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# Neurological feedback from perception of architecture in virtual reality: a methodology study

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**Abstract:** The paper will present the findings from a pilot study and a larger study that uses a virtual reality feedback collection methodology with building information modelling. In the pilot study, the methodology includes a neurological headset. All test subjects were fitted with Oculus Rift Head Mounted Display and, in the pilot study the Emotiv Insight EEG headset. In both studies, the test subjects took a virtual tour through a 3D model. The pilot study allows us to evaluate the methodology, frame and content in order to undertake the larger study using a more precise selection of measuring devices. The matching of the test subjects' location in the model, field of view, the task, and the neurological activity, shows a possibility to link an architectural experience to specific emotional responses on the level of the individual test person. The pilot study showed us also that a comparison between the test subjects was difficult, and hence the larger study made us change the setup towards the elements that could yield the most qualifying feedback. The larger study thus focuses on the location and the field of view of the test subjects, in combination with a subsequent question matrix.

**Keywords:** representation, virtual reality, neurology, perception.

## 1. Introduction

During our research with virtual reality, we have through the last three years performed experiments using virtual reality combined with other digital technologies such as BIM modelling, eye tracking, and neuro scanning. We have been comparing how people experience architectural space discussing the possible use of representation models in architecture. We have been using eye tracking and neuro scanning technology in combination with qualitative questionnaires (reference omitted for peer review) The research project is called Virtual Scenario Responder – VSR [reference omitted for peer review].

In the latest parts of our VR research, we have been looking further into getting a useful and easily implemented system, that could work also in architectural studios without the full technological machinery fleet. A VR response system that can be used in the design process, for modification and for validation of an architectural project, including user involvement. We want to eventually connect the system to a wide range of different applications adressing new construction, restoration, and accesibility. There are many possibilities, and it requires input from many different fields. An important part of the concept is a systematic feedback from a question matrix and the subsequent studies of these data.

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We are currently working with three architectural cases in Denmark under the slogan 'Fitness for Everyone' [2]. The project used in this study is a new section of the sports facility Gaarslevhallen close to the city of Vejle, where accessibility is an important issue. We use this case study to test how we can manage a VR workflow allowing user feedback, without unnecessary interfering in the test subjects' experience of the architecture.

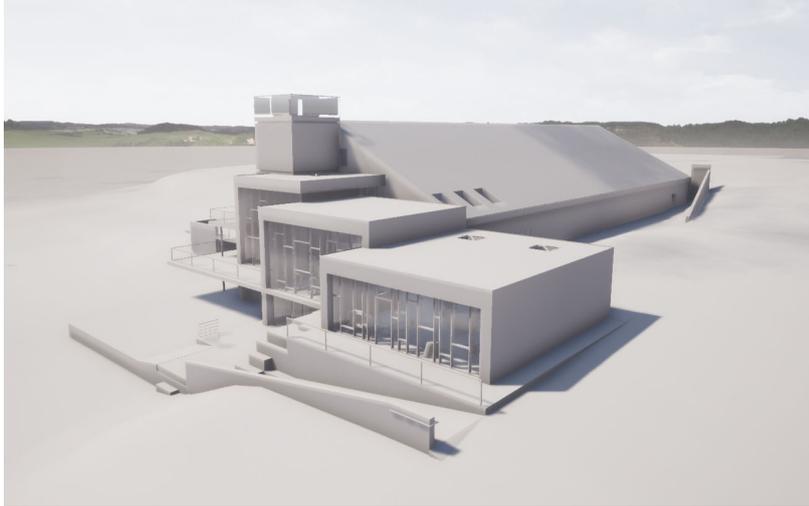


Figure 1 - the addition to the sports facility as a white sketch model.

