The Perception of Architectural Space in Reality, in Virtual Reality, and through Plan and Section drawings

A case study of the perception of architectural atmosphere

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This paper presents the findings from a comparative study of an architectural space communicated as the space itself and its two different representations, i.e. a virtual reality model and traditional plan and section drawings. Using eye tracking technology in combination with qualitative questionnaires, a case study of an architectural space is investigated in physical reality, a virtual reality 3D BIM model, and finally through representation of the space in plan and section drawings. In this study, the virtual reality scenario seems closer to reality than the experience of the same space experienced through plan and section drawings. There is an overall higher correlation of both the conscious reflections and the less conscious behaviour between the real physical architectural space and the virtual reality space, than there is between the real space and the space communicated through plan and section drawings. We can conclude that the scenario with the best overall size estimations, compared to the actual measures, is the virtual reality scenario. The paper further discusses the future applications of virtual reality in architecture.

Keywords: Architectural representation, Virtual Reality, Perception, Tradition

INTRODUCTION
Through dissemination of results from the last part of a tripartite experiment this paper discusses the possibilities of representation models of architecture. The experiment compares how people experience architectural space using eye tracking technology in combination with qualitative questionnaires. It is a case study of an architectural space is investigated in three scenarios (A) physical reality, (B) a virtual reality 3D BIM model, and (C) through representation of the space in plan & section (figure 1). This paper presents the results from the last part of the experiment (C) using the results to compare with the previous results and to further discuss the architectural representation in traditional and new media, in the broader context of tradition, perception, and neurology. Through this comparative study of physical and virtual scenarios, the paper discusses how new
versions of architectural representation can fundamentally change architectural designing. The results from the first parts of the study can be found in previously published work (Hermund et al. 2016, 2017, 2018), and will hence not be presented here, except for briefly mentioned and when needed for a comparison with the last results from the part (C) of the study.

The results conveyed in this paper sustains the overall notion, that representing architectural projects through virtual reality can, if used correctly, significantly improve the usability of digital architectural representational models.

**METHOD AND EXPERIMENT SETUP**

A medium size auditorium was used as the case study in the experiment. The architectural space was investigated through three different representations: A real life scenario, a BIM model of the same auditorium as the virtual scenario, and finally the same space communicated through the use of traditional plan and section drawings. Questions were asked during the session, and eye tracking was applied to capture the test subjects fixations in a period of 10 seconds after each question. In this way both a reflective (answers to questions) and a less conscious behaviour (eye movements) of the test persons could be logged for further comparison.

**The questionnaire**

In all three scenarios, the same questionnaire (figure 2) was used to gather qualitative data from the test subjects answers. This quantitative/qualitative interview matrix was established to assess to what extent the perception of space through VR technology holds similarities to the experience under normal, or close to normal, circumstances and to the experience of space through more traditional plan and section drawings. The questions could be answered on a scale from 1 to 7 where 1 was ‘not at all’ and 7 ‘in a very high degree’. The questions about estimation of height and width were to be answered in full meters. The series of questions were posed to the test subjects, and the answers, along with the eye tracking data, were logged. In addition, a silent ten-seconds-long eye tracking logging at the beginning of each location was done. In the plan & section scenario, the test subjects were watching the plan and
Eye tracking
Eye tracking technology was used in order to collect a quantitative mass of less reflective data, by tracking the eye point fixations of the test subjects. Instead of a completely free movement, the investigation was limited to two view points, each with 360 degrees of view, but with the test subject remaining immobile (except for turning on the spot) throughout the investigation. For the physical scenario and the plan & section scenario were used Tobii Pro Glasses. For the virtual scenario was used an eyetracker built into the virtual reality head mounted display. All the eye-tracking data collected was processed using iMotions software to map and generate heatmaps, spotmaps, and maps of areas of interest.

