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Introduction

This paper explores whether the traditional digital model as such lacks the relevance of measurement in itself, while the virtual reality (VR) model actually does contain the *architecturological* scales of *reference*, *measurement* and *relevance* that Philippe Boudon links to the semiotic system of Charles Sanders Pierce as *firstness*, *secondness* and *thirdness*. The paper is an exploration of the nature of scale of the digital models used in representation of architecture. Through the establishment of a framework of terms and methodologies derived from Philippe Boudon, Charles Sanders Pierce, and Albena Yaneva, the paper argues, through case studies, for a use of virtual reality models that brings architectural representation closer to the experience of real-world spaces than other uses of digital architectural models.

Forms of representation of architecture have always been inseparable from the design of architecture. Traditionally an array of tools has been used in the process of representing architecture through scale models, drawings, and in the last half century, also other media including digital models. This paper explores how an existing potential use of scale models in virtual reality might bring the representation of architecture in the design phase closer to its purpose as a framework or articulation of the interaction intended to be taking place within the finished building. Representations of architecture are in their fundamental mode of operation not in themselves the final product, but only showing an aspect of the potential full-scale architectural idea. In relation to scale, the representation of architecture has to be aware of this link between the full scale and its representations that makes use of many different scale ratios showing different aspects of an architectural idea, according to their size and level of detail. To some degree, this aspect has changed with the digital models where zooming in and out has become trivial as a possibly both useful and confusing way of working. The paper will in conclusion show how a virtual reality system has been designed to accommodate some of these issues using the potentials of the implicit human scale possible in the virtual reality architectural representation.

Literature Review

This brief review of literature will be dealing with relevant aspects of scale models and perception in digital scale models in virtual reality. Though almost chronological, it is understandably not a full review of all literature in the field, but rather a selection deemed interesting for the reader of this paper. Charles Sanders Peirce, Philippe Boudon, and Albena Yaneva will be addressed seperately in their own right, and are thus not included in this brief review.

The article ‘Defining Virtual Reality: Dimensions Determining Telepresence’ (Steuer, 1992) is included here because it defines virtual reality in a matrix of vividness and interactivity and so expands the understanding of VR to something that potentially enables and engages more than just a visual relationship.

In ‘Distance Perception and the Visual Horizon in Head-Mounted Displays’ (Messing and Durgin, 2005) the topic of mesurement and percieved distance distortion in vrirtual reality is tested and examined. Another interesting field in relation to the virtual environments and the sensation of being present is found in ‘From presence to consciousness through virtual reality’ (Sanchez-Vives and Slater, 2005) where the claim is that the concept of presence engendered by virtual reality is sufficiently similar to consciousness that it can sustain research within this domian. ‘How we experience immersive virtual environments: The concept of presence and its measurement’ (Slater *et al.*, 2009) introduces a notion of presence as the extent and capability of participants in a virtual environment to respond to virtual situations and events as if these were real. This is due to the idea of the brain as a correlational engine producing reality. In a paper dealing with two- vs. three-dimensional (in virtual reality) presentation of mental rotation tasks the conclusion is, that this type of test is easier in 3D in virtual reality than in 2D (Neubauer, Bergner and Schatz, 2010). This is interesting and correlates to assumptions that virtual reality can be easier accesible in order to understand architecture than 2D architectural plan and section drawings (Hermund, Bundgaard and Klint, 2018). The mental rotation task has been performed with similar results (Kozhevnikov and Dhond, 2012) showing that the task in 2D and flat 3D on a screen are very different from results using a virtual reality headset. Immersion - the objective level of sensory fidelity provided by a VR system - is another important aspect when talking about perceived presence in the digital models. This can be furthered by the use of avatars (Leyrer *et al.*, 2011) or even used to change or transcend the sense of self (Slater and Sanchez-Vives, 2014). A study indicates that user engagement and flow states in immersive virtual reality are higher when using your hands to navigate instead of keyboard and mouse, though performance in the test game was lower (Brondi *et al.*, 2015). Other smaller pilot-studies have been dealing with assessing the difference of perceived size, scale, and spaciousness in virtual reality presentations of High-Density Apartments (Griffiths, Lamb and Pelosi, 2017) and how architectural design impacts on the users (Moleta, 2018) and can be neurologically measured (Hermund, Myrup Jensen and Klint, 2019). Attempts have been made to quantify the architectural experince in a case study using virtual reality analyzing visual traits in relation to various algorithms developed upon processing fluency theory (Maghool, Schnabel and Moleta, 2020). This type of framework could presumeably, in combination with AI machine learning, be a powerful tool to qualify the experience of digital scale models in virtual reality. Another take on the connection between human emotions and architecture focuses on the aspect of geometry (Shemesh *et al.*, 2021). Here emotional reactions to space, both positive and negative could be measured by changes of curvature, protrusion, scale, change of proportion in height or width of virtual spaces. On the topic of cognitive load - whether an architectural representation in virtual reality requires more

