The Augmented Design Process

Research into the integration of VR and AR into the architectural design process

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Abstract

Virtual Reality and Augmented Reality have the potential to enhance the capabilities of the architect. This thesis explores the implications of the integration of these technologies into the architectural design process. It provides a theoretical framework by discussing what VR & AR would mean to the architect's workflow, and to his workspace. In doing so, VR & AR are not regarded solely as tools or media, but also as a potential design environment. This is reflected in the main research question: "What are the implications of using VR & AR as the workspace in the architectural design process?" As a conclusion of the theoretical framework a personal view of a possible virtual design environment is argued.
The thesis also provides a practical framework in the form of a comparison between the 'traditional' design process and the 'augmented' design process, which is based on a set of VR & AR experiments done during the design process of the 'University Forum for the TU Delft'.
The underlying function of this thesis is to kickstart the discussion on VR & AR in the architectural design process.

Keywords: Virtual Reality, Augmented Reality, Architectural design, Design environment

“I think we are at the dawn of a new age in human history. There have been four major historical eras defined by the way we work. The hunter-gatherer age lasted several million years. The agricultural age lasted several thousand years. The industrial age lasted a couple of centuries. The information age lasted a few decades. And now today we are on the cusp of our next great era as a species: Welcome to the Augmented Age.”

- Maurice Conti at TED (2017)

Table of contents

Introduction

What futurist Maurice Conti means with the 'augmented age' is that we will enhance our human capabilities by computational systems. Systems that can help you think, robotic systems that can help you make, and digital nervous systems that connect you to the world far beyond your natural senses (Conti, 2017).

As a practice of visual imagination architectural design can also be augmented through technology. Especially through technology that can aid us in visual perception, like Virtual Reality (VR) and Augmented Reality (AR). This is why a lot of architecture firms have already started using these technologies to visualize and present their designs to their clients. But VR and AR allow for much greater potentials than you would initially think. Some even say that VR and AR will revolutionize the way we practice architecture (Mahon, 2016) (Halsey, 2016). Others go even further by saying that these technologies will transform the way we relate to spaces and will open up a whole new design field in the form of 'Virtual Architecture' (Martín, 2016).
Whether these statements will become a reality or not, what is certain is that there is a tidal wave of technological opportunities headed our way. To find evidence of that you only have to follow the money. When we look at these last few years 230 companies have started working furiously on hardware and content for this new platform (Kelly, 2016). Facebook alone has over 400 people working on VR, which is actually not such a big surprise, seeing as they bought the Oculus Rift Company for $2 billion in 2014 (which actually was a big surprise, as Oculus was only a Kickstarter in 2012).
Also Microsoft has put in a lot of its resources to develop and market their newest product, the 'Hololens', which has total revenue of $5.2 billion. Seeing this product, and all of the potentials it offered, was actually the initial spark for me to do my graduation project about VR and AR. Even though the Hololens has been on the market for a small period of time, it has already shown that Augmented- and Mixed Reality can, and will, have a big impact on our way of life.
The most interesting company at this moment however is probably 'Magic Leap'. A startup-company that has never had any product or service on the market and is extremely secretive about what they are developing. All we know is that they are working on Augmented- or Mixed Reality technology. Despite that, they have received up to $1.4 billion in funding, of which most came from Google (Kelly, 2016).

All of this shows how much big tech companies, like Facebook, Microsoft and Google, believe in the uprising of this technology, and what their

significance will be. When (not 'if') VR and AR are fully incorporated in our lives, like computers and phones are now, there will be a few companies that will dominate the VR network. "These artificial-reality winners will become the largest companies in history, dwarfing the largest companies today by any measure" (Kelly, 2016).

New Realities

Virtual-, Augmented- and Mixed-Reality are terms that have existed for quite some time, but have only recently been mainstreamed. This is why there can still be some confusion over what exactly these terms imply. So I will discuss their definitions briefly.

Virtual Reality, or VR, places the user in another context entirely. Whether that location is computer-generated or captured by video, it entirely occludes the user's natural surroundings (Myers, 2016).

Augmented Reality, or AR, overlays the visible natural world with a layer of digital content (Myers, 2016).

Mixed Reality, or MR, can be seen as an extension of Augmented Reality, where the digital content is integrated into, and can interact with, the natural world (Myers, 2016).

Figure 1:
Virtual Reality Augmented Reality Mixed Reality

The way I see it there are only three kinds of realities. The real world, where no digital content is introduced. Virtual Reality, where your entire reality is replaced with a virtual world. And Augmented- or Mixed Reality, which is a combination of the real world and the virtual world. Society just has to choose which term it wants to use, Augmented or Mixed. This is why from this point on I will not use the term Mixed Reality anymore, but only Augmented Reality, as I believe that this term also covers Mixed reality, and is more descriptive of what it insinuates.

Immersion and Communication

When you start to read and think about the possibilities VR and AR can offer to the architectural practice you can become a little bit overwhelmed. The functionalities that come with this new platform seem to be endless, and every article written about it state new insights. But after reading a lot of these articles I started to notice that they provide two main potentials, namely 'Immersion' and 'Communication'.

Immersion is the potential for the architect to create and evaluate his/

her designs on a one-to-one scale. This main potential brings with it a multitude of sub-potentials; like accurately evaluating scale and proportion, providing intuitive insights, being able to spot construction issues, simulating real-world scenarios, in situ viewing of the design, better control over lighting conditions, furniture layouts and materiality, and bringing architects closer to reality by unburdening them from the persistent 1:X scales (Martín, 2016) (Mahon, 2016) (Bye, 2015).
This first main potential covers how VR and AR can enrich the way an architect designs.

The other main potential, communication, allows for the architect to bring his/her ideas across to other stakeholders in a more efficient and effective way. The building development process involves a lot of people who all have something to say about the design, and it is up to the architect to make sure everyone is on the same level of understanding. VR and AR can become the ultimate media to make sure that happens, because these technologies can show the future building without leaving much open for individual interpretation. This is not only good for the outward communication towards the client and end-users, but also good for internal communication between other designers and technical advisers (Fröst, 2000).
This second main potential covers how VR and AR can make an architect more communicative.

These two potentials, immersion and communication, can also be seen as the two main goals that we want to achieve with VR and AR, which is why they are central themes within this thesis.

A Virtual Design Environment

If we truly want to augment the architectural design process with VR or AR, than this would mean that VR or AR will need to facilitate our design environment. That way it becomes more than just a tool or a medium, but rather an environment that encapsulates all tools and media.
This is how I see the augmented design process take shape in the future; by having an environment, similar to what our PC's are now, but then fully customized to the needs of the architect. A virtual design environment that aids the architect in every possible way.

This thesis focuses on the potentials that VR and AR can offer the architectural design process, not only as tools or as media, but also as a potential design environment. This is why the terms 'design environment' and 'workspace' play an important role within this thesis, and why I deliberately say 'VR & AR as the workspace' in my main research question:

What are the implications of using VR & AR as the workspace in the architectural design process?