Selection of test subjects
In total, a number of 131 test subjects were used for the complete study. 30 subjects for the physical scenario, 63 subjects for the virtual scenario (33 subjects with eye tracking and 30 without), 32 for the plan & section scenario, and 6 test subjects from an architectural studio as a benchmark in the plan & section scenario. All the test subjects were students except for the 6 professional architects. The total gender distribution was to 50/50. The age span among the students ranges from 19 years to 41 years with an average of 22.8 years. The students are primarily in the beginning of their study at the Royal Danish Academy of Fine Arts School of Architecture (KADK) or Aalborg University Sustainable Design (AAU). The age span of the 6 professional architects (JFA arkitekter) ranges from 27 to 52 with an average of 37.2 years. It was an important factor that the test subjects were not familiar with the test space.

In both the two 3D scenarios (physical and virtual reality) we used the same two specific locations: i.e. just inside the entrance to the space, and approximately in the middle of the space. We applied each test person’s correct eye-height in the virtual reality viewer.

The physical scenario
In the physical scenario, an auditorium space at The Royal Danish Academy of Fine Arts School of Architecture was used (figure 3). The test subjects were introduced to the scenario outside the test space and then asked to close their eyes while they were placed at the first point of view, just after the entrance door to the auditorium. Here the first ten seconds of eye tracking (referred to as Instance 1) recorded their fixations upon entering the room. The test subjects were then asked to describe the room with three freely chosen words. The first set of questions were asked and the answers with eye tracking was recorded. The test subjects were then asked to close their eyes again and brought to the next point.
of view a bit further inside the auditorium. Again 10 seconds was recorded (referred to as Instance 2) followed by the last set of questions.

**The virtual scenario**

In the virtual scenario, the architectural space, was presented to the test persons through the HMD VR technology (an Oculus Rift SDK 2 combined with in-built eye tracking equipment from the Eyetribe), showing a 3D digital architectural building information model (figure 4) of the same space as in the real scenario. The briefing took place and the test subjects were allowed some seconds to get used to the virtual reality equipment in the anteroom of the test space model.

**The plan & section scenario**

In the plan and section scenario, the students were introduced to the study and then asked to look to the ground while they were being positioned in front of the drawings hanging on a wall. We had one architectural plan drawing and one section drawing (figure 5) showing the test space in scale 1:50. In this case it was not logically feasible to use the two specific points of view, as in the other phases of the study, so we had to deal with the nature of 2D drawings and let the test subjects overview the entire material from the beginning. The same eye tracking equipment was used to collect data of fixations from the test subjects. We have been using students with no prior knowledge of the space, which is crucial, especially in this phase of the study. A memory of the actual real space, invoked from watching the drawings, could disturb the study if the answers were more related to the memory of the space than to the space experienced through the drawings.

![Figure 3](image3.jpg)

*Figure 3*  
The entrance to the auditorium used as test space.

![Figure 4](image4.jpg)

*Figure 4*  
Revit model created of the real life auditorium.
Figure 5
The drawings from the plan & section scenario. They were presented i scale 1:50 hanging on a wall side by side.

Figure 6
The hierarchy of words chosen to describe the atmosphere of the room in Physical scenario.

Figure 7
The hierarchy of words chosen to describe the atmosphere of the room in the virtual scenario.

**FINDINGS**
Like in the previous phases of the study, we collected the data from the questionnaire and from the eye-tracking of the test subjects in the plan and section phase of the study. After the first instance, the test subjects were also asked to describe the architectural atmosphere of the space they were in, with three freely chosen words.

*Describing the architectural atmosphere*
The three freely words chosen for describing the architectural atmosphere of the space were collected for all test subjects. The outcome of these answers can be compared between the different experiences of the space as shown in figures 6-8.
The colours in the diagrams correlate for easier comparison between the scenarios. The seven highest scoring words from each of the three scenarios are shown, while the rest is put in the ‘other’ category. The physical and the virtual reality scenario seems immediately closer to each other in terms of words chosen. In virtual reality, however, words as ‘sterile’ and ‘clinical’ score high, and ‘friendly’ is not mentioned. It is noteworthy that in the plan & section scenario a relatively large amount of test subjects felt unable to describe the architectural atmosphere of the space. Also in plan and section some test subjects used the word ‘cinema’ to describe the space. This word was never mentioned in the two other scenarios.