Our own previous research indicates that it is possible to simulate a physical scenario in virtual reality to a degree where humans behave in a way that can be compared. A virtual reality scenario can possibly be closer related to reality than the experience of the architectural space communicated through traditional drawings of plan and section. Representations of architectural projects through virtual reality can, when applied correctly, significantly improve the usability of digital architectural building information models. (reference omitted for peer review). Also other pilot studies have been studying VR in combination with pupil dilation, as a means of capturing the behavioral aspect of perception (Moleta et al. 2018). Through interacting with the environment in the virtual reality model, a feeling of immersiveness can be generated or reinforced (Steuer 1992), as the sensation of actually being present in an architectural space, even while knowing that it is a model and thus an illusion created by a digital virtual environment (Slater et al. 2009). In this line of thought it can be considered a serious issue that the early sketching phase of architectural projects usually contains very little information of details and materials. The different way that our brain identifies form and shape compared to materials, textures, color, and details, are investigated in Sarah Williams Goldhagen's work (Goldhagen 2017) with an analysis of form-based cues and surface-based cues. The link to memory and previous emotional states, is apparently linked closer to the experience of surfaces (material, texture, color, detail) than to the pure geometric form. This can be an issue to be addressed when working with architectural sketch models with little detailing and materials. However, even though our brains

combine input from different areas to create an experience (Mallgrave 2010), it is not necessarily requiring photorealistic models to imagine an architectural space.

What has been the difficult task in our research has been to find the sufficient level of detail in the virtual 3D model. Enough to create the feeling of immersion, but without too much of the detailing that can be experienced as distractions. A neurology study comparing learning in VR to conventional media (flat 2D screen computers systems) shows that VR increases both sense of immersion and the risk of creating an increase in processing demands on working memory, which can lead to a decrease in knowledge acquisition. (Makransky et al. 2019).

While the immersion is a fundamental requirement in the field of sketching architecture, a cognitive overload is not desirable, and should be avoided. There are several issues that continuously needs attention in relation to reducing background noise in the architectural experience. One parameter here, is removing unnecessary details from the test models

## 2. Pilot study

We used the same architectural space for all the studies, but a slightly different data collecting setup for the pilot study and the larger study. In this section, the pilot study is summarized and the full study explained. A more extensive dissemination of the pilot study is available at (reference omitted for peer review). In the pilot study, we had 8 test subjects and in the larger study, we had one group of 30 test subject and an additional group of 10 test subjects in order to compare the influence of the markers we used to guide the test subjects. This will be explained more thoroughly in the chapter addressing the full study.

### 2.1 Pilot study summary

The pilot study consists of hardware, software, and methodology enabling a preliminary study of how to apply equipment and what methods to use. This was to a high degree a study investigating if it would make sense to include the neurology EEG in the full study or not.

#### 2.1.1 Test subjects, equipment, and model

The test subjects were equipped with an Emotiv Insight 5 channel EEG technology brainwave recorder and an Oculus Rift HMD. We used a digital 3D model of the architectural extension to a sports facility, presented in 1:1 scale in VR. The test model is modelled in Autodesk Revit as a white sketch 3D digital model, with no use of textures, in order to eliminate as much background noise as possible (Figure 1). The six test subjects were students of architecture and two were architects and educators. One test subject was female and the rest was male.

#### 2.1.2 Method

The test subjects were presented with a short brief explaining the outline of the pilot study. Before the real test, we had designed a tutorial VR room where the test subjects could practice moving around and interacting, and we recorded the compulsory individual neurological baseline. There were four sequential locations in the model that they should traverse, from the Outside of the building through the open foyer, to the changing room, to the fitness room, and finally back outside again. This relatively free task was designed in order to simulate a possible close to normal use of the fitness facility. All

through the study the EEG was recorded. The output from the Emotiv Insight is from the EEG signal transformed into graphs providing metrics showing six different areas. We chose to focus more on Excitement, Interest and Engagement. These are relatively precise when measured with the Insight. A precision of about 70% for Interest to over 85% for Excitement, and Engagement a little less, when measured against standardised tests and other biosignals in Emotive's lab [3].

#### *Summary of the EEG readings*

The amount of neurological correspondence between the individual metrics of the eight test subjects was, as expected, not very easily comparable. This probably endorse the assumption that the experiences of architecture is very dependent on the individual. Even though we are well aware that the sample size cannot be used as a quantitative data set, it seemed worthwhile to check if we could find similarities in the neurological metrics related to the perception of the architecture.

A relation to the spatial quality of the architecture and its different appearances could not be read directly from the metrics on a general level for the eight test subjects. An estimation in relation to the overall excitement in two different spaces, i.e. the large foyer and the narrow stairwell, indicates that only three out of eight feels more excitement in the foyer than in the hallway. However, in six of the eight cases, we could observe a rise in the Excitement when the test subjects entered the changing rooms. Likewise, we could observe that six of the eight test subjects felt a drop in Excitement once they finish the test.