Workflow and Workspace

For this thesis I would first like to discuss the 'workflow', or process, of the architect, and how VR and AR can relate and benefit that process. This will be done in the first section called 'VR & AR in the Workflow'.

The second thing I would like to discuss is the 'workspace' of the architect. The workspace that I am implying here is similar to the 'laboratory' that Elise van Dooren (2014) discusses in her work, where the laboratory is the collection of tools and media (primarily sketching and modeling) available to the architect. The workspace differs from van Doorens laboratory in the sense that it also implies an environment.
Because VR and AR are also used as tools or media I would like to compare them to the other tools and media that make up the workspace of the architect and see how they relate to one another.

The third section will discuss a hypothetical view on what a VR/AR architectural design environment, or workspace, would look like, using the research discussed in the previous two sections.

The fourth and final section will discuss the advantages and disadvantages of presently using VR and AR in the architectural design process as I give a summary of my own design process for my graduation project, in which I tried to use VR and AR as much as possible.

In the end I hope to have given a convincing overview of what VR and AR can mean to the architectural design process, and why we need to prepare for its implementation.

Section 1 | VR & AR in the Workflow

Architectural design is a process that is very hard to fathom. Over the years there have been countless articles, researches and books that try to describe the architectural design process. Unfortunately most of these writings cannot go beyond the generic, because design is just too complex, personal, creative and open-ended (Dooren, 2014, p. 1). Some even say that there are more architectural design methods than there are architects.

This does not mean that it is useless to try to integrate technologies like VR and AR into the architectural design process. It just means that we have to look at how the generic elements and the fundamental principles of architectural design can benefit from these technologies, and how these could be applied.

1.1 | The fundamentals of architectural design

Philip Plowright (2014) wrote a very extensive book on the architectural design process, called 'Revealing Architectural Design', where he goes very deep into the theory behind architectural design and discusses its various methods, frameworks and tools.

Architecture as a discipline

Plowright starts of by defining architecture as a *discipline*, with a specific *domain of knowledge*. We define architecture as a discipline in order to separate it from the other disciplines. That way we know what knowledge is relevant to the architectural profession, and what is not. By having discourse we examine the content of that knowledge and explore possible new content. This discourse uses a certain language, a.k.a. the *architectural syntax*. This syntax can also be considered as the representation of the culture of the discipline. Architectural design methods will always require content from the architectural syntax in order to work.
The architectural discipline focuses on developing 'experiences through constructing physical environments' (Plowright, 2014, p. 43). This is why architecture will always be biased towards form-making, and what makes the architectural syntax very dependent on visual imagery. Using technologies like VR and AR, that push the boundaries of visual representation, can therefore be very useful in further defining the language of architecture, and making the architectural syntax clearer.

Methods

Most methods in architectural design are focused on problem-solving. This is useful because it gives us a clear goal to work towards. Unfortunately in architecture there really are no problems, but rather a complex layering of pressures, forces, perceptions, desires, priorities and values, which drive

us to practice architecture (Plowright, 2014, p. 59). This is why methods that focus on problem-solving will ultimately lead to designs with lesser qualities, because they do not focus on providing quality, or on addressing certain potentials. Methods that do try to focus on these are a lot more complex and harder to use.
But what if our design environment could support us by facilitating those methods? Architectural design methods are used to structure content, tools, types of information, suggest thinking styles, location of judgment, and points of decision-making (Plowright, 2014, p. 60). All of these aspects could be incorporated into a virtual design environment, as they do not require real cognitive thinking, just structuring of information. The heart of architectural design, and of all design, would still require an intellectual structure – the active thinking of a human designer.
Choosing a certain method to work with is important because it immediately narrows our options and starting positions, creating limits for ourselves, rather than staying open to any influence (Plowright, 2014, p. 91). The chosen method plays a big part in creating the design options, and therefore also in shaping the final proposal.

Decision-making
Eventually we need to choose between the options that are produced from working with the chosen method. Those decisions are based on your philosophical position, framing position, starting biases and judgment criteria. Plowright (2014, pp. 121-122) introduces these terms in that order, because each is built on the previous. Philosophical belief creates a framing effect, which sets up starting biases, which in turn produces testing mechanisms and judgment criteria. For example, you can use these terms to look at the idea that materialization must always be truthful (based on Aristotle's philosophy that "all things had within them an essence, which was the nature of what they are and should be"):

1. Philosophical position: Truth and honesty are important.
2. Framing position: architecture should express truthfulness and honesty.
3. Starting bias: materials and construction processes will express truth.
4. Testing mechanisms and judgment criteria: this is the way materials and constructions are truthful.

In order to end up with a design proposal that is coherent architects will always start out by setting up a framing position, starting biases and judgment criteria, upon which they can base their design decisions. Unfortunately in architecture decisions are never perfect. This is why architect make decisions that are good enough. This is a decision-making strategy called *satisficing* (Plowright, 2014, p. 158). With satisficing

decisions are temporary, until confirmed or reinforced by other decisions. For the decision-making process to be successful, and produce a coherent result, it is very important to keep track of the framing position, starting biases, judgment criteria and all the decisions made along the way. In that sense it would be very useful to have a virtual design environment that could help us do so. Having a design environment that keeps track of the decisions we have available, which of those work well together, and which fit the design goals best, can give a structure to the decision-making process like never before.

Thinking styles

Generally speaking the architect has two styles of thinking while designing, namely *divergent*- and *convergent* thinking (Plowright, 2014, pp. 137-138). Divergent thinking is also called *exploratory thinking*, and convergent thinking is also called *evaluative thinking*.

In order to find a design decision that fits the design goals it is important to first create the options to choose from. The more options you create, the more outcomes you have considered, and the more substantiated your final decision will be. One of the strengths of an office like OMA is its very aggressive exploratory phase with multiple lines of investigation (Plowright, 2014, p. 155). The most important aspect of these exploratory periods is that they are done non-judgmental and non-critical.

After having made more than enough options to choose from, the evaluative thinking starts, where it is all about synthesis, evaluation, testing, and reduction of the content. This period makes use of the framing position, starting biases and judgment criteria stated earlier.

What is important, and what a lot of less-experienced designers forget, is that these two periods should not overlap. During exploration there is no evaluation, and during evaluation no exploration. In the figure below you see a diagram of Durand's design method, where you can clearly see that exploratory- and evaluative thinking alternate each other:

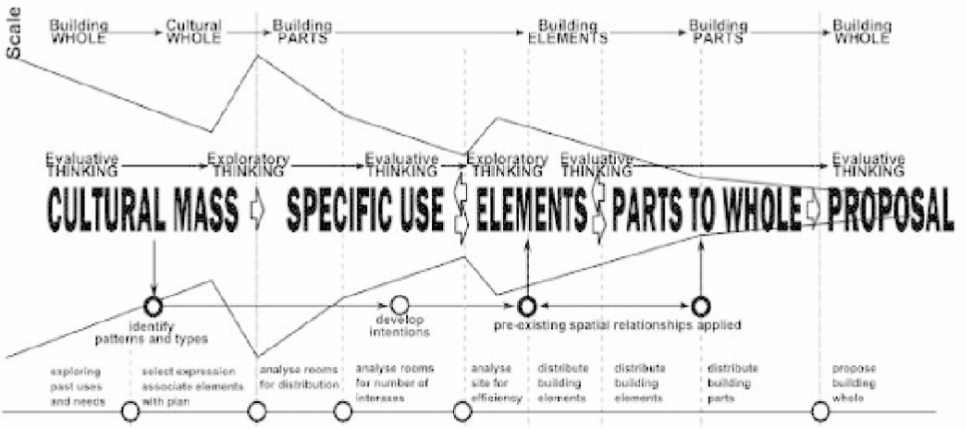


Figure 2: Diagram of Durand's design method.