If the same data is represented, as in figure 9, the words can be compared in groups with top scoring words from all the three scenarios. The words ‘bright’, ‘open’, ‘large’, and ‘empty’ are much closer in physical and virtual reality than to the plan & section scenario. The words ‘quiet’ and ‘calm’ score high in the physical scenario, while considerably lower in both the virtual and plan & section scenario.

Comparing answers to the questionnaire

The answers from all the test subjects are shown in table 1. The value of the questions are from 1-7 and in the ‘Comparisons’ part, the divergence has been converted to percent. The plan & section phase of the study includes a cross reference to a small group of professional architects as an indication of the difference in using students or trained test subjects. This indicative difference between students and professionals will be considered in a subchapter.

Physical, virtual and plan & section. The numbers show the difference between the answers to the questions in respectively the physical and virtual scenario, and the between the physical and the plan & section scenario. The colour intensity shows the more divergent answers in the specific question. The high score between the physical and the virtual scenario is in the questions related to materials, expectations, and placement of exits. The high score between the physical and the plan & section scenario are concerning materials and view to the screen and presenter. In addition, the room is found much more boring in the plan & section scenario. Furthermore, it is obvious that the overall divergence from the physical scenario is found to be much higher in the plan & section scenario than in the virtual reality scenario.

Estimated size. When looking at the numbers for estimating the size of the room, there is a high correlation between the perceived length, width, and height of the room in respectively the physical scenario and the virtual reality scenario. The estimations diverge from the actual measure with a maximum of 3.9 m (length of the room), and are thus not completely right in relation the actual real measures, but it is noteworthy that the divergence between the physical and virtual is similar within a margin of less than 1 m. In comparison the divergence between the plan & section scenario and the actual measures are much higher with a maximum of 11.5 m. In all the estimations of the plan & section scenario, the divergences are higher than between the physical and the virtual scenario.

Where to sit for a lecture. When comparing the answers to the question of what row to sit in for a lecture, the similarity between the physical and the virtual is also very high, while less between the plan & section scenario and the two others.
Students and professionals
Since the plan & section eye tracking data cannot be translated with precision from a 2D environment to a 3D environment, as used in the previous phases of the study, a comparison between these data sets would not be logically feasible to a useful degree. However, we could use the eye tracking data for an investigation of the behaviour of the students while decoding plan and section drawings. We were also curious to see if there was a traceable difference between the perception and eye fixations of students and professionals. We decided to make a cross check with a small group of professional architects as a pilot study addition to the research. When considering the heat maps from this exercise in relation to the questions it is easy to see a difference in the perception of the architectural test space between the two groups.
Table 1
Answers to the questionnaire in the three scenarios.