That there does not seem to be a clear pattern directly corresponding to the spatial qualities of moving through foyer and into the narrow hall, could indicate that the sample size is too small for these comparisons, but also that the perception of architecture is a highly individual experience based on many different subtleties. We could observe consistency within the individual test subjects performance metrics, when analysed as individual cases. Nevertheless, a common pattern in relation to a general perception of the architectural qualities could not be found.

The results from the neurological pilot study are more or less, what we expected. It would have been intriguing to discern correlations between the test subjects, but we can still use the findings to streamline the elements that we believe will yield the best results in the larger study.

### **3. The full study**

Based on the results from the pilot study it became evident that the difficulties of a comparison across the whole group of test subjects in the EEG setup did not yield enough comparable data to be scaled up in a meaningful way for use in the full study. The larger study contains data from the same project but without the EEG. We have collected the position data and the gaze data, and the feedback from the questionnaire.

#### **3.1 Method**

A total of 40 test subjects, divided in two groups of respectively 30 and 10 subjects, were used for the study. The first group of 30 subjects were 14 male and 16 female students of architecture with an average age of 23.6 years. The group of 10 test subjects were 4 male and 6 female students of architecture with an average age of 24.8 years. The test subjects were equipped with an Oculus Rift HMD. We used the same digital 3D model of the architectural extension to a sports facility, presented in 1:1 scale in VR. Still a white sketch 3D digital model, with no use of textures, in order to eliminate as

much background noise as possible. In order to point a direction in the model, we initially put markers the first group of 30 test subjects could follow. This was to ensure we had an approximately equal basis for comparing their behaviour. The additional group of 10 test subjects did not have any markers to guide them, so we could compare the influence or possible distraction of the markers themselves.

Much like in the pilot study, the test subjects were presented with a short brief explaining the outline of the study. Before the real test, we used the same tutorial VR room where the test subjects could practice moving around and interact e.g. with opening doors and using a laser pointer tool. After this, they were teleported to the test, beginning at the entrance of the sports facility. Here they received the second brief explaining how to proceed. In order to make a feasible comparison, we used markers in the model (Figure 2), that the test subjects were told they could follow. The markers disappeared on approach, showing the next place to go. This method of course contains the risk of guiding too much, rendering the results biased. We tried to evaluate this but adding the second test group with no markers. The relatively free task was designed in order to simulate a possible or close to normal use of the fitness facility, without interrupting the test subjects more than necessary. The feedback from the study is based on the location tracking, the gaze tracking, and the subsequent questionnaire.

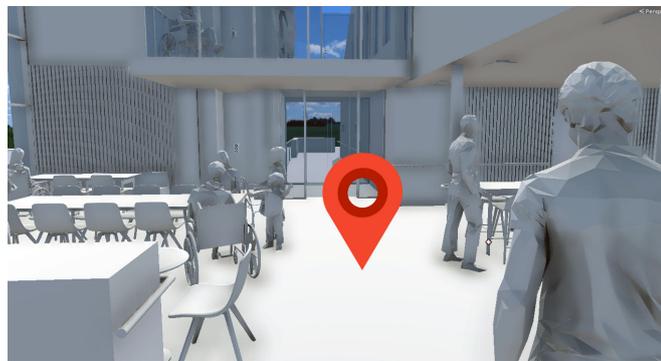


Figure 2 - The markers were designed with a high visibility, but at the same time to look familiar in order to reduce their distracting factor. The Markers disappear on approach.

## 4. FINDINGS

The study provides examples of the possible feedback from using the VSR system in the architectural sketching phase. The collected feedback is communicated as visual location data, gaze data, and questionnaire answers.

### 4.1 Location tracking

The location tracking is a mapping of the movement path of every test subject. Every 20ms a dot is marked in the model at the location of the test subject. That data can be visualized as heat maps, intensifying from green over yellow to red, where more people are walking or stopping. The following maps (Figure 3) show the three floors of the case building and the accumulation of 'heat' where most people have been.



Figure 3 - the location heat maps based on the 30 people test group.

The group with no markers (Figure 4) show that the test subjects are actually taking more or less the same route through the building as our guided tour, with the markers.



Figure 4 - the heat map based on the location of the 10 people test group.