These styles of thinking have been clearly described and there are multiple methods and strategies to encourage them. These methods and strategies could also be incorporated in a virtual design environment. If our design environment could encourage exploration, and discourage evaluation, during divergent phases, it would result in more design options and further exploration. And if our design environment were to encourage evaluation, and discourage exploration, during convergent phases, it would result in more effective and efficient decision making.

This is something that Hans Hubers (2008) also investigated in order to substantiate his theory for a 'Collaborative Architectural Design in Virtual Reality'. Seeing as there was not much literature about collaborative design yet to base his theory on, he had to look at architectural design in general. As he studied the different articles and theses he derived that the main processes in architectural design are "the developing of ideas (creation) and the evaluation of them with criteria in a cyclic sequence" (Hubers, 2008, p. 64). He then concluded that 'the speeding up of the creation and/or the evaluation' should be the goal of his COLADIVIR system.

1.2 | The phases of architectural design

The architectural design process is often split up in phases. The amount of phases and the terminology of those phases can differ among practices, but in the end they all try to bring order to the design process. Each of these phases has a purpose and a level of expectation. In general the phases are treated sequentially, meaning that a project moves forward to the next phase once the decisions from the previous have been made (HMH Architecture, 2017).
HMH Architecture + Interiors made a very clear and elaborate overview of their design phases. In the figure below you can see a diagram of what their process looks like:

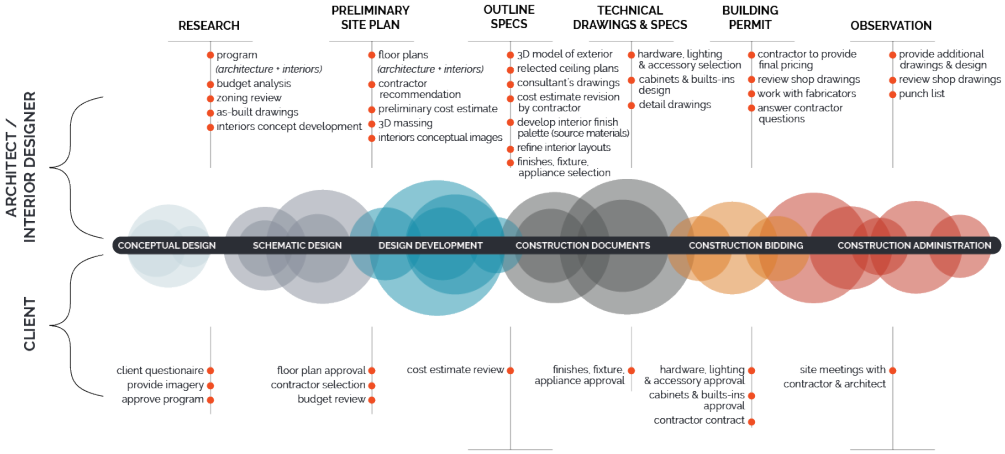


Figure 3: Architectural design phases of HMH Architecture.

They divide their process, and in extend their services, into six phases; conceptual design, schematic design, design development, construction documents, construction bidding, and construction administration. These are the phases that I will use to discuss how VR and AR can benefit the activities during those phases.
I have chosen to discuss the phases of the architect instead of that of the project manager, because I wanted to put focus on the architectural design process, even though the process of the project manager would cover more of the building development process as a whole.

Conceptual design
Before we actually start with the conceptual design phase it is important to do background studies, site analysis and discuss design approaches. Some architecture firms prefer to treat this as a separate phase, and others include it within the conceptual design phase.
With background studies it is often useful to look at similar projects for reference. Unfortunately most good reference projects are not around the corner, which limits the observation of those projects to photos and floor plans. In the future it could be very helpful to have a database of those projects with their 3D models, so that they can be studied in VR. This would give the architect a much better understanding of his/her reference projects.
Site analysis is often done by sketching over floor plans and photos. This gives the architect insights and understandings that merely looking does not provide. By introducing AR to the site visits the architect could sketch over and put marks and annotations within the real world. This can also be combined with different analyzing strategies, like SWOT- analysis.
As a lot of urban planners will tell you, analyzing a context at different scale levels is important. That is why they investigate scales from 1:10 to 1:100.000. By using AR during site visits we can also add the 'human' scale to that list.

The conceptual design phase is very important as the decisions that come out of it will dictate the direction that the project will take. At this point in the design process the architect has the most influence over what the final proposal will look like. This is why it is important for an architect to quickly understand the spatial implications of the different concepts. VR and AR can both help with that understanding, whether it is by doing mass studies in VR or by sketching and modeling in situ through AR.
VR and AR can in that respect also help to make certain design ideas clearer towards other stakeholders, providing a common understanding among the interested parties early on.

Schematic design
For the schematic design phase the same reasoning applies as for the conceptual design phase. Quickly understanding and communicating spatial aspects of a design can be an invaluable improvement to the design process. At this stage of the design process it would also be very good to involve public audiences. VR could be a very effective and efficient medium in facilitating that involvement.
During this phase it is important to look at landscape design, as the success of the exterior architecture and its surrounding landscape are very dependent on one another. Being able to evaluate, or even create, these landscape designs in situ through AR, would be a very useful tool. This would also provide a platform for better collaboration between the architect and the landscape designer.

Design Development
In this phase everything about the design gets worked out. As VR and AR provide immersive ways of looking at the design they can help with designing the lighting, furniture lay-outs, materialization, or even in designing for certain emotional or spiritual experiences.
During this phase VR and AR can provide overall quality control and quality assurance by facilitating immersive reviews in true-to-scale environments (Valdes, 2016c). These immersive reviews not only allow for the different parties to quickly comment on certain aspects, but also identify collisions, conflicts and mistakes intuitively, which usually come to light much later in the process.

Construction documents
This phase is also called the 'technical design phase' and is all about adding a level of detail and technical information to the design. Usually these technical drawings are all in 2D. In my opinion this is something that is ripe for change, as it is inefficient, ineffective, and simply outdated. Drawing a detail in 2D can be a very useful tool when quickly sketching technical principles, or to abstract technical drawings to make them more understandable. But having to make a highly detailed drawing for all three sides (x,y and z), for every differing joint in the building, only to end up with a big pile of confusing drawings, just seems illogical to me. Especially when making a 3D model of the joints takes less time, provides a clearer overview, contains more information and makes it easier to detect conflicts. The main reason why we have not implemented 3D technical models in construction is that they are less accessible at the building site. It is simply easier to take a piece of paper with you than a laptop, and less expensive to tear up your drawing when it is on paper, than on a tablet.
This is however no excuse why architects and technical consultants should not work more with 3D models. VR can in that sense provide a platform

where the architect and consultants can intuitively evaluate technical solutions, solve complex coordination issues and test modularized systems. And with AR you could even virtually simulate the entire building process on site, allowing you to intuitively detect problems with for example foundations, crane locations and site accessibility.