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<tr>
<td>Compelled to enter the room</td>
<td>5.2</td>
<td>5.4</td>
<td>4.0</td>
<td>5.3</td>
<td>-0.2</td>
<td>2.9</td>
<td>1.2</td>
<td>16.7</td>
<td>-0.1</td>
<td>1.9</td>
<td>-1.3</td>
<td>18.6</td>
<td>-0.2</td>
<td>2.9</td>
<td>1.2</td>
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<td>Expectations of the room are met</td>
<td>4.6</td>
<td>5.5</td>
<td>4.7</td>
<td>3.5</td>
<td>-0.9</td>
<td>12.7</td>
<td>0.0</td>
<td>0.3</td>
<td>1.1</td>
<td>16.2</td>
<td>1.2</td>
<td>16.5</td>
<td>-0.9</td>
<td>12.7</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Easy to move about in the room</td>
<td>6.0</td>
<td>6.2</td>
<td>5.6</td>
<td>6.3</td>
<td>-0.2</td>
<td>2.2</td>
<td>0.5</td>
<td>6.7</td>
<td>-0.3</td>
<td>4.3</td>
<td>-0.8</td>
<td>11.0</td>
<td>-0.2</td>
<td>2.2</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Room is boring</td>
<td>3.4</td>
<td>3.8</td>
<td>4.9</td>
<td>2.8</td>
<td>-0.5</td>
<td>6.7</td>
<td>-1.5</td>
<td>21.5</td>
<td>0.5</td>
<td>7.6</td>
<td>2.0</td>
<td>29.2</td>
<td>-0.5</td>
<td>6.7</td>
<td>-1.5</td>
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<tr>
<td>Window placement sufficient light</td>
<td>5.9</td>
<td>5.9</td>
<td>5.2</td>
<td>6.3</td>
<td>0.0</td>
<td>0.2</td>
<td>0.6</td>
<td>9.3</td>
<td>-0.5</td>
<td>6.7</td>
<td>-1.1</td>
<td>15.9</td>
<td>0.0</td>
<td>0.2</td>
<td>0.6</td>
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<tr>
<td>Room sufficiently lit</td>
<td>6.1</td>
<td>6.4</td>
<td>5.1</td>
<td>4.8</td>
<td>-0.3</td>
<td>4.4</td>
<td>1.0</td>
<td>14.4</td>
<td>1.3</td>
<td>18.1</td>
<td>0.3</td>
<td>3.7</td>
<td>-0.3</td>
<td>4.4</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Lighting as intended</td>
<td>5.5</td>
<td>5.2</td>
<td>4.4</td>
<td>3.8</td>
<td>0.3</td>
<td>4.2</td>
<td>1.1</td>
<td>15.6</td>
<td>1.6</td>
<td>23.3</td>
<td>0.5</td>
<td>7.7</td>
<td>0.3</td>
<td>4.2</td>
<td>1.1</td>
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<tr>
<td>Feeling well in the room</td>
<td>5.7</td>
<td>5.4</td>
<td>5.2</td>
<td>5.7</td>
<td>0.4</td>
<td>5.6</td>
<td>0.7</td>
<td>0.9</td>
<td>12.6</td>
<td>0.7</td>
<td>9.5</td>
<td>-0.2</td>
<td>0.4</td>
<td>5.6</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Feeling safe in the room</td>
<td>5.8</td>
<td>5.4</td>
<td>5.2</td>
<td>5.7</td>
<td>0.4</td>
<td>5.6</td>
<td>0.7</td>
<td>0.9</td>
<td>12.6</td>
<td>0.7</td>
<td>9.5</td>
<td>-0.2</td>
<td>0.4</td>
<td>5.6</td>
<td>0.7</td>
<td></td>
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<tr>
<td>What row to sit in</td>
<td>3.7</td>
<td>3.7</td>
<td>2.8</td>
<td>2.7</td>
<td>-0.1</td>
<td>0.8</td>
<td>0.8</td>
<td>11.8</td>
<td>1.0</td>
<td>14.3</td>
<td>0.2</td>
<td>2.5</td>
<td>-0.1</td>
<td>0.8</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>Materials are nice</td>
<td>5.0</td>
<td>4.2</td>
<td>3.9</td>
<td>4.0</td>
<td>0.8</td>
<td>11.1</td>
<td>1.1</td>
<td>15.2</td>
<td>1.0</td>
<td>14.3</td>
