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## **VR|DMA – Virtual Reality Design Methods & Application VR/AR in Urban Design**

### **Abstract**

*Virtual- and Augmented Reality (VR/AR) are core products in (serious-) gaming environments. Nevertheless, in Architecture and Urban Design practice these technologies are rarely used. If used, they only play a part in visualisation of the final design.*

*In our strategy we aim to use VR/AR for design, evaluation, assessment, visualisation and communication. From this perspective VR/AR are an effective means to provide inside in the design for practitioners and students and to communicate design proposals with laymen (citizen participation). In this position paper we will address the use of VR/AR in urban design education and the application in research and practice.*

*In education we are running a pilot in a BSc design studio in which students learn computational design skills based on specific tools, i.e. density, land use, mobility and climate. Key is designing immediately in 3D, using AR to overlay 3D models, quantitative assessment of 3D models using specific scripts, and qualitative eye-level evaluation in VR. In our research projects VR/AR provide an experimental platform for citizens engagement and collaboration with practice. VR technology plays a key role in involving citizens and government bodies in the design process from analysis until synthesis.*

*Our institution hosts a “Creative-Industries Field Lab” called “Virtual Reality Design Methods Lab” (VRDML). The focus of this lab is to use VR in the process of designing, modifying, and re-using new and existing buildings, city districts and landscapes. This lab offers the necessary space, equipment and staff support for selected small and medium enterprises (SME's) in architectural services industry to get acquainted with VR as a new technology. Developed knowledge and tools are used for education and research. Besides, the field lab is a driver for the research agenda and framework.*

*This multi-core approach in education, research and practice provides an integral base for development and application of VR-technology in urban and architectural design. The use of 3D and VR is not limited to visualising geometry and materials, but also includes qualitative and quantitative analytics. (309)*

## Introduction

This paper on the use of Virtual Reality (VR) and Augmented Reality (AR) in Architecture and Urban Design is based on the premises that VR and AR will have great impact on the design process. We expect it to do so in four ways in particular: Firstly, VR will be a powerful tool for developing and proofing of spatial design concepts (Araby, 2002; Bellini, 2016; Chen, 2011; Milovanovic, 2017); Secondly, VR will enable collaborative 3D design at a distance (Portman, 2015); Thirdly, VR will improve citizen participation (Heydarian, 2015; Schubert, 2012); Finally, VR will increase the comprehension of spatial data (Chen, 2011; Portman, 2015).



**Figure 1.** Virtual Playground (image by Institute of authors).

### *Why AR/VR?*

Today, Virtual- and Augmented Reality technologies are core products in (serious-) gaming environments. Besides, large companies, like IKEA, car manufacturers and the aerial industry, use VR and/or AR technologies to promote or test their products. Nevertheless, in architecture and urban design practice these technologies are rarely used (Hanssen, 2017). If used, these technologies only play a part in visualisation of the final design. The products that architects, urban designers or landscape architects design are too large to discuss with clients using 1:1 mock-ups or 3D prints. Up to now, 2.5D representations (print or screen) or 3D scale models are being used, together with video. These representations lack the actual experience of scale. Designers, potential users or clients are not able to immerse in an experience that comes close to the impact of the real object when it is built (Schubert, 2012; Araby, 2002). VR reality offers exactly that quality and becomes potentially an important method in the design process of

architects, urban designers and landscape architects. In our strategy we aim to use VR/AR for design, evaluation, assessment, visualisation and communication. From this perspective VR/AR technologies are an effective means to provide inside in the design for practitioners and students and to communicate design proposals with layman.

*What is AR, VR, MR? A short definition.*

*Virtual Reality (VR)* provides a fully artificial digital world. People use a headset to fully immerse into an artificial environment and walk or move around that environment by themselves (Wikipedia). Hardware: HTC Vive, Oculus Rift (Bellini: Goldman Sacks, 2016).

*Augmented Reality (AR)* overlays virtual objects on the real-world environment with spatial registration that enables geometric persistence concerning placement and orientation within the real world (Wikipedia). Today AR Kit (Apple) is capable of recognizing objects in front and behind virtually placed objects. Hardware: Smartphone, Tablet (Bellini: Goldman Sacks, 2016). Example: IKEA Place AR app, Ingress<sup>1</sup>, Pokemon Go<sup>2</sup> (Boulos, 2017).