mental energy to experience than reality or flat 2D digtal models – there are different opinions and indications. A recent study (Breves and Stein, 2022), with a extensive summary of the various positions and arguments, shows that there is neither more nor less cognitive load in the virtual reality representations, unless the user experiences motion sickness, which is unfortunately not an uncommon phenomenon. This being said, then the spatial presence is perceived higher in virtual reality in relation to flat 2D media representation, which plays an important role for the virtual reality system created by the author's research cluster and displayed in the final part of this paper.

Scale and Representation of Architecture

While the benefit of digital models operating less statically in relation to scale can be a topic of discussion, and probably to a certain extent depends on individual preferences, it is important to distinguish between digital models on a flat screen and digital models as seen in an interactive virtual environment. The argument of this paper is that the virtual reality model can be closer to the architectural perception of space than other digital models, simply because of its implicit relation to scale.

For a better discussion of the term "scale" it seems useful to examine it from a couple of different angles associated with architecture and the world in which architecture exists.

Scaling up and Down

An example of a discourse that discusses the immediate effect of scale, or scaling, on the perception and conception of architecture, is the ethnographic study performed Albena Yaneva. By following architects working with scale models in the design process, Yaneva studies how the scaling up and down between different architectural physical scale models help the architects to understand the space they are designing (Yaneva, 2005). She notes how the different sizes and levels of details in the models each work in their own respect contributing to the overall design process by informing on several layers of scale, shifting back and forth. Especially the endoscopic working method, using a small monocular, inserted into a cardboard scale model, allowing the architect to experience the space from his own analogously simulated eye height, seems interesting when comparing to contemporary possibilities of digital virtual simulations.

Use of the semiology of Charles Sanders Pierce

With the combination of his work on *architecturological scales* (Boudon, 1992) with the semiological system of C.S. Peirce, Philippe Boudon expands and adds to the discussion of scale, or scales, as an important frame of reference in understanding architecture and its conception. Peirce based much of his semiotic theory on triads in order to structure the perception of the world as a series of interrelated signs. A theory that can be interpreted as a complex system (Feibleman, 1960), which in this context is used mainly in its principal division between Firstness, Secondness, and Thirdness.

In the Peircean triad *Firstness* is simple and elemental, potential; *Firstness* is not yet involved in a conceptual relation and marks the experience that the world is more and different from what we know, and that we must continuously relate creatively to this otherness in order to orient ourselves. *Secondness*, by extension, marks our conscious relation to that which has not already been named; *Secondness* can be a realization of the *Firstness'* quality in a relational experience, that we by a *Thirdness* reflexive approach to the relation can name as a scale. Then, if *Firstness* is feeling and *Secondness* is marked experience, *Thirdness* is naming of the relation between *Firstness* and *Secondness*. *Thirdness* is relating quality and (when it comes to architecture) giving measure, or scale, to that relation. Habits, the laws and science are found here. *Thirdness* realizes a given phenomenon from the *Firstness* of possibilities associated with a *Secondness* of events. Or put another way: *Firstness* is equivalent to the predicate, *Secondness* to the subject and *Thirdness* to the relation and to the naming of the relation between *Firsness and Secondness* (Peirce, 1994).

Architecturology

Philippe Boudon continues to work with definitions of scale and its different meanings in relation to geometric space, that does not require concrete measurements, and architectural space which on the contrary does have specific measures, or at least need those in order to be build. In "Back to Scale" (Boudon, 2009), Boudon establishes a definition of scale as the "relevance of the measurement: no longer a graduated ruler, but the relevance of the latter." This is an important definition that stresses the construction of a relevant relation between the measured as the measurer. This can be understood as connecting the physical Secondness with the quality of Firstness, through inherent mental processes of Thirdness. Scale understood as relevance of the measurement consequently substitutes the mundane heterogenous meaning with empirically identified relevancies of the measurement. In conclusion Boudon arrives at the three *architecturological* concepts of *reference, dimension* and *relevance* (Firstness, Secondness, Thirdness) permitting to understand the complexity of the term scale.