Construction bidding
In this phase VR and AR can help communicate the design intentions more effectively and efficiently to the potential contractors. This will leave less information open for individual interpretation, resulting in fewer miscommunications.
Another aspect of this phase is acquiring permits from the local municipalities. For that the same reasoning applies; better communication means faster negotiations.

Construction administration
During this phase the building is actually built. Here the architect plays the role of an overseer, administrator, information-provider and problem-solver. With VR and AR the architect has the potential to also play the role of training facilitator, enabling builders to practice complex or unique construction operations through VR (Webster, 1996, p. 6). This will speed up the building process and reduce potential mistakes.
AR also makes it easier for the architect and client to oversee the construction and recognize potential risks and mistakes, by laying the virtual 3D model over the actual building.

Looking at how VR and AR can benefit the architectural design process in every phase, it becomes more and more logical to implement them as a design environment, rather than separate design tools. Over the course of the design process the potential usage of VR and AR fluctuates, but will always be present. This is why I would argue that the VR/AR environment should automatically know when to be present and when to be more in the background.

1.3 | Collaborative design

One of the two main potentials of VR & AR discussed in the introduction was ‘communication’. Being able to easily communicate design ideas, not only to your colleagues, but also towards your clients and end-users. This alone can greatly improve the efficiency of the design process and the consensus on the final result.
But VR & AR allow for another potential, which can be seen as an extension of this scenario, namely ‘collaborative design’. In a collaborative

design process it is not the individual architect that designs the different design iterations, but a group of designers and other stakeholders working simultaneous. The Oxford English Dictionary describes collaboration as 'joint problem solving', or 'to work with others with shared goals for which the team attempts to find solutions that are satisfying to all concerned' (Hubers, 2008, p. 69).

As you can imagine collaborative design can greatly improve and speed up the consensus on a design project amongst the different stakeholders, seeing as they all work on it together simultaneously. This can be especially relevant during the first conceptual design phase, as at that point a decision needs to be made on which direction the design team will go. That decision can have a lot of impact on the final cost and quality of the resulting building (Hubers, 2008, p. 23). For that reason Hubers focused his thesis on this phase of the design process.
This does not mean that collaborative design is not useful during the other phases of the design process. Collaboration can actually be useful in every situation that demands a creative solution, because it promotes creativity, and facilitates a common understanding of the different design tasks and how they relate to one another (Fröst, 2000, p. 569).

But if collaborative design is this useful in theory, then why has it not been accepted in common practice? Hubers gives multiple possibilities on why this is the case (2008, p. 24). One of them is the inability for different stakeholders to exchange data properly, with as a result an inability to understand ones intentions. I believe that this is the most important reason why collaborative design has not been accepted yet in the architectural practice.

When an architect has a certain design envisioned, he/she will need to make representations of that design to communicate with the other stakeholders. The easiest and fastest representations are (or at least 'used to be') traditional 2D architectural tools, like the diagram, floor plan, section or elevation. These are however still hard to read (especially if you are not trained in doing so) and, more often than not, open to interpretation. Because of this it is only natural that the architect will design most of it individually, and only make representations at key moments in the design process. Fortunately, with the rise of 3D-modelling programs it has become a lot easier for the architect to communicate his/her ideas. The downside of this however is that modeling software is fairly complicated and every professional field uses their own preferred program.
Now we have a new potential medium on the rise, VR and AR, which can act as the facilitator for a true collaborative design process.

Collaborative Design in VR and AR

Peter Fröst and Peter Warren (2000) from the Malmö University College in Sweden organized a project where a design team, consisting of the different stakeholders, underwent a collaborative design process while working in a 'Virtual Reality Cave'. The Virtual Reality Cave functioned as a 3D modeling program that could be operated intuitively by not only the architect, but also for example by the management and the end-user (after some explanation and practice). So in other words, they came up with a way that the architect can represent his/her designs while working on it, and also make it easily understandable for the other stakeholders, giving them a better way to comment and suggest possible alternatives.

Fröst and Warren concluded that this method worked very well. The collaborative design process, enabled by VR, helped the participants by providing a method with which their ideas could be better formulated, analyzed, tested and finally realized (Fröst, 2000, p. 571). Even the end-users were successful in convincing the other participants, including the management and architect. Especially the immersive scale 1:1 environment that the VR provided strongly contributed to the forming of a 'common ground' and a 'common understanding'.

Figure 4: Virtual Reality Cave System

This project already took place 17 years ago, in a time where VR was not even heard of by most people. They required the use of an entire Cave system to facilitate their VR. Nowadays the hardware for a VR is accessible to almost anyone in the form of an HMD (Head Mounted Display), which even makes the model more immersive and of higher quality.

So if the collaborative design process has been proven effective and the hardware is readily available, why do we not see Collaborative design in VR more often? I believe this has to do with a number of things. First of all,

the VR-headset is often seen more as a cool toy to play games with, then as a tool to design with. This is arguably a consequence of people not being proven otherwise, but it does make it harder for software developers to find support for their 'Collaborative design in VR'-software.
Secondly, there is no pressing need for it. Because the architectural society is already bombarded with new modeling software every year, and architecture firms need to implement new software more and more often, it is hard to convince them to invest in yet another system, or even make them aware of its existence.

Despite the problems that VR has in order to evolve into an architectural design tool, there have been several innovations that allow for collaborative design in VR. For example, Autodesk provides software called VRED that allows for people to review designs in VR collectively on the internet (Autodesk, 2017). Because this software works over the internet the different stakeholders can be located all over the world, but still evaluate the same model simultaneously. This software is mostly meant for the automotive industry, but you can imagine that this can be just as useful for the architectural industry.
IrisVR is a company that also enables collaborative design reviews through their software (Valdes, 2016b). They do this by allowing one person to walk through the model while wearing a VR-headset, while the rest of the team can follow him/her on a TV screen. The reason they give for working this way is to add more 'quality control' and better 'quality assurance' during meetings (Valdes, 2016c). Architectural firms that used this method have experienced, among others, reducing change orders, a shorter client approval process, better and more specific client feedback, reducing mockup costs and better engagements with public audiences (Valdes, 2016a).
There have also been advancements in creating a collaborative design environment in AR. For example, ARTHUR is an Augmented Reality enhanced round table to support complex design and planning decisions for architects (Broll, 2004).

Figure 5: ARTHUR - Collaborative design in AR.