*Mixed Reality (MR)* not just overlays, but anchors virtual objects to real-world objects and allows the user to interact with combined virtual/real objects (Wikipedia). *Open AR Cloud* will improve the connection between the physical and digital worlds (OpenARcloud.org)<sup>3</sup>. Hardware: Microsoft Hololens (Bellini: Goldman Sacks, 2016).



**Figure 2.** HTC Vive: VR headset and controllers as used in our Education and Research (image by Institute of authors).

*Setup of this paper: Application of VR/AR in Education, Research and Practice*

In this paper three fields of application of VR/AR are described: education, research and practice. In education VR and AR are used to improve design education using new technologies and provide better insight in the design. In research VR is used to collect feedback on design scenarios by registering experience of the participants and on the tool itself. Finally, in the VRDML field lab VR is used for collaboration with practice.

## **Education**

In 2016 we introduced *VR and AR technology* as part of our design methodology in the 'Computational Design' pilot track as part of a BSc design studio: both VR/AR tools were used *from day one* and are a main component of the daily design process. Besides, our VR-lab developed new applications to improve the use of VR/AR: the VR multi-player and an AR interface (Freeke, 2017). The BSc design studio is a 10 EC (10 weeks / 280 hrs workload) part-time course<sup>4</sup>. This studio is the third design course for the 'Architecture and Building Sciences' students, the first 'Urban Design' project.

The pilot consists of four weeks thematic exploration with specific digital tools in groups, a design masterclass and five weeks for individual urban design project. The exploration contains an introduction into 3D drawing, building the 3D environment and application in the VR and AR environment. Theme of the first week is 'The City at Eye-level perspective'. In the second week "Landuse and Density" are explored. The third week explores mobility: Accessibility, Centrality and Gravity based on the UNA toolbox<sup>5</sup>. In week 4 Climate is explored including Urban Heat Island (UHI), Temperature, Energy Potential, Wind and Water. *In all exercises the current situation is investigated, and multiple designs alternatives are prepared*, improving the specific aspect researched. Finally, a masterclass is organised exploring specific topics in more depth and accelerating the design process.

### *Application of VR and AR*

*All designs are made and evaluated in 3D with VR at eye-level and from bird-eye view or projected with AR on a specific surface using iPads or Smartphones (Milovanovic, 2017).* Students draw in Rhino and use Grasshopper scripts for the thematic analysis and calculations in automated workflows. The outcomes of all studies are projected in the 3D environments: visual performance, density, climate performance etc. The results are exported to VR/AR using Sketchfab<sup>6</sup>, Enscape<sup>7</sup>, IrisVR<sup>8</sup> or using other available apps<sup>9</sup>. For high-quality experience in VR, a time-consuming conversion to Unreal engine or Unity software is necessary. Optimisation of the base model and the designs interventions is crucial to have a working model in VR. Today, more plugins exist to render Rhino real-time into VR or build AR apps to show the designs in a scaled model. *From our perspective, the next level is to use AR at the*

*project location to assess the design in its real context.* Especially, to discuss the projects with the students, the multi-player is essential to 'walk' simultaneously with the students through the design in VR (Freeke, 2017). At the moment up to 16 students can join a full immersive presentation of the design.



**Figure 3.** VR in Education (image by Institute of authors): from Rhino to Unreal engine for high-quality presentations.

### *Results/Conclusion*

Although this paper doesn't draw in detail a comparison between the different design approaches, respectively analogue and digital studios, some observations can be shared:

*-Do students in the studio with AR/VR design quicker?* No, more time is used for the 3D models, optimizing the models, acquiring material. Nevertheless, students start thinking earlier in 3D and from eye-level perspective.

*-Do students in the studio with VR/AR design better?* No, the designs do not discuss different topics or result in better performing designs. Nevertheless, it is clear that the designs have a far more 3D, spatial component than other design approaches.

The objective is to introduce digital design skills to the students. According to their feedback, they especially benefit in adjacent projects with ongoing growth in digital skills. The students benefit from easier, quicker design iterations and connection to data facilitating data-driven design or parametric design (Araby, 2002). *The exact contribution of this technology requires*

*comparative research between the 'digital' and 'analogue' students. This will be addressed in future research on design education methods.*

### *Discussion*

Three major topics will be discussed in this section: the impact of digital design on the (design) studio, the impact on tutoring and the scalability of VR in education.