Different interpretations of the term scale in relation to digital representations

With the intention of activating new reflections on the nature of the digital models as representations of architecture, the hope is towards an opening up to a discussion instead of the closure of (too) permanent conclusions. Through examples of scale in a sereies of experiments in virtual reality performed by the author's research cluster, the issue of scale in the real world and digital world is discussed using the abovementioned theory and ideas from Peirce, Boudon, and Yaneva. Focusing on the scales of the digital model, the paper will discuss the potentials and inherent caveats of digital and virtual scales, using examples and feedback from using a digital virtual reality dialogue tool prototype in evaluation of universal design and architectural quality.

Digital Scale

As an example of the fundamental importance of both *reference, dimension,* and *relevance* and the possible s*caling in and out* in the digital representation of architecture, let us begin by looking at a digital model and a photo of the garden of the Royal Danish Library in Copenhagen.

When looking at a digital 3d model representation of the Royal Danish Library complex (Figure 1 left) we can most probably discern at least the buildings and elements of infrastructure from the green parts and the water. If we know the area, we can probably recognize this typical part of the city, even though we do not usually see it from a bird's eye perspective. While the perception of cities from the sky is an interesting topic on its own accord, it is, for the sake of this example, rather the level of detail and its relation to *relevance* one should pay attention to here. In the bird's eye view it seems appropriate for our senses to accept that this is a part of a city. But if we change the scale, and zoom in, while maintaining the same 3d model (Figure 1 right), we probably begin to experience that something seems wrong in comparison to our expectations of a perception of the everyday world experienced at more or less our own eye height.

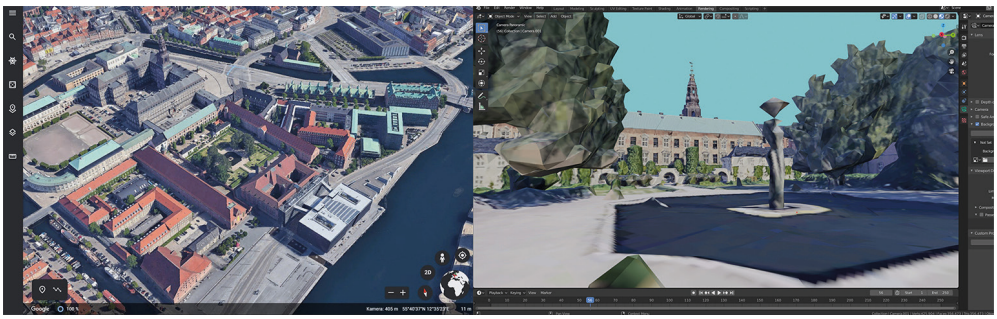

Figure 1 - Google Earth 3d digital model of the Royal Danish Library in Copenhagen (left) and Google Earth model of Royal Danish Library garden extracted and shown in the 3d modeler Blender (right).
Source: Google and the author.

This becomes evidently clear if compared to a photographic image of the garden at more or less the same place, and even more, if the texture images are removed (Figure 2). It is easy to tell the many differences between the photographic representation and the digital model representation, but the point here is, that even though the digital model inherently contains the possibility of very fast scale changes, this does not necessarily link up to any criteria of relevance e.g. for the level of detail. In other words, while a digital model reproduces scalability in relation to quality (colours, geometry) and quantity (buildings, tress, water), it does not contain the scale as a relevance of the measurement. At least not before this relevance has been established by a specific cognitive use of it. Fortunately, this Peircean *thirdness* can be established rather easily, but one has to know how to decide what is appropriate in each given situation. What level of detail will be sufficient for a specific 3d digital architectural model to exactly convey its purpose, has to, or will unconsciously

become, decided by a human being, a *measurer*. In an architectural design process this human being could very well, and preferably, be an architect.

Moving into the model

As opposed to the lack of scale-relevance in a digital model, something happens when we *move into the model*. As mentioned above with Yaneva's study of the endoscopic investigations of cardboard models, the immersion into a simulated full-scale room seen from human eye height proves helpful, if not crucial, in the architectural design. With virtual reality a digital model allows this full-scale immersion to varying degrees. With bilateral vision humans are physically present in physical reality (Sussman and Hollander, 2015). VR head mounted displays are working by generating exactly bilateral vision creating a sense of depth in the digital model, so perhaps we are actually not scale-less to the same degree in a VR digital representation model, as in a 3d model on a screen.

