around screen**
3. **Screen**
4. **Acoustic wall 1**

One of the most striking observations is, that the **Large window side** receives a lot of attention in virtual reality, but closer to none in the real situation. An explanation to this might be, that in reality the test subjects are logically aware about what they will find outside – after all they have just arrived in the place and were on the outside a few minutes before. They do not need to check what is outside, because they feel they already know. In virtual reality, however, they know that it is a simulation, and are eager to check if the outside corresponds to their expectations and can add to or sustain their experience of being in a specific room. One way to check this hypothesis, would be to include the arrival situation in the simulation, so they had the fundamentally same visual experience of the outside, and perhaps no need to check the view outside the window.

The difference between fixations on the **Rear wall** in virtual reality and the **Wall side (without acoustic wall)**, **Wall around screen**, **Screen** and **Acoustic wall 1** in the real situation, might be partly explained by respectively the visual appearance of the interviewer in the real situation and the lack thereof in virtual reality. The physical location of the interviewer was the same in both situations, i.e. behind the test subject, but he was only visual in the real situation. To observe the **Rear wall**, the test subjects would have to turn their face towards the interviewer. The eye tracking could indicate that the test subjects are less likely to turn directly towards the interviewer, when they can see him. All the four top scorers for the real situation are pointing away from the interview person. Another reason could be, that the new VR technology simply instigates a natural curiosity in the test persons, causing them to look around more than they would normally do. Another explanation might concern the difference between the peripheral vision in the field of view using respectively the virtual reality head mounted display and observing freely. The virtual reality system is bound to its screen size and the fact that this screen is currently only in front of the test persons eyes, limits the field of view considerably. It might be that the peripheral view in the real situation gives the test subjects sufficient information for experiencing the architectural space, without turning their heads as much. Perhaps the development of new HMD such as the StarVR [6] can provide a solution to the challenges in relation to peripheral vision in virtual reality. A way to check these hypotheses could be to repeat part of the study using a virtual reality HMD supporting the full peripheral vision. It could also be useful either to include the interviewer in the virtual reality model or exclude him in the real situation, e.g. using telecommunication for the questions. That the **Wooden floor** receives more fixations in virtual reality than in the real situation, seems harder to conclude anything certain about.

The eye tracking in relation to **Question 7** shows also a high correlation between respectively virtual reality and the real situation. The difference between eye tracking in the architectural experience of the two situations ranges in percent from 0.5% up to 8.8%, but with an average of 3.85.

Observing the results of the AOI eye tracking mapping in relation to the **Question 7** allows for an overall analysis of the behavior in the specific situation of choosing where to sit. Generally, this part of the study indicates, that the test subjects are following the question by looking at the seats, and therefore meanwhile not watching the rest of the architectural space. As mentioned previously in this paper, it is noteworthy that a clear majority in both the real situation and in virtual reality chose to sit on row 3 or 4 in response to the questionnaire. If this is compared to the eye tracking data from this phase of the study, we learn that the first four rows are showing far most fixations. It can also indicate that the last rows in the back (rows 5 to 7) are very fast screened as being not wanted as seating places. The first row is considered slightly longer but also rejected. Row two is considered for the longest span of time, but is also, after some consideration, rejected in favor the decision to choose row 3 or 4 as the more preferable place he sit.

<table>
<thead>
<tr>
<th>Comparison of amount of time spent on fixations at AOIs in relation to question 7</th>
<th>Eye tracking data</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Virtual FIX ms</td>
<td>Real FIX ms</td>
<td>Difference %</td>
</tr>
<tr>
<td>Row 1</td>
<td>376,8</td>
<td>723,1</td>
<td>3,1</td>
</tr>
<tr>
<td>Row 2</td>
<td>418,7</td>
<td>847,2</td>
<td>8,8</td>
</tr>
<tr>
<td>Row 3</td>
<td>573,5</td>
<td>723,1</td>
<td>3,1</td>
</tr>
<tr>
<td>Row 4</td>
<td>251,8</td>
<td>322,0</td>
<td>1,4</td>
</tr>
<tr>
<td>Row 5</td>
<td>376,8</td>
<td>116,4</td>
<td>5,1</td>
</tr>
<tr>
<td>Row 6</td>
<td>417,3</td>
<td>188,2</td>
<td>4,5</td>
</tr>
<tr>
<td>Rest of the room</td>
<td>327,0</td>
<td>300,4</td>
<td>0,5</td>
</tr>
</tbody>
</table>
A comparison between the virtual reality and the real situation is not considered so obvious, due to the high correlation between the trends in both situations. However, it can be observed, that also here, the test subjects in virtual reality are looking more towards the location of the interviewer than the subjects in the real situation. This can presumably be attributed to the same causes as described for the Instance I.