Studio: Although this way of working accelerates design as students have to decide quicker, get better insight and material is exchanged digitally with mentors, a major setback is that due to that everything is digital, the studio looks 'empty'. Normally, design studios are a mess of models and drawings. Though we save the environment from printing and using modelling material, the ideation and conceptualisation needs to be supported.

Tutoring: Another setback is that most conversation between students and mentors are on-the-fly: students prepare less for their explanation and discussions are distracted by all kinds of information popping up at the screen during the mentoring.

Dependency on software: Another setback is that availability, versions and capabilities software changes yearly. For every studio the whole workflow needs to be reviewed, tested and updated.

Scalability: running the track with a small group of students and dedicated teachers has been proved successfully. The question is how to scale the VR/AR facilities up to the whole studio.

Opportunity: New improvement for coming year is the use of mixed reality using the Apple AR app: base models of the current situation will be provided. With AR layering additional buildings, changes or more detail will be added to the scenery. The new AR kit is able to make a distinction between foreground and background objects, placing virtual objects at the true position in the mixed-reality view. Besides new layers of data will be provided offering students to interact with their model and see performance of different scenarios and solutions.

## **Research**

### *The Project*

While experimenting with VR in education, our group was approached to participate in a multidisciplinary project on "Public Space, Health and Well-being"<sup>10</sup>. In this project VR/AR was foreseen as an experimental platform for citizens engagement and collaboration with practice. The objective of the UDIHiG project is to improve health and well-being by spatial design. The project is a collaboration between TU Delft and the Municipality of Groningen, the City Architect, the local university (RUG), the local hospital (UMCG), the local health services (GGD) and local representatives. In the first phase of the project a pilot location was selected: Paddepoel. A huge issue is that the central shopping mall is surrounded by a circuit of roads

with high intensity of motorised traffic. Objective of the first phase was to investigate how to improve accessibility of the shopping mall for elderly in order to stimulate active behaviour, provide better access to healthier food and increase social interaction.



**Figure 4.** VR in Research (image by Institute of authors).

#### *The role of VR*

In this project the role of VR was to provide a novel platform to better engage citizens in the development of their surroundings. The starting point was that 2D maps and 3D images do not provide enough insight to laymen to assess design scenarios adequately (Schubert, 2012; Stauskis, 2014). VR provides a full immersive environment which can be experienced at scale 1:1 from eye-level perspective. During the pilot phase both the virtual environments as well as VR as an instrument were assessed.

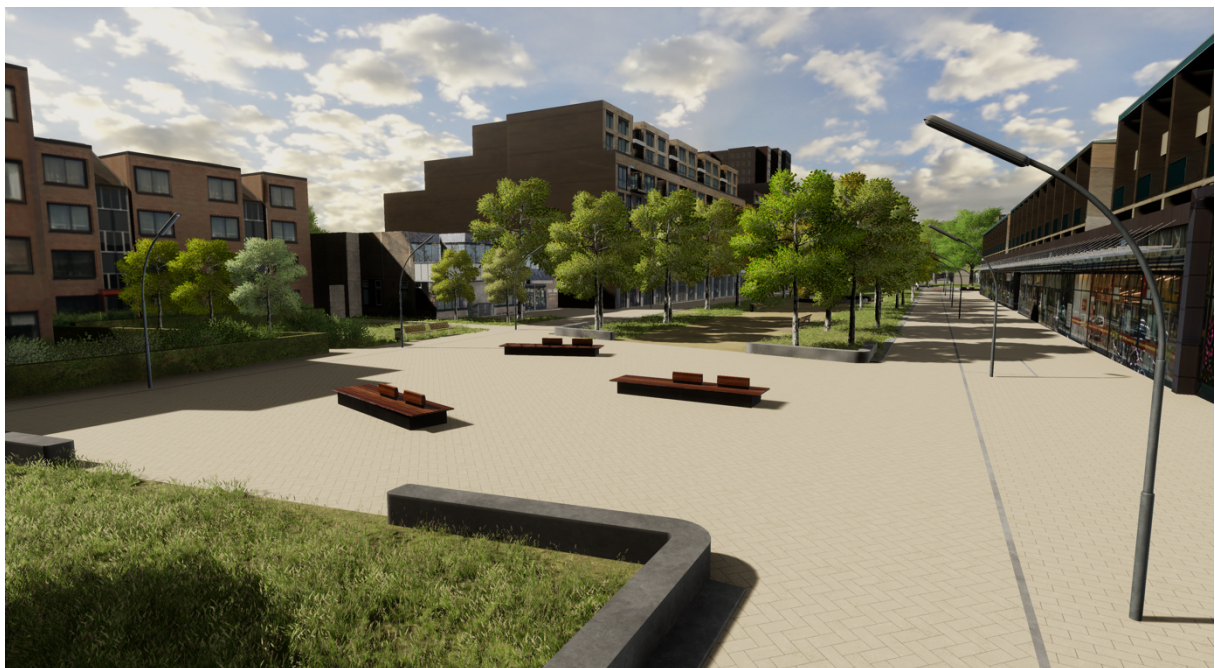
A requirement from the participation Institutes was an approval by the Human Research Ethics Committee (HREC). In the application a data-management plan, a privacy protection strategy and a risk analysis plan have to be written. The risk of using VR is limited to nausea and motion sickness (Heydarian, 2015). To limited the risks for the elderly participants in this research, TU Delft took several measurements in the experiments: (1) motion was limited to 360° viewing from predefined viewing points, (2) limiting time to 15-20", (3) if necessary, people can sit and (4) participants are always assisted and monitored by staff. The HREC was approved.