The goal of this system is to support collaboration within meetings, and in turn allow for much faster design and review cycles. They do this by giving a spatial overview of the different building blocks, by introducing different analytical tools to aid the evaluation process, and by integrating a full CAD system that allows for 3D modeling. One of the notable things that the collaboration in this system caused was that users began to see it as a game (Broll, 2004). In turn this added a strong social dimension, which enhanced the level of collaboration significantly.

What is noticeable about most of these applications is that they focus on the 'evaluation' part, rather than on the 'creation' part of the collaborative design process, making them incomplete in regards to Hubers' vision for a Collaborative Architectural Design in VR. This is probably due to the fact that 'evaluation' requires less complicated software and is easier to implement in the architectural workflow than 'creation'. Seeing as these are issues that can be resolved over time, and as Fröst and Warren have already shown that 'creation' in collaborative design can be very valuable as well, it is safe to speculate that it will not take long before the collaborative design process, through VR or (in my opinion more likely) AR, will become common practice in the world of architecture.

1.4 | Gamification

In the previous chapter we discussed the ARTHUR system, and one of the things that was notable about it was that users began to see the design process as a game. This is actually a phenomenon called 'gamification', and has recently been studied more and more, as it shows a lot of benefits. In the case of architectural design it is especially helpful to improve collaboration and encourage involvement in a project (Kapp, 2012).

So what is gamification exactly? Schnabel, et al. (2014, p. 1) gives a good description of gamification as "the use of game design elements in non-game contexts". So that does not mean that gamification turns an activity into a game, but uses elements of games to make that activity more engaging and enjoyable.
They further describe that these game elements consist of Mechanics, Dynamics and Aesthetics (a.k.a. the MDA Framework), where mechanics are the technical components of which the game is constructed, dynamics are the reactions and interactions between the game and the player, and aesthetics describe the emotional responses such as discovery, fantasy, competition or narrative (Schnabel, 2014, p. 2). This is also the order in which game designers construct a game. When applying gamification to an activity it is good to take these three in consideration, but it does not necessarily require using all of them, seeing as the activity is not really a game to begin with.

In order to understand how gamification could apply to the architectural design process we have to look at the fundamentals of gaming first. Some might think that gaming is nothing more than shooting zombies or crushing candy, but they are actually a lot more complex. In fact they would require a behaviorist, cognitive, constructive and humanist learning theory to fully understand them (Routledge, 2016, p. 28). Helen Routledge (2016) discusses the key principles behind games in her book 'Why games are good for Business'. After reading her book I found many interesting relations between the fundamentals of gaming and that of designing, which is why I would like to discuss these principles a little bit more elaborate.

Choices

At the core of games are 'choices'. This is what distinguishes games from movies, books or lectures, and what makes you an active participant. Choices in games are never just simply between A or B, but always have some sort of implication, which requires careful consideration. The freedom to make these choices does not only give you control over what you are doing in the game, but also give you a sense of purpose, making you more likely to become engaged. The gaming environment is all about giving you the freedom to make choices, whether they are right or wrong, encouraging you to make mistakes and allowing you to learn from them. (Routledge, 2016, pp. 30-32)

Architectural design could also be described as a process of choice-making. The only difference with most games however is that the choices are not laid down in front of you, but you have to make them yourself. The process of making these choices requires a thinking style called 'divergent thinking' (or 'exploratory thinking'). This way of thinking is all about imagination and idea generation, which is done non-judgmental and non-critical (Plowright, 2014, p. 137).

In that sense it would be very useful to have a virtual design environment that encourages you to make choices, whether they are right or wrong, as long as it progresses the exploration.

Feedback

The second key principle of games is 'feedback'. Everything in a game is designed to give you feedback. This is also what allows you to learn from a game and become better at it, because it allows you to understand the consequences of your actions and choices. However, in order to give good feedback the user needs to understand what the primary purpose is of the activity, otherwise the feedback would be meaningless. To that end the feedback should give answer to the following three questions:

1. “Where am I going?” The ultimate goal, which in turn consists of smaller goals.
2. “How am I doing?” The up-to-the-minute feedback.
3. “Where do I go next?” The guidance feedback towards the ultimate goal.

These three questions are what the feedback needs to answer, as the user will continually be asking themselves these questions on a subconscious level. (Routledge, 2016, pp. 32-36)
Processing feedback can be compared to ‘convergent thinking’ (or evaluative thinking), which is on the other end of ‘divergent thinking’. Here it is all about synthesis, evaluation, testing of choices, and reduction of content (Plowright, 2014, p. 138), in other words, understanding the consequences of our choices. Also the questions we ask ourselves during the design process are similar to what the feedback of games give answer to: “Where am I going with this design?” “How am I doing at this moment in the design process?” “To what part of the design do I go next?”
These questions need to be related to the primary purpose of the activity in order to give the feedback meaning. In architectural design you could think of that primary purpose as the ‘guiding theme’, described by Elise van Dooren (2014, p. 8), or as Philip Plowright describes, setting up a ‘framing position’, ‘starting biases’ and ‘judgment criteria’ (Plowright, 2014, pp. 121-123). After we have set this primary purpose for ourselves we need to relate all our design choices to that purpose. In that sense it could be very helpful if a virtual design environment could help us keep track of that primary purpose in the form of feedback.

Pacing
The third key principle is ‘pacing’, which is about regulating the amount of information that is thrown at you. As humans we cannot process large amounts of information all at ones, because we have a limited ‘Working Memory’. Pacing makes sure that you get the right amount of information at the right time. Good pacing however never happens linear, but in peaks and troughs, like good movies do (see fig. 6). This also makes it more interesting and keeps the audience engaged. With well-designed games it is even more complex, because they allow for the player to decide their own pace, through their own choices (see fig. 7). And when a game is able to cleverly balance the choices given, with the asked goal, with the information already acquired and the new information, the reward becomes intrinsic to the activity. Then the reward is the mastery of the knowledge or skill. This is why people can enjoy playing games for hours on end, without ever expecting any other reward. (Routledge, 2016, pp. 36-43)

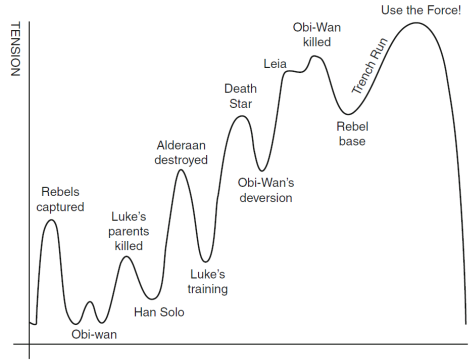


Figure 6: Pacing in movies, like Star Wars.

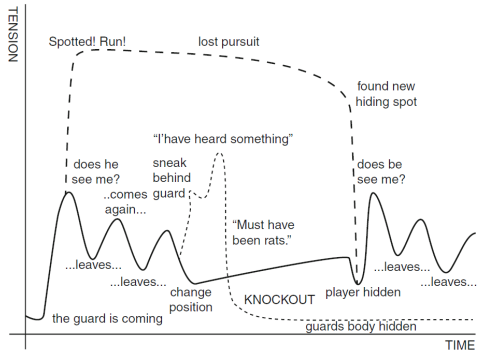


Figure 7: Pacing in games, like Assassin's Creed.