There is no doubt from reading these heat maps, what part of the building is the most busy, namely the large foyer with the café and reception, also functioning as distribution space to the facilities. From the use of this methodology, it is of course also possible to isolate the individual heat maps, to learn where specific test subjects spent most time and what they looked at in order to evaluate their answers about the architecture.

#### 4.2 Gaze tracking

Previously we have been working with eye tracking equipment in both reality and in virtual reality. In this study, we wanted to minimize the equipment and optimize the feedback with the focus on easily recognizable visual feedback. Thus, we designed a system that would not require a complete eye tracking of the pupil movement, but simply logged the center of the view in the virtual reality glasses. This made the system much lighter in respect of both the equipment and the data processing. The heat maps shown in (Figure 5 & Figure 6) are the center of the direction of the test subjects' heads that we assume is the average gaze direction on general level. The trade off in this case is between the precision and the almost instant visual feedback.

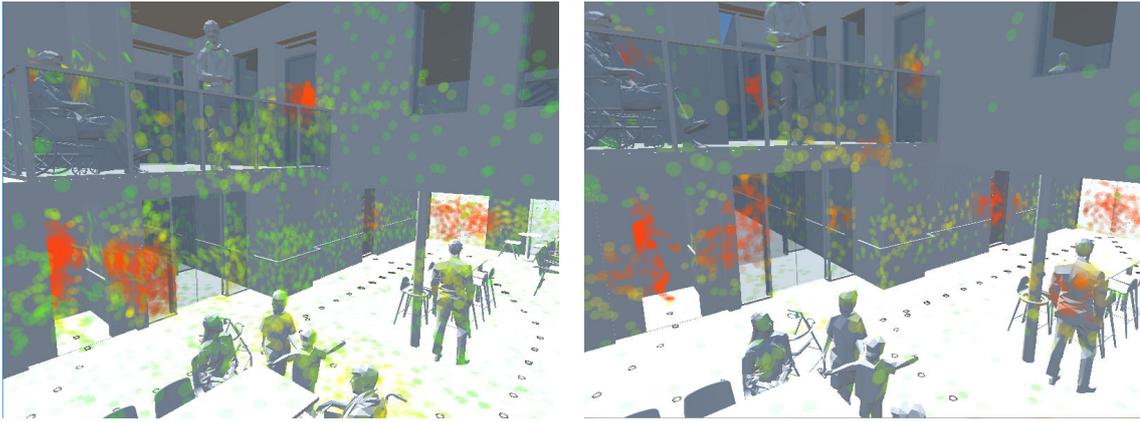


Figure 5 – a comparison of the collected gaze points of all the subjects in the two test groups, i.e. with markings (left) and without markings (right), shows a high correspondence in the gaze data.

The two different groups show a rather high similarity in the visual attention span in the model. The areas that requires interaction, such as door handles and the elevator button, are obviously receiving a lot of attention. In addition, the view into the large sports arena gets attention. The dummy people in the model are also noticed, despite their non-photorealistic appearance.

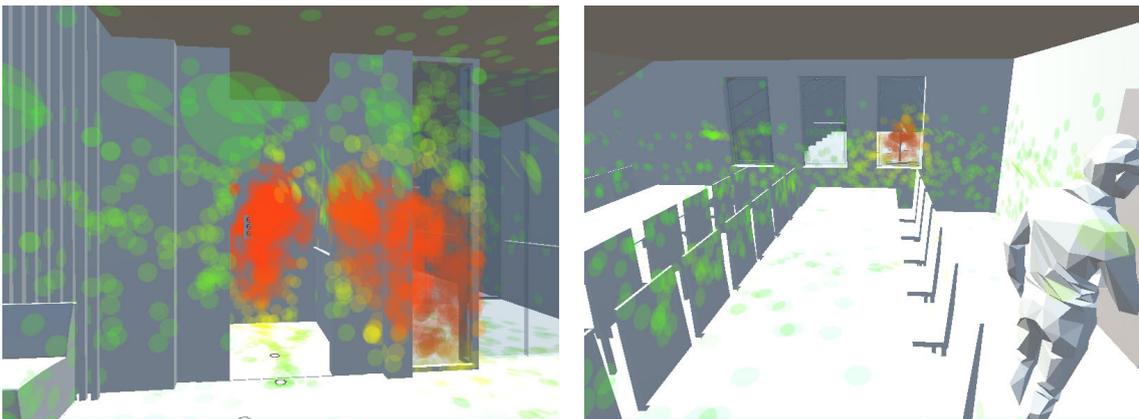


Figure 6 - the gaze heat maps allows to find the areas that receives the most attention in the model.