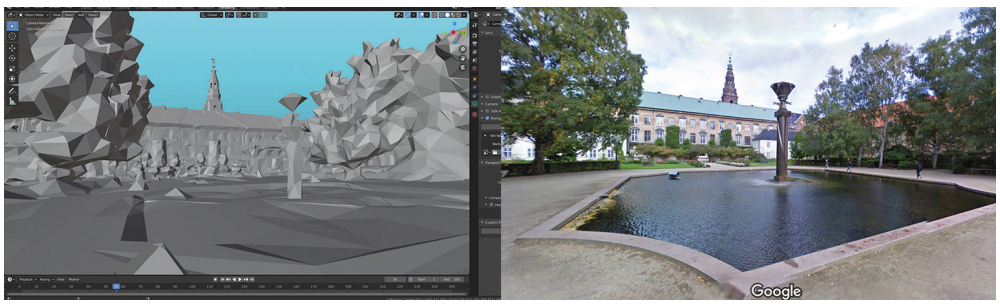

Figure 2 – Blender 3d model without textures (left) and a Google Earth 360 photographic image of the garden of the Royal Danish Library (right)

Source: Google and the author.

Studies of proxemics, i.e. "the interrelated observations and theories of human use of space as a specialized elaboration of culture" (Hall, 1990), has been performed also in VR showing correspondences with real life behaviour (Hecht *et al.*, 2019). Also, in addition to the scale and dimension studies mentioned in the literature review, studies have been made in relation to measurement of distances in VR. Curiously, most of this research show, that there is an evident underestimation of distances in VR (Jamiy and Marsh, 2019), which is an issue of investigation. Nevertheless, a VR model could perhaps in its very fundamental mode of operation provide the missing architecturological thirdness of scale to the digital model, owing to its inherent immersive effect for the user. In this way the user's own body could possibly provide the relevance of scale.

Virtual reality case studies

An initial experiment was set up by the research cluster of the author to test the correspondences between real life and VR. The experiment used a medium size auditorium as the real-life scenario and a building information model of the same auditorium as the virtual scenario. An architectural space was then presented to two groups of test subjects in real life and in VR. Afterwards the experiences were compared through both eye tracking analysis and a quantitative/qualitative interview

matrix. The study suggests that VR can indeed simulate a physical scenario to a degree where human behaviour shows correspondences, and that a virtual scenario contains the possibility to incorporate interactive elements which cannot be provided to the same extent, using traditional drawings or even non-immersive 2D and 3D models (Hermund, Bundgaard and Klint, 2017).

A continuation of the study with focus on the estimation of sizes (length, width, height) within the virtual environment compared to real world and to plan & section drawings showed a very high correlation between the VR model and the real-world space in contrast to comparisons with the plan & section drawings. Remarkably did this study also show that the test subjects estimating the measures in the VR environment came closer to the actual measurements than subjects experiencing the real-world space. However the estimations were all quite close to the actual measurements (Hermund et al., 2018).

Virtual Scenario Prototype

The studies mentioned above led to the programming of a prototype tool using VR to simulate architectural projects in the design phase, (Hermund, 2021). A real architectural project in the early design phase became the testbed for the functionality of simulations in VR (Figure 3 left). The VR model was presented for users to walk around in, and their behaviour was tracked in order to get feedback. What is special about such an experience is the sensation of being immersed into a full-scale model while maintaining the knowledge that it is only a model. To sustain the user's experience of walking around in a not yet finished building, decisions were made to preserve a cardboard like quality of the experience, by removing materials and using non-photorealistic stand-ins of people simply to stress the sketchy phase of the design. Feedback of where the users looked in the models (Figure 3 right), where they moved, and if they collided with furniture or edges on the way, was collected in a report.

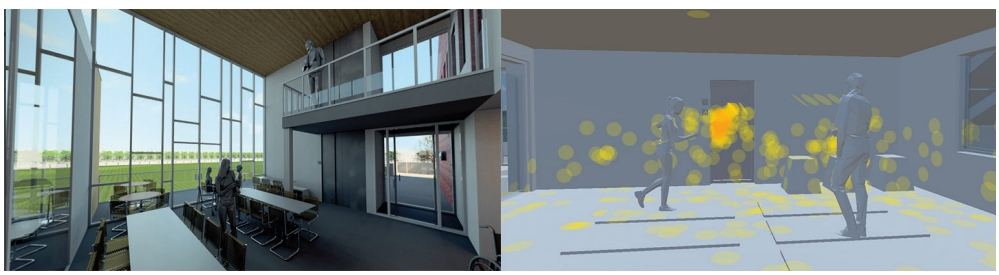

Figure 3 - A 3d rendering from the project (name omitted for peer review) (left) and heatmap showing where users looked when traversing the VR model (right).