Architectural design also requires us to juggle many different inputs and chunks of information from all sorts of 'domains' (Dooren, 2014, p. 10). "These domains contain the names of elements, features, relations and actions, and of norms used to evaluate problems, consequences and implications" (Schön, 1987, p. 58). In order to make sense of these domains and how they relate to the bigger picture of the design we need to process their information, while juggling between them. Experienced designers are able to do this more easily than students and are also able to work in multiple domains simultaneously (Dooren, 2014, p. 10). However, both the experienced designer and the student still have a limited 'Working Memory', making them both take in chunks of information at a given time. In that sense it could be very helpful to have a game-like pacing system within a virtual design environment to help us regulate the information we take in. That way we get the right information at the right time, which helps us to evoke ideas and aid in making creative steps (Stellingwerff, 2005, p. 117).
Who knows, maybe even architects would then enjoy designing for hours on end, without ever expecting any other reward.

Other principles behind games include 'practice', 'enjoyment (or fun)' and 'readiness', where readiness makes sure that the game environment puts you in a state of focus and directs that focus to certain objects, scenes or events. (Routledge, 2016, pp. 43-46)

Into the Zone

What the combination of all these principles try to achieve is to put you 'in the zone' or 'in the state of flow', which is the ultimate mental state for performance. It is the sweet spot between boredom and frustration, where we work at our best and enjoy our work the most. (Routledge, 2016, p. 46)
This will most likely sound familiar to you, as you have probably been in

that state (even if you have never played a game). From my own experience I know that most of my good design ideas take shape while being in that state of mental focus. To that end it would be extremely valuable if our environment could help us get into 'the zone' by taking advantage of gamification principles.

Now that we have an idea of how gamification can benefit the architectural design process we need to find a way to implement it. In order to do that we need some sort of environment that can be regulated by computational systems. This is where VR and AR come in. These technologies are unique in their capability to alter our perception of reality and can completely immerse ourselves into the design environment. If that design environment were to be created following the principles of gamification, we could augment our design process and enhance our capabilities as architects.

In the previous chapter I said that one of the problems with the image of VR and AR is that they are seen as cool toys to play games with. Maybe this is not such a bad thing. Maybe we should just experience design more like a game, but then for a more serious purpose of course.

1.5 | Way of thinking

Whenever a discussion starts about AR or VR in architecture I often get the question: "But does it change the way we think about design/architecture?" Most of the people that ask this question are worried that this technology would negatively affect the architectural practice. Personally I would not know if it would have a positive or negative effect. Frankly, that is for the architectural historians of the 22nd century to figure out. What we can debate today however is how AR and VR could generally affect the way we think about design and architecture.

One of the things that these technologies are very good at is making design ideas tangible and understandable for everybody, including the non-professionals. The stakeholders and end-users would then be able to follow the design process alongside the architects. This could lead to more appreciation of the architecture, but it could also lead to more critique. It could lead to more input for design ideas, but it could also lead to more misunderstandings. As more people get involved with the process the design tends to be more well-considered, but it also complicates decision making.
So something that could happen is that the architectural practice shifts from an aristocracy to a democracy – the democratization of the design process.

In my opinion this is a double-edged sword. On the one hand there have been a lot of good architectural projects that have benefited from public involvement, and personally I am all for more user-oriented buildings. On the other hand there is good reason why architects have to study almost a decade before they can practice architecture. That is because they are entrusted with the shaping of our built environment. Though by involving the public with the architectural process, you could distract, or even corrupt, the architect with politics and make the architectural practice susceptible to populism.

It seems that an ongoing debate is needed on what degree of public involvement is desirable, in order to find the right balance between respecting the opinions of the public on the one hand and the expertise of the architect on the other.

Section 2 | VR & AR in the Workspace

"Architecture lives a biomodal life in the world of art and in the world of functional technical performance. (Schön, 1985, p. 30)"

What Donald Schön implies with this statement is that architecture struggles with its identity. On the one hand architecture is seen as a technically rational profession, as it is about building real world objects for real world applications, using rational sciences like soil mechanics, climatology and structural engineering (Schön, 1985, p. 31). This is why architecture is often taught at technical universities, even though the 'biomodal life' of architecture can make a university feel uneasy.
On the other hand architecture requires artistry in its design in order to succeed. This is because architecture has to pursue abstract goals, as it needs to accommodate an abstract structure of related human activities (Lawson, 1979, p. 59). In other words, because the goal is unclear, the method is unclear. This is why architecture cannot be approached purely scientific, and why the methods of a scientist cannot be used for architecture.
Scientists are taught to use certain methods and principles to solve certain problems. They use examples in order to demonstrate that they can apply these principles (Lawson, 1979, p. 66), but they do not necessarily need the solution. Architects however are taught by example and practice. They are judged by their solutions, rather than their methods. This way of working is also called 'reflection-in-action', where you start of by making solutions and then reflect on those solutions to find the potentials and implications for a certain situation (Schön, 1985, p. 50). You can also see it as a reflective conversation between the architect and the situation, whereas the more you 'talk', the clearer the goal becomes. And the more experienced you are as a designer, the more effective you are at steering the conversation the right way.

This conversation between architect and situation can only work through a medium. This medium takes form in the tools and media that architects use to produce representations of their ideas and designs, like sketching and modeling. The collection of these tools and media, together with the environment in which they are used, is what I call the 'workspace' of the architect.
So the workspace is not just a laboratory for experimentation, but is also the means, through which an architect speaks. The different tools and media are the different ways of saying what is on the mind of the architect, and by housing all of them in one environment you unify them into one language - *the manifestation of the architectural syntax*.

Defining the ideal workspace

These three sides of the conversation (the situation, the architect and the medium) are also described by Martijn Stellingwerff (2005) in his PhD thesis as the three cornerstones of his research. He describes them as 'reality' (the urban context), 'mind' (the architect's imagination) and 'media' (contextual and design representation).

In one of the essays of his thesis he describes how design media are able to reflect and mediate information of real world objects and of objects of thought (Stellingwerff, 2005, p. 65), and what the capabilities are of the different kinds of design media in doing so. In order to visualize these capabilities he creates a co-ordinate system by putting the three cornerstones on three different axes, creating a cube in which he can compare the different design media (see figure 8).

By putting the different kinds of design media in this cube you can see how much they involve reality, mind, and media in relation to one another. From point A, where there is no information about anything, to point G, where there is a perfect balance between the three cornerstones and what could be seen as the ideal design media (Stellingwerff, 2005, p. 68). In his essay Stellingwerff discusses six kinds of design media; design through contemplation, by means of traditional media, using desktop computers, within a VR environment, with ubiquitous computers, and through augmented interaction. In figure 9 you can see how these would fit in the co-ordinate system.

This co-ordinate system would be a good measurement tool in the pursuit of defining the ideal workspace; where reality, mind and media are equally represented.