The conclusion from this part of the study is that the eye tracking using AOIs are sustaining the previous assumptions about the correlations between virtual reality and real-life situations and the usefulness of virtual reality in combination with building information models for simulating an architectural experience or architectural atmosphere. The cohesion between the time used to extract and convert the data for a meaningful analysis is probably not one to one with the increased degree of awareness about the application of virtual reality. Nevertheless, the study shows that a more precise use of eye tracking with BIM models, can begin to show how behavior is influenced by the experiencing and interaction with architectural space. This study further sustains the notion that it is worthwhile to continue working for an integration of virtual reality and behavioral science within the field of architecture in order to maintain both the objective quantities and measurements, but also to include the more incommensurable subjective behavioral aspects of architecture’s influence.

V. DISCUSSION

With this phase of the study, it has become increasingly apparent that a virtual architectural environment through the visual dimension can provide response perceived to a certain degree as a real experience. Using BIM models with VR for architectural simulation can be useful as a means of communicating more than just the physical frame of a building. Also to a certain degree the invisible interaction potentially taking place within architecture can be communicated. In Pallasma’s words all that which transcends geometry and measurability, The perception of architectural space continues to intrigue us. As it did as a phenomenological search for a structure of perception [7] it will probably take us into new realms of neurology and neuroaesthetics [8] in our attempt to apply new technology in the wisest and most productive way. The field of perceiving aesthetics should be addressed, by architecture and neurology, with combined studies of architectural perception and the biological foundation of sensing. The phenomenon of perception in virtual reality has relatively early on been described [9] as a combination of the vividness and interactivity. Here it is interesting that interactivity seems to be the predominant of the two, overruling the need for a high level of realism in the virtual reality situation [10]. Understanding virtual environments and the direct influence in simulations of our potential architecture [11] must continuously be challenged.

Neurology opens a new method to investigate how architecture and perception intertwines. Different studies indicate that the human brain needs less working memory perceiving models in virtual reality compared to seeing two-dimensional models on a computer screen due to reduced task complexity and the need for translation of geometry from two-dimensional to three-dimensional [12]. Similarly, the assessment of a small virtual reality game in HMD and on a flat screen [13], showed that virtual reality did induce less cognitive load on the brain than the task performed on a flat computer screen. This could suggest that the use of digital building information models in virtual reality can actually be more precise and less demanding when communicating the not so tangible qualities of architectural space.

The research focus of our group will continuously be on developing pragmatic methodologies for applying virtual reality in the architectural design and building phases.

Using the results from this study, we will be developing a virtual scenario response system which is basically a suggestion for a framework for collaboration on simulating architectural challenges in virtual reality. Establishing a project about a virtual reality scenario responder can be a way to really simulate and communicate about the experience of space, architecture and urban spaces in the sketching phase or in an evaluation of the role of urban planning. Such a response system must communicate through many different scenarios such as accessibility: how would e.g. a visually impaired person be experiencing the architecture. It must be addressing how to simulate materials in virtual reality, defining what threshold is sufficient to experience immersion in an architectural space. Such a system must also potentially be addressing the simulation of different panic and escape scenarios. How to track peoples’ reaction in the event of fire, a disaster, or riot at a sports event. Also, urban spaces can be simulated e.g. municipal planning in virtual reality, etc. The virtual scenario response system should also address the architectural atmosphere as the more everyday experience of the influence on people and their moods from being in and interacting with architecture. The entire concept is of course based on the idea that good architecture essentially helps raise the quality of life.

The response system should be able to save, or log, the response given when test persons are experiencing a given scenario. Virtual reality is thus brought from being a means of representation to being a work tool with the ability to increase the quality of the architectural project in the early stages, where it is cheap to change the project. If virtual reality technology is to be used for anything more than a personal visual experience, it is necessary to provide a documented feedback on how a given architecture is experienced. The response system contains a questionnaire for collecting experiential feedback from the virtual model. The matrix is developed from an architectural behavioral approach to the experience of space, based on studies like the one this paper presents. This feedback addresses several challenges, the most important being that continuous reporting may seem to interrupt the virtual spatial experience. The virtual reality scenario responder project seeks to resolve this conflict so that the user will be able to report continuously without the experience losing his or her focus. The response system is the functional kernel in which multiple scenarios, with different focus, can be connected, or plugged-in.

In other words, we would like to apply our research of the use of virtual reality technology in combination with digital building information models to develop a software interface to demonstrate how to integrate quality (inclusive design) into the built environment and support the results with neurological
studies of specific cases. This will be an ongoing project for the next years, and we will continue to disseminate the progress and scientific results of our project and research through conference papers and seminars.

VI. REFERENCES