Source: The author.

Because the eye height is exactly the users own, and the user can see virtual hands in the model, the sense of scale is referenced through the sensation of one's own body size in comparison with the sizes of spaces, openings and furniture in the model. The relevance of scale in this VR case is thus fundamentally related to the users own experience of moving through space.

Level of detail

Even though an early architectural sketch project does not yet hold much information about materials or colours, the digital VR model does permit to include these levels of detail, when the architect decides. But even though including this kind of information can enhance the feeling of presence, it is presumably not necessary for feeling immersed in the VR model. It seems that there are some visual levels of detail that are more or less autonomous in relation to the relevance of scale. However, they might reinforce the firstness as the quality of sensing the materials, or the secondness in relating more directly to dimensioning traits of the physical world (Figure 4 left & middle).

Figure 4 - Quality of e.g. materials in different flooring relates more to firstness and secondness than to thirdness of scale (left and middle) and wheelchair-user commenting on distances (right).

Source: The author.

Universal design seen from a virtual wheelchair

The suggestion is that it could be the intricate relation between one's own body scale and the VR model that, through relevance, connects reference and measurement. But the VR representation also allows a different jump in scale, so a user can experience an architectural space from the point of view of someone else i.e. a child or a person using a wheelchair. Enabling a feature in the prototype system allows feedback from the movement through the building seen from the eyes of disabled people. A report based on the observations in the VR representation is then brought back to the architect that can align the project according to the suggestions and enter a qualified dialogue with the users. The user in the specific space (Figure 4 right) pointed to the scale of the landing which should be at least 1.5 m to be spacious enough, even though the permitted minimum requirement is only 1.3 m. In this case and similar occasions (Hermund and Bundgaard, 2019) an experienced scale in the VR sketch model was sufficient to point to areas of the architectural design, that needed further attention from the architect. In such a case all scales from reference and measurement to relevance are used in the VR model, e.g.: The sensation of spaciousness (or in this case the lack of it), the actual physical measurements of a wheelchair, and the relevance of the body, and the fact that the law requires a distance which is insufficient for the bodily space in a wheelchair.

Discussion

As stated earlier, this paper has the intention of spurring new reflections on the nature of the digital as representations of architecture. An invitation to a discussion.

The different scales of digital models that provides different use - the local scale of a building information model (BIM) with less extension than a geographic information system (GIS) model covering large areas with relatively fewer local details, and the VR model that could be a possible back to nature (of the human scale) in a digital regime. The ideal of a digital model is not a map containing all information about a given architecture, but a repository for information that can be pulled when relevant at the right time for the right person. The VR model could as such be seen as a supplementary representation of full-scale architecture with a lot of potential, but not a substitution for all other methods of architectural representation. The explorative nature of this paper, as mentioned, calls for a discussion rather than a conclusion, and it is the hope that the suggestions in relation to the use of scale applied to the different uses of digital models, can inspire such a debate among designers and architects working with the representation of their work through digital media and models.

The claim for discussion is now that the virtual reality model relates more naturally to an experience of an actual real-world experience, than other types of digital models, because of its intricate relation to relevance through the scale of the human body. This would be interesting to discuss. Could the relevance of measure of architecturological scale be found implicitly in the VR representation? Even though the VR model is indeed a virtual reality, could it really be bringing us all the way back to Protagoras with a crispy digital “HOMO MENSURA”?

Conclusion

Despite the above discursive attempt to evade a too conclusive closure of a potential discussion, it seems fair to conclude that moving into the virtual reality model has the potential to re-introduce measurement on the scale of the human body in a hybrid relevance of digital rigidness and sensous bodily non-scalability.

Using the term borrowed from Philippe Boudon it seems that the virtual reality model potentially sustains the architecturological scales of reference, measurement and relevance, if applied with the fundamental understanding of the right level of detail and interaction in the model.

Through the virtual reality case study introducing the virtual wheelchair, it can be said that all scales from reference and measurement to relevance are in use. Consequently, the sensation of spaciousness relates to firstness. The actual physical measurements of a wheelchair, and the relevance of the body, relates to sencondness. The fact that legislation is questioned, based on the virtual reality model, relates indirectly to thirdness. This points to an actual possibility of capturing more relevance of measurement in dealing with the virtual reality representation than a mere reductionist cartesian dimensionality or a purely visual representaion of the world. In other words: this type of virtual reality model implicits human scale.

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