<td>-0.1</td>
<td>0.9</td>
<td>0.8</td>
<td>11.1</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>Materials live up to expectations</td>
<td>5.1</td>
<td>5.1</td>
<td>4.2</td>
<td>4.2</td>
<td>0.1</td>
<td>1.2</td>
<td>1.0</td>
<td>14.0</td>
<td>1.0</td>
<td>13.8</td>
<td>0.0</td>
<td>0.1</td>
<td>0.1</td>
<td>1.2</td>
<td>1.0</td>
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<tr>
<td>Material quality</td>
<td>5.4</td>
<td>4.0</td>
<td>3.2</td>
<td>4.2</td>
<td>1.4</td>
<td>20.3</td>
<td>2.2</td>
<td>32.1</td>
<td>1.3</td>
<td>16.1</td>
<td>-1.0</td>
<td>14.0</td>
<td>1.4</td>
<td>20.3</td>
<td>2.2</td>
<td></td>
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<tr>
<td>Good view to the screen</td>
<td>6.7</td>
<td>6.6</td>
<td>4.7</td>
<td>6.2</td>
<td>0.1</td>
<td>1.3</td>
<td>2.0</td>
<td>28.3</td>
<td>0.5</td>
<td>7.1</td>
<td>-1.5</td>
<td>21.1</td>
<td>0.1</td>
<td>1.3</td>
<td>2.0</td>
<td></td>
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<tr>
<td>Good view to the presenter</td>
<td>6.1</td>
<td>6.5</td>
<td>4.5</td>
<td>4.8</td>
<td>-0.4</td>
<td>5.1</td>
<td>1.6</td>
<td>22.9</td>
<td>1.3</td>
<td>18.6</td>
<td>-0.3</td>
<td>4.2</td>
<td>-0.4</td>
<td>5.1</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>Enough space around you</td>
<td>5.9</td>
<td>6.1</td>
<td>4.6</td>
<td>5.0</td>
<td>-0.2</td>
<td>3.1</td>
<td>1.3</td>
<td>18.2</td>
<td>-0.1</td>
<td>1.4</td>
<td>-1.4</td>
<td>19.6</td>
<td>-0.2</td>
<td>3.1</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>Good placement of exits</td>
<td>4.4</td>
<td>5.2</td>
<td>4.4</td>
<td>5.0</td>
<td>-0.8</td>
<td>11.5</td>
<td>0.0</td>
<td>0.6</td>
<td>9.0</td>
<td>-0.6</td>
<td>8.5</td>
<td></td>
<td>-0.8</td>
<td>11.5</td>
<td>0.0</td>
<td></td>
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<tr>
<td>Length of the room in meters (14m)</td>
<td>17.9</td>
<td>3.9</td>
<td>17.6</td>
<td>3.6</td>
<td>25.5</td>
<td>11.5</td>
<td>19.7</td>
<td>5.7</td>
<td>0.2</td>
<td>1.8</td>
<td>18.6</td>
<td>5.8</td>
<td>0.2</td>
<td>1.8</td>
<td>18.6</td>
<td></td>
</tr>
<tr>
<td>Width of the room in meters (8.5m)</td>
<td>10.0</td>
<td>1.5</td>
<td>10.7</td>
<td>2.2</td>
<td>14.1</td>
<td>5.6</td>
<td>11.3</td>
<td>2.8</td>
<td>-0.7</td>
<td>4.1</td>
<td>-1.3</td>
<td>13.3</td>
<td>-0.7</td>
<td>4.1</td>
<td>-1.3</td>
<td></td>
</tr>
<tr>
<td>Height of the room in meters (5m)</td>
<td>6.5</td>
<td>1.5</td>
<td>5.6</td>
<td>0.6</td>
<td>6.8</td>
<td>1.8</td>
<td>5.2</td>
<td>0.2</td>
<td>0.9</td>
<td>0.4</td>
<td>1.3</td>
<td>1.7</td>
<td>0.9</td>
<td>0.4</td>
<td>1.3</td>
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In the Instance 1 (figure 10), the first 10 seconds after entering the room, it is obvious that the students (top) are more dispersed in their eye movements than the professionals (bottom) are. The students spend a relatively long time looking at the tree icons outside the building, and not very long time at the section view in comparison to the professionals.