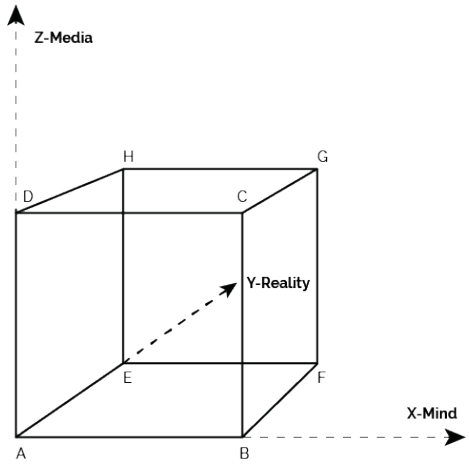


Figure 8: Co-ordinate system to compare different design media.

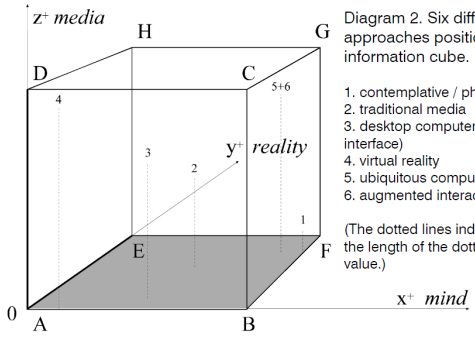


Diagram 2. Six different design approaches positioned within the information cube.

1. contemplative / philosophical
2. traditional media
3. desktop computers (graphical user interface)
4. virtual reality
5. ubiquitous computers
6. augmented interaction

(The dotted lines indicate the x-y placement, the length of the dotted lines indicates the z value.)

Figure 9: Six different design media in the co-ordinate system.

Tools and media

The workspace will ultimately consist of tools and media. Tools are mainly used to carry out specific tasks for specific domains. Unlike media, they will only do that which is told to them by the designer. Media however are open to different and even unintended uses. They are able to reflect the ideas that we invoke by our actions (Stellingwerff, 2005, p. 116). Because of this Stellingwerff argues that the architectural practice needs more design media that can enhance creativity, instead of tools that can enhance productivity (2005, p. 117).

In order to see how VR or AR could facilitate these tools and media as a workspace I will discuss the most prominent ones that make up the current design environment, and how they relate to VR and AR. The tools and media discussed in the section are *drawing, model-making, 2D CAD drawing, 3D modeling, Building Information Modeling (BIM), rendering, game engines, Virtual Reality and Augmented Reality*.

2.1 | Drawing

David Bernie (2010) wrote a very elaborate book called 'Architectural Drawing', in which he discusses the different drawing media, tools and types, and how we should try to synthesize hand- and digital drawings. Bernie begins to explain why it is important for an architect to draw.

We use drawings like bridges for our imagination. They convey the things that we cannot just simply say through speech. Throughout the design process drawings reflect 'how we think' about a project. By using the appropriate drawing techniques at each stage of the process we can make our intentions clear and move forward. This is why it is important that they convey a particular part of the design. Bernie gives as a rule of thumb that an architectural drawing should only try to show a few aspects of the design – as few as three (Bernie, 2010, p. 17). Otherwise the drawing would become unclear in what it is trying to say. Because of this, drawings can only bring across a certain amount of information at a time, so they will have to work in reference to each other to convey the bigger picture.

In general there are three kinds of drawings in regard to their purpose (Bernie, 2010, p. 16). The first are generative drawings, which try to reveal ideas. These kinds of drawings are often the most difficult, as it requires you to draw something without knowing what the end result will be. You just draw in order to discover. The second are analytical drawings, which articulate a specific aspect or concept, like diagrams. And the third are illustrative drawings, which convey the information of a design. These drawings range from perspectives to details, and contain most of the architectural drawing types.

Figure 10: Generative Drawing

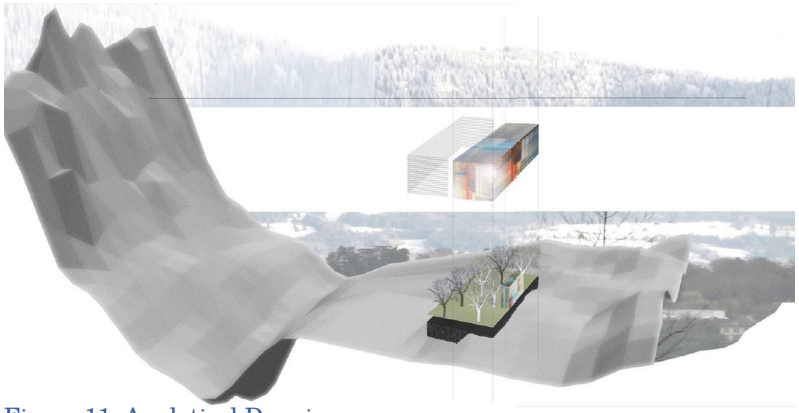


Figure 11: Analytical Drawing

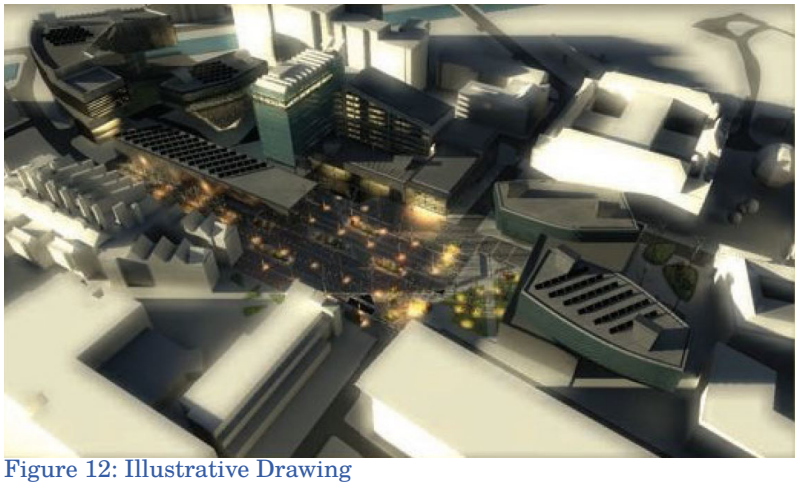


Figure 12: Illustrative Drawing

The combination of these three kinds of drawings helps to order ideas throughout the design process. Because architecture is about bringing together ideas into coherent spatial relationships, it is important to work fluidly between the different drawing techniques. A great building is never the result of one single idea, and therefore requires a multitude of drawings that work together, each using the technique that works best to visualize their respective ideas. This is why Bernie pleads for a hybrid workspace that is neither the CAD office nor the artist's studio (Bernie, 2010, p. 21). A place where the architect can easily switch between the different kinds of material drawing, CAD drawing, 3D modeling, physical modeling, and every other tool or media. This kind of workspace of the future would be able to facilitate the diversity of ideas that go into the creative process of an architect.