This way of heat mapping the collected gaze data visually, allows for an general analysis of the areas in the models that gets the most attention. We can see e.g. from what window, the test subjects are looking into the large hall.

### 4.3 The questionnaire

We designed the questionnaire with two different purposes. First, the answers can be used to evaluate the user experience of the building. Since the questionnaire is filled out in retrospect, the answers will require a reflection about the architecture. The test subjects were told that they would be asked about the architecture after the virtual tour, and so they would pay attention to the building. This was a way of getting the test subjects to look at the architecture and avoid them to rush through the building like if it was a game, a race that simply needed to be won.

We have collected some of the answers from the questionnaire, to exemplify what kind of data can eventually be cross-referenced with location and gaze data. There are some coherence between the experience of the rooms with a nice view (Figure 7) for both the two groups of test subjects.

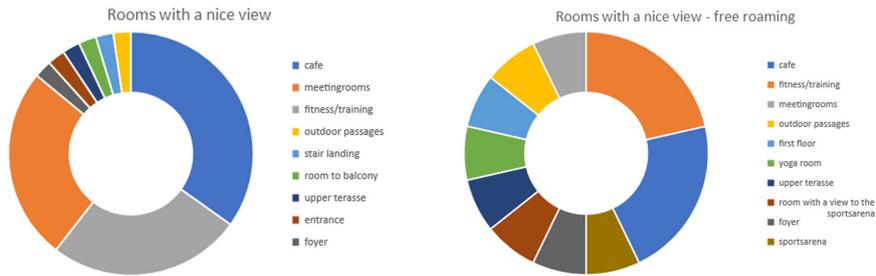


Figure 7 – diagrams of rooms experienced to have a nice view to the outside. Respectively 30 people (left) having guiding markers and 10 people (right) roaming freely through the building.

Using this type of data (Figure 8), it will be possible to pinpoint test subjects' answers to their specific path through the building, and what they actually saw in order to experience what they did. This can be used both for accessibility assessments, but also for an investigation of the architectural atmosphere of the building.

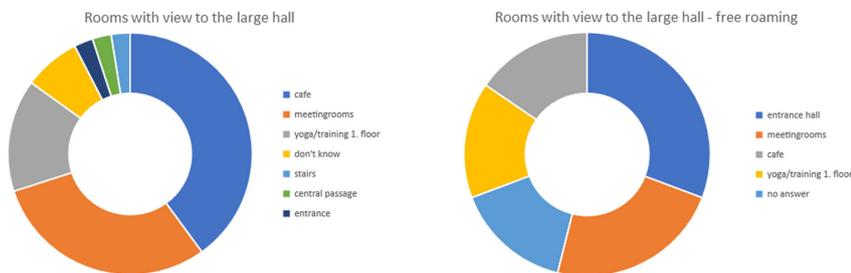


Figure 8 - Rooms experienced to have a view to the large hall sports arena. Respectively 30 person group (left) and the 10 person group (right).

The description of the building, in a few words (Figure 9), can be listed and shown visually as diagrams for an easy overview of the impression of the architecture in the test group. The qualitative feedback can be specified in particular areas to be evaluated, in line with the desire of the architects.

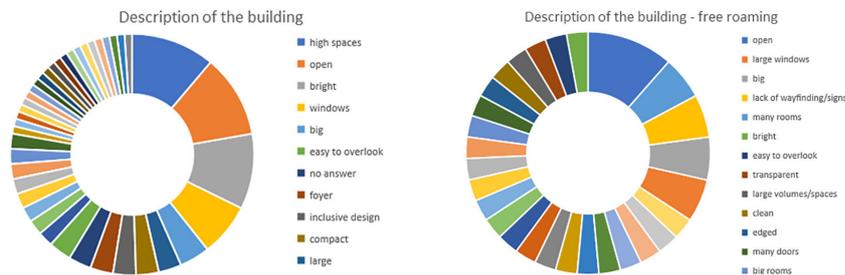


Figure 9 – Descriptions of the building. Respectively 30 test subjects (left) and 10 test subjects (right).