*The pilot (application/process)*

The project started in Fall 2018 with an analysis and definition phase. As a result, four problematic locations were selected by the project team. These four locations were converted into 3D and evaluated in VR by a selection of elderly residents in the first workshop. This first workshop, organised in a community building in the neighbourhood, consisted of: (1) a general introduction presentation covering the project, aims and setup of the workshop; (2) a personal questionnaire investigating health and well-being conditions of the participant; (3a) evaluation of the four selected location in VR and (3b) experience of the VR.

Based on the feedback of the first workshop, the City Architect prioritised two locations and developed design scenarios for these locations. In Spring 2019 a second workshop was organised. In this workshop, (0) the current situation, (1) a minimalistic design and (2/3) two strategic design scenarios were tested by the participants using VR. For both locations the respondents answered standard questions regarding the design, physical safety and social security for all three design variants.

In Fall 2019 a third workshop will be organised to communicate the results of the pilot to the participants and residents. The results from the first two workshops will be used by the City Architect (1) to adapt the minimalistic design and (2) to develop a new design scenario which will be presented in VR. In the final workshop, VR will be used to communicate an extended version of the design scenario.



**Figure 5.** 3D Environment of Scenario 2 used in Behavioral Research (image by Institute of authors).

### *Results*

In the initial workshop 13 elderly resident with an average age of 65 years participated. From the four locations which were evaluated, two locations were prioritised based on the feedback on physical (un)safety, the frequency of use and the intensity of motorised or bike traffic. Both locations are informal crossings at the moment and are therefore not (well) supporting crossing the busy roads for pedestrians. A significant aspect is that many elderly have either visual or physical limitations.

In the second workshop 9 original respondents participated and 22 new respondents. This workshop was spread over two days. The sessions were carried out in smaller groups and three VR systems were applied parallel. The respondents answered specific question on experience, barriers, attractiveness, visibility, social- and physical safety for three variants: (1) a minimalistic in which only zebra-crossings were added, (2) a scenario reducing traffic by introducing shared space and (3) a scenario limiting traffic and adding more green. Based on both the quantitative technical questions and qualitative responses, scenario 2 scored the best. After finishing the VR respondents were asked their general preference. This outcome contradicted the earlier responses, as respondents here preferred the last scenario (3). A possible explanation is that at the end respondents firstly prefer a greener environment and secondly hesitate the uncertain implications of shared-space.

The participants spend more time in the VR than expected based on dry runs in the lab. A key cause is that local participants intent to answer much broader, give extended context to answers and like to tell stories and anecdotes. The durations did not affect their responses. An important success was that 100% of the participants was willing to join a follow-up workshop.

### *Discussion*

Four topics will be discussed in relation to the use of VR for participation in research projects: the representativeness of the respondents, the Level of Detail, the Representativeness of VR as a method and the scalability.