Figure 11
Heat map showing test subjects estimating the height of the room - students (top) and professional architects (bottom).
When looking at the estimation of the height of the room (figure 11), there is a lot of attention to the section view. The professionals are almost exclusively looking at the section while the students in addition to that are still looking moderately at the plan. It is interesting that the professionals are estimating the height of the room closer to its actual height than in any of the students’ scenarios, especially the students from the plan & section scenario.

In relation to the question of where to sit (figure 13), the heatmaps are obviously focused in the seats in both scenarios. The professionals are using the section drawing a little bit. The general picture from the questionnaire shows that students and professionals agree in this particular question and chooses to sit closer to the front of the room than in the physical and virtual scenario.

It is also noteworthy that the professional architects in the questions concerning the lighting situation were less inclined to rate it very high, possibly due to the lack of information of light sources in the drawings.

CONCLUSION
The investigation presented in this paper suggests that virtual reality can simulate a physical scenario to a degree where human behaviour shows correspondences, and is closer related to reality than the experience of the same space communicated through more traditional plan and section drawings. There is an overall higher correlation of both the conscious reflections (the questionnaire) and the less conscious behaviour (eye fixations) between the real physical
architectural space and the virtual reality space, than there is between the real physical architectural space and the space communicated through plan & section drawings. We can conclude that the scenario with the overall size (length, width, height) estimations closest to the actual measure of the architectural space, is the virtual reality scenario with a total of 6.4 m divergence. The real scenario estimation has a total divergence of 6.8 m, the plan & section student scenario has a total divergence of 18.9 m, and the plan & section professionals scenario has a 8.9 m of total divergence from the actual measure. From the plan & section part of the research, we can furthermore suggest that trained professional architects are better at estimating dimensions of the test space than the students. This, in combination with the eye tracking heat maps, indicates as expected, that these trained architects are better to understand traditional drawings than students in the beginning of their study.

We can conclude that the combined method of eye tracking and a qualitative/quantitative questionnaire can be a useful tool to assess the differences in perception of representations of architecture.

**DISCUSSION**

A virtual environment can through the visual dimension of perception, in combination with interactive feedback, be helpful in generating immersiveness, understood as the sensation of actually being present in an architectural space. A sensation of being present, even while one is maintaining a conscious knowledge that this feeling is only an illusion created by a digital model. Digital models, and models in general, are still a central tool in the process of creating architecture. Until not so long ago, the digital method of working all happened on flat computer screens, although it is fundamentally a 3D regime. Recent pilot tests (Sonne 2017[2]) involving playing a 3D game in virtual reality and on a traditional flat 2D computer screen while measuring the electroencephalogram, indicates that the virtual reality version actually induces less cognitive load on the brain than the task when performed on a flat 2D computer screen. Other results from testing 2D & 3D non-immersive and 3D immersive scenarios (Kozhevnikov) are concluding that desktop graphics are counterproductive or at least ineffective in relation to 3D immersive environments when aiming for tasks in simulated real world scenarios from an egocentric frame of reference. Here virtual reality contains the potential for creating a more natural environment, brainwise, than the 2D computer screens. Through this approach, virtual reality could perhaps be representing a more natural way of dealing with digital architecture as a tool for estimating spatial qualities (Griffiths et al. 2017). Our future research will address these assumptions, in collaboration with neurologists (Lauring et al. 2014) and psychologists, in research projects such as the Virtual scenario Responder project [1].

The virtual representations can, if combined cleverly with our sensorimotor skills, create a functioning experience of perception. This sort of the sensation of movement in a virtual space is precisely what can be sustained by the accurate use of virtual reality simulations. Instead of struggling for a photorealistic virtual triple A game-like paradise, we propose that the virtual reality simulations be opened up to imagination by an active choice and removal of some of the visuals in favour of more potential interaction. Thus interaction (Steuer 1992) becomes a crucial part (Slater et al. 2009) in simulating the consistency of architecture.

Our brains are combining input from different areas to create an experience (Mallgrave 2010). This does not inevitably mean that we need more than a few sketchy indications to imagine an architectural space. However the difficult part is to find those gestures which are needed, and screen out those which are essentially just noise. We probably soon need to establish a conventional general foundation for assessing where a digital virtual reality representation can deliver a realistic, but still imaginative, set-up for future architectural visions and buildings.
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