## 5. CONCLUSION

The study with the VSR methodology we are currently developing, shows that an architectural 3D BIM model can provide the foundation for many investigations on the behavioural aspects of the experience of architecture. The neurological non-intrusive EEG scanning results proved useful on the level of the individual test subjects, but difficult to generalize. The study also shows that a streamlined collecting of data can, without the need of additional equipment (EEG and pupil eye tracking), provide useful information about the movement and areas of interest in an architectural model.

While we cannot conclude a precise terminology for the experience of architecture in a true EEG neurological perspective, we could use the results of the pilot study, with the purpose of streamlining the methodology into a 'slim' version based on the location, gaze, and questionnaire data. In the VSR, the individual or the group (or any part of the group) location data can be cross-referenced with both the gaze maps data and the questionnaire in order to pinpoint the type of the experience, at a given location, and the potential reasons to the specific type of experience. We believe that we are getting a step closer to determine what kinds of architectural traits result in pleasant and emancipatory experiences, and which experiences are the result of frustration or confusion.

We have not abandoned the idea of setting up a larger scale experiment with EEG and virtual reality in the field of architecture. This work will presumably continue as a side project to the VSR. Currently we focus on fewer and more stylized architectural means to establish a common catalogue of behaviour in relation to a clear framework in the 3D model. A transition from a small space to a larger space, from darkness to a bright space, could perhaps be a way of gathering data, eliminating some potential sources of error. We will in this case design a 3D model, which will be more precise in the study than a real world 3D model. Accessibility will be a focus for the near future of the VSR, and the prime focus will remain on the investigation of the representation of architectural atmosphere.

## 6. Acknowledgements

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## 7. References

- Goldhagen, S. W. 2017. *Welcome to your world: how the built environment shapes our lives* (First edition. ed.). New York, NY: Harper, an imprint of HarperCollinsPublishers.
- Hermund, A., Myrup Jensen, M. & Klint, L. 2019 'The Neurological Impact of Perception of Architectural Space in Virtual Reality: Virtual Reality with Building Information Modelling and EEG' VIRTUALLY REAL - 7th eCAADe Regional International Symposium - Aalborg University, Aalborg, Denmark
- Hermund, A, Bundgaard, TS and Klint, LS 2017 'Speculations on the representation of architecture in virtual reality: How can we (continue to) simulate the unseen?', *Back to the Future: The Next 50 Years - 51st International Conference of the Architectural Science Association (ANZAScA)*
- Hermund, A, Bundgaard, TS and Klint, LS 2018 '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', *Computing for a better tomorrow: eCAADe 2018, Poland*, pp. 735-744
- Hermund, A and Klint, LS 2016 'Virtual and Physical Architectural Atmosphere', *Proceedings of the International Conference on Architecture, Landscape and Built Environment (ICALBE 2016)*, Kuala Lumpur, Malaysia, Kuala Lumpur, Malaysia, pp. 3-4
- Hermund, A, Klint, LS and Bundgaard, TS 2018 'BIM with VR for architectural simulations: Building Information Models in Virtual Reality as an architectural and urban design tool', *The 6th Annual International Conference on Architecture and Civil Engineering (ACE 2018)*, Singapore
- Makransky, G, Terkildsen, TS and Mayer, RE 2019, 'Adding immersive virtual reality to a science lab simulation causes more presence but less learning', *Learning and Instruction*, 60, pp. 225-236
- Mallgrave, HF 2010, *The architect's brain: Neuroscience, creativity, and architecture*, John Wiley & Sons
- Moleta, TW and Schnabel, MA 2018 'The Virtual Mirror - Cognitive Loads in VR and VR Visualisations', *Computing for a better tomorrow - Proceedings of the 36th eCAADe Conference- Volume 2*, Lodz University of Technology, Lodz, Poland, 19-21 September 2018, pp. 815-822, p. 8
- Slater, M, Lotto, B, Arnold, MM and Sanchez-Vives, MV 2009, 'How we experience immersive virtual environments: the concept of presence and its measurement', *Anuario de psicología*, 40(2), p. 8
- Steuer, J 1992, 'Defining Virtual Reality: Dimensions Determining Telepresence', *Journal of Communication*, 42(4), pp. 73-93
- [1] reference omitted for peer review
- [2] <https://bevica.dk/projekter/fitness-for-alle>
- [3] <https://emotiv.zendesk.com/hc/en-us/articles/210680463-How-accurately-does-our-Insight-detect-emotions->