Participants: The initial phase of the project focused on a limited area/assignment and also limited user group: only the accessibility of the central shopping mall by elderly, less mobile residents. An important characteristic of this user group is that they do not only move on foot, but also use rollators or motorised scooters. On the other hand, they move far less by bike. This group does not represent the community in the area. The proposed interventions will never be a one-to-one translation of this research based on this group only. Therefore, also general knowledge from literature and practice is used to define the issues and develop design interventions. *An essential question is how to incorporate multiple user perspective, satisfy the weakest group, but balance the interventions for all users.*

A main response from the participants is the Level of Detail (LOD) (Biljecki, 2014; Chen(R), 2011): which level is appropriate for which (research) question? How far does VR have to go in mimicking the real-world (Bouwman, 2007; Paes, 2017)? For our project we had two main questions: what LOD to deliver at what stage and adding animations of other users, i.e. pedestrians, bikes, cars and buses or not. For this project it was concluded that too much detail in the beginning is not necessary. The key is the experience of public space and the performance of the overall model, not details of buildings. Nevertheless, a too abstract environment is difficult in scale to interpret for laymen. Adding simulated people and cars improves the reality, but also disturbs the experience of public space. If interactions are not part of the research, these features should be left out to reduce interference. In a final design communication, these features can be added to show changing use of space by different modalities and the implications of the spatial design.

What is the value of the answers of the respondents in VR? How are the results compared to the real world? The conclusion was that this project cannot provide answers for this. More insight is absolutely necessary, e.g. by experimenting with control groups: Future research should cover parallel experiments in VR and with other methods, to define a ground truth on the impact of VR hardware, LOD, way of moving (free versus pre-defined), other simulated traffic in relation to the characteristics of the respondent (Paes, 2017). This will be a key topic in our future research agenda.

Scalability: Using VR the user group is able to provide very detailed and accurate feedback on the problem analysis and design solutions. Nevertheless, this way of working is labour-intensive. With four VR stations (three operational, one backup), it takes in average an hour per respondent for the general introduction, the questionnaire and the VR session. In one hour, six respondents can be taken through the whole process. A crucial question is how scalable the method is as research instrument, both in spatial area covered, topics covered and number of participants. From our perspective, here the multiplayer as well as an integrated questionnaire can play an important role to provide digital aids to have more parallel VR sessions. Now a respondent is monitored and questioned by staff. In the ideal situation the questionnaire is provided by a digital tablet in VR. Besides, more measurements will be carried out. In the next chapter 'Practice' tools are developed which will provide automated data collection in VR, providing more tools and underpinning of experiences.

## **Practice**

### *Field lab*

Since 2018 the TU Delft hosts a Creative Industries Field Lab. The name of the field lab that is the subject of this application is Virtual Reality Design Methods Lab (VRDML). The focus of this field lab hosted at BK-City is the use of virtual reality in the *process of designing, modifying,*

*and re-using new and existing buildings, city districts and landscapes.* Although the concept of virtual reality (VR) is around for quite some time now, it is only recently that the use of VR in the architecture services industry is picking up with pilot projects, exhibitions and through education projects. This project aims at accelerating this uptake process in the Netherlands. The field lab offers the necessary space, equipment and staff support for selected small and medium enterprises (SME's) in architectural services industry to get acquainted with VR as a new technology. It enables these SME's to co-develop with TU Delft staff new applications that will increase the competitiveness of their design-led firms in the (international) market.

The area of use of VR in this field is the design process. The products that architects, urban designers or landscape architects design are too large to discuss with clients using mock-ups or 3D prints. Up to now, 2D representations (print or screen) of 3D models are being used, together with video. These representations lack the actual experience of scale. Designers, potential users or clients are not able to immerse in an experience that comes close to the impact of the real object when it is built. VR reality offers exactly that quality and becomes potentially an important method in the design process of architects, urban designers and landscape architects.

The field lab will issue two research calls in 2018 and 2019. The calls will invite design-led firms in the architectural services industry to submit a so-called two-pager. The SME should describe in two pages A4 the nature of the VR-experiment and the application of VR in architecture, architectural engineering, urban design, landscape architecture, spatial planning, and geo-information. Additionally, it should make a case how their experiment / experience / concept will strengthen the services that are provided by the SME.

Each project can request for support up to a maximum of €20K. A project applicant matches the required funds in cash or in-kind. A cooperation agreement with TU Delft is to be signed before kicking off the project. The agreement aims at ensuring that the private contribution does qualify in the process of obtaining so-called PPS-allowance for the Creative Industries. The field lab will provide the space, facilities, materials and the staff (working hours) that are necessary for elaborating the selected proposals. In case the applicant has sufficient experience with issuing and managing research calls of a limited size, both in the case of calls that target academics and calls that target SME's a larger budget can be requested (up to €50K). It also brings the experience of tutoring such projects.

### *Projects<sup>11</sup>*

Currently two projects are running in the field lab: The *City at Eye-Level* with STIPO and BSAF and *VRenovate* with Mateboer.

The *City at Eye-Level*: Together with the companies STIPO and BSAF a workflow between designers and developers was set up to create VR city simulations from Revit (BIM). Using VR

different planning options for the urban environment were tested by the actual future resident. The novelty is that the simulations were used to record behaviour of the VR users: both *actual movement tracks* in the virtual environment and the *eye-tracking* data.

The *VRenovate* project works on an architectural scale. Here the assignment is the use of VR for communication between housing association, constructor and residents during a renovation project, as well as to aid the inhabitants with design choices for their social rental house.



**Figure 6.** VR in Practice (image by Institute of authors).

### *Results*

The City at Eye-Level project delivers two valuable features for the research projects: the movement tracking and the eye-tracking tools. Besides, in this project dynamic cars and pedestrians are introduced. The movement tracking data provides information on the logic of space and the patterns people will possible walk, or not. This is comparable with tracking and application in design the real world (Schaick, 2008). The Eye-tracking data provides crucial information where people look and for how long. Especially this information is valuable for the design of urban form, the streetscape and the positioning of landmark buildings.

The research in the *VRenovate* project revealed information on the choices inhabitants make, and the contribution of VR for easier communication. An important feature for other projects was the use of 360° sound to simulate construction works. This feature can be used in future research project to improve mimicking of the real world.

### *Discussion*

Conclusion: The projects are small building blocks, answering research questions from practice, which facilitate future research projects. On the one hand, the projects help practice out in a technical field they would otherwise not be able to integrate into their projects, on the other hand, development versus technical aid must be balanced to prevent unfair competition. The way the field lab is set up provides a structure for acceleration and innovation, which is essential in this field. A requirement is that after finishing the project developed knowledge, methods and tools must be transferred to practice as open source.

### **Conclusion & Discussion**

The most important observation is that VR/AR can provide 1:1 simulations of virtual futures, providing insight in design alternatives in architecture and urban design for designers, students, stakeholders, citizens or other participants: Both VR/AR provide freedom to walk through virtual objects, choose your own route and choose your own viewpoint. The technology was applied in education, research and practice. All fields can benefit from VR/AR, but for each field several research questions emerge as well. Based on the exploration in this paper, we will address the following topics in this final section: VR as design tool; VR as evaluation tool; Level-of-Detail; And the requirements to optimally make use of VR.

#### *VR as design tool.*

The use of VR as a design tool has obvious benefits for the quality of design, but also requirements: without the ability to validate in VR and without quick workflows for preparing 3D or interacting with VR, the benefit is limited. Understanding how and what to evaluate in VR is crucial. *A framework to research this will be setup in the future VRDMA lab.*

A first example is in the research project *UDIHiG: Urban Design for Improving Health in Groningen*. Here VR was originally only used for evaluation by the residents, but during the project the added value of VR was acknowledged for the design team itself as well. In the initial process the design team from the *City Architect* delivered 2D drawings which were translated to 3D and prepared for VR by the academic team. In the last stage the design team will participate in the conversion and interact with the design, before it is communicated to the community during the final event.

A second example is the practical project *City at Eye-Level* in which was revealed that by producing the VR for communication with residents specific design questions arose. These questions were not discovered during the design phase. Here the design project was forced back to the design table and VR was introduced to test the design.

A last example is education, where students start with the 3D environment instead of ending with 3D images when the project is finished. Although it is limited to observations, using this

methodology discussion shift and students are more aware of the 3D implications of their designs. But full proof of the benefits has not been researched or delivered so far: Do students design better, quicker or get a better (spatial) understanding?

The main question is what makes VR a design tool and how can this be arranged in an optimal way? How can we scale up VR in the classroom to cover full curricula with VR?

#### *VR as evaluation tool.*

VR as an evaluation tool is an objective in itself and a prerequisite for being a design tool. VR can be seen as a 3D evaluation tool in case citizens participate in the evaluation of design proposals in VR. Another example is in case a stakeholder, municipality or teacher evaluates a design made by a design firm, project developer or student. This requires not only technical knowledge about workflows, but also requires experience and insight how to evaluate these designs in VR. *Experiments with control groups are key aspects of the future research agenda.* The question is what the influence/bias of VR is on the evaluation (Jones, 2008)? How reliable is it? Does it cover all (essential) aspects of the design or does it emphasize on a limited set? Does this method of analyzing replace existing tools like models and drawings or is it an additional tool? Do evaluators using VR make different, better decisions?

#### *Level of Detail (LOD)*

LOD is a term which pops up in 3D and VR/AR like privacy does in data science. LOD is highly related to the performance and experience of VR/AR. The LOD can be arranged by extended geometry and by sophisticated imaging (ref). Both ways have advantages and disadvantages. LOD is seen as a research field on its own.

The choice for LOD depends on the project, the research questions and the objective of visualization: The more detail, elements, or materials, the more time-consuming, expensive, complex and slower the model becomes. LOD is not an average for a whole project but can be differentiated within the model: A general rule used in the 3D projects is to limit details on parts which will not be visible and only to extent materials and details for the key places of the design. Another lesson learned is to limit the use of beautiful libraries, but build 3D objectives yourselves, eventually in a multiscale<sup>12</sup> approach.

Returning questions in practice and research were: which LOD is expected? what is the influence of LOD on the experience? How can performance and LOD be balanced?

#### *Requirements for optimal use of VR:*

A base requirement for all projects in education, research and practice is a clear workflow, aligning the capabilities of the hardware, performance of the software and the requirements

from the project. Besides the way the model is organized, the Level of Detail and the scale/size influence the performance.

An important aspect for using VR is the complexity and duration of the workflow between CAD/BIM application and VR application (Yan, 2011). Expertise in several specialistic programmes is essential to build high quality VR applications. Originally, gaming engines like Unity and Unreal Engine were essential (Johns, 2006), but time-consuming stages in this process. In 2016 students who wanted to deliver a high-performance VR had to deliver their final project one week earlier to process the application. Today, smart plugins can provide a live connection the CAD/BIM and the VR application. Of course, platforms like Unity and Unreal Engine provide far more powerful features for visualization (Johns, 2006).

On the one hand changing hardware and new plugin software offers opportunities for improving the workflows in VR, making VR more accessible for everyone, on the other hand the weekly updates destabilize workflows.

The question is where we are in five years? What dot can we put on the horizon for the use of VR in education, research and practice? Can we already roll out the use of VR to a whole curriculum? Is that a valuable method? What is necessary in hardware, software, support and facilities to achieve that? What research questions do we have to formulate to reach this objective?

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## Endnotes

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<sup>1</sup> Ingress by Niantic: <https://www.ingress.com/>

<sup>2</sup> Pokemon Go by Niantic/Nintendo: <https://pokemongolive.com/en/>

<sup>3</sup> <https://www.openarcloud.org/> : Building a better Reality Together, accessed 23.09.2019

<sup>4</sup> The Computational Design track ran in 2016, 2017 and 2018 in the Urban Design studio. The track covered in average 20-30 students from a total of 360 following the studio. Three teacher with background in design and programming were assigned to the track. Besides the track was supported by student assistants to assist with the VR and AR integration.

<sup>5</sup> Urban Network Analysis Toolbox by City Form Lab : <http://cityform.mit.edu/projects/urban-network-analysis.html>

<sup>6</sup> Sketchfab is a plugin/app which export models into VR and AR format and makes these available on an online, shareable platform. <https://sketchfab.com/feed>

<sup>7</sup> Enscape is a plugin which provides a real-time link between the CAD/BIM programmes and the VR interface. <https://enscape3d.com/>

<sup>8</sup> IrisVR provides a seamlessly integrated platform for several 3D formats and VR headsets. <https://irisvr.com/>

<sup>9</sup> Apps and plugins for VR are under constant development. The institute provides licenses where applicable to guarantee optimal workflows and integration, but students can choose other freeware or trial versions as well.

<sup>10</sup> UDIHiG : Urban Design for Improving Health in Groningen. The project will be elaborated on in another paper, specifically addressing the use of VR for participation and co-design, the statistics of participants and results of the workshops.

<sup>11</sup> The projects in this section are only discussed minimally. Separate papers on the different projects are in preparation.

<sup>12</sup> Multiscale approach: objects have different shapes depending on the scale used: at larger scales details disappear to improve visual performance.