Because Bernie also believes that material drawing and physical modeling are of importance to the creative process and therefore should be a part of the workspace, a VR environment would not work. VR would exclude all tools and media that do not rely on virtual imagery. An AR environment however would be able to facilitate 'real world' drawings and 'virtual world' drawings in one workspace. Maybe this could be the technology that can realize Bernie's (and for a large part also my own) vision for the architect's workspace.

Even though VR would not be suited for Bernie's envisioned workspace it can still be used as a drawing tool. 'Tilt Brush' is a present-day example of an application made for VR in which you are able to draw in 3D. This application is particularly good in making generative drawings, as it allows you to freely draw in mid-air. It is of course also possible to make analytical- or illustrative drawings, but it seems that the developers of Tilt Brush focused their efforts on creating an application for the exploring artist.

Figure 13: Generative Drawing in VR using Tilt Brush.

2.2 | Model making

Nick Dunn (2010) also wrote a very elaborate book, similarly setup as David Bernie's, on the making of physical models, called 'Architectural Modelmaking'. Like architectural drawing, architects use model making as a way of communicating ideas. A significant advantage of using physical models is their immediacy, which allow architects to talk about material, shape, size and color in a highly accessible manner (Dunn, 2010, p. 10). This is because the model is a three dimensional medium, making them very provocative and easily understandable. Our perception then provides instant access to any part of the model, whether it is in a detail or in the overall view (Dunn, 2010, p. 10). This is why the main significance of a model does not lie in being able to depict the end product in plastic terms, but rather in giving the architect the means of actually seeing and controlling spatial problems (Dunn, 2010, p. 14). Most models are therefore dynamic in nature, and very dependent on the situation and the one who is using them (Dunn, 2010, p. 15).

Dunn realizes that with the rise of computers it is possible to make models much more efficient digitally than physically. Despite of that Dunn still pleads for the making of physical models to describe and explore the qualities of architecture. The first reason he gives for this is the tangibility of physical models that, unlike the cropped and flat digital ones (seen from a computer screen), offer substance and completeness (Dunn, 2010, p. 47). The second reason is the sense of authority you get when holding a miniature version, which also comes with a sense of closeness as you enter a private affair with it (Dunn, 2010, p. 47). The third reason Dunn gives is the tactile quality of constructing and handling a physical model that brings the maker in contact with the real world (Dunn, 2010, p. 48).

When Dunn wrote this book in 2010 he did not take into account the implications VR and AR would have on his reasoning. Now that VR and AR allow us to make immersive models and holographic representations, does Dunn's reasoning still apply?
If we look at the first reason of tangibility, it is arguable that VR and AR could never allow for real touch, as they are 'visual' technologies. They could however still provide a substantial and complete representation that is un-cropped and un-flat. Even more so, if we compare a physical model and a holographic representation, the hologram can be a lot more substantial and even more 'complete' than the physical. This is because someone making a physical model would always be bound by the materials and equipment available. He/she would almost never use real brick, stone or metal, or give wood the finish that the designer has in mind. With a holographic representation you would have the freedom to use any means necessary to make the model as substantial and complete as needed. In

that sense it would be more efficient and effective to use a holographic representation over a physical model.
Looking at the second reason of creating a sense of authority and closeness with a miniature version of the design, we can simply say that exactly the same can be achieved with a holographic representation using AR.
The third reason is a very significant quality that physical models provide, as architecture cannot solely exist in the imagination of the architect where everything is possible; something that a digital world also suggests. In this regard it becomes very important to make physical models that are bound by the laws of the real world, reminding the architect that architecture is also still bound by it, and should be designed accordingly. This is something that digital models will not be able to achieve. They can wake the illusion of real world implications, but it would never be as good as the real thing.

Even though VR and AR can be used to do a lot of things much more efficient and effective than the physical model, model making is still far from obsolete. "…the need for architects to engage with the tangible and physical aspects of their practice becomes ever pressing as the plethora of digital technologies grows" (Dunn, 2010, p. 492). In fact, with the rise of computer generated physical models, like CNC-milling and 3D-printing, it is also likely that we will see more hybrid models, which make use of the physical and the digital. For that, AR can be the digital half that can interact with the physical half, whether it is to put an animated virtual person in your physical model or to simulate airstreams for the climate design, or even to directly link your physical model to the digital in order to create a seamless workflow.

Figure 14: Physical model with an AR overlay of the direct context.

2.3 | 2D CAD drawing

Ever since architects started using the computer to make architectural drawings there has been a heated discussion between 'hand drawing' and 'computer aided design' (Stott, 2015). This is of course a nonsense discourse, as they both allow for very different functionalities. It is like comparing whether it is better to use wood- or steel construction, which are completely circumstantial. This is why we have to look at CAD drawing separate from hand drawing.

CAD drawing has allowed architects to adapt to a modern construction industry that has moved away from traditional craft (Bernie, 2010, p. 10). Digital drawings are now dimensionally more precise, allowing us to describe a whole building in precise detail like never before (Bernie, 2010, p. 11). This medium can bring across the information for a new building over to the fabricators and constructors, without leaving much open for individual interpretation. This has reduced a lot of the costs caused by miscommunication and wrong interpretation. It has made the workspace a lot more organized and the workflow more controlled. All in all, the CAD drawing has become a vital tool in order to illustrate and communicate building plans.

The 2D CAD drawing is however not well suited in progressing the creative process. This is why it is such a shame that a lot of architects still have to put so much time in making these CAD drawings. Architects should be focusing on design and design development, and having to make CAD drawings only disturbs that process. Fortunately, with the rise of modeling software like Autodesk Revit it takes less time to generate these drawings, as they are automatically generated as you model.

The lesson that can be taken from this to the virtual design environment is that the CAD drawings that are meant for illustration, communication and documentation should be automatically generated, or created by others, as much as possible, so that they do not disturb the creative process of the architect.

2.4 | 3D modeling software

Even though digital 3D modeling is at the center of the workspace of the contemporary architect, it has actually not been around for that long. Nowadays most architecture students could not imagine working without it, which is very weird if you think about. Architecture is one of the oldest professions, or art forms, there is, dating back thousands of years, but somehow this 50-yearold technology has become fundamental to the modern practice.
From the moment Ivan Sutherland (1963) introduced the world with the

Sketchpad in 1963, which was the first computer graphical user interface, the architectural practice was bound to change. Sutherlands Sketchpad allowed man to interact with computers without the need to learn coding. “It is a looking glass into a mathematical wonderland” (Sutherland, 1965). The Sketchpad was also the very first platform where digital 3D models could be made.

Since then software developers created hundreds of 3D modeling programs. The most used software programs in architecture include Sketchup, AutoCAD, Revit, 3DS Max, Maya and Rhino. All of them thank their basic structures to Sutherland’s Sketchpad.
And so do VR and AR, because in abstract terms they are also just a way of allowing man to interact with computers in intuitive ways. At the end of one of Sutherland’s essays he describes the ultimate display as “a room within which the computer can control the existence of matter” (Sutherland, 1965). VR or AR might not be able to control solid matter, but if we may interpret matter as virtual as well, then VR and AR are the ultimate displays that Sutherland described back in 1965.

To VR and AR, 3D modeling software is now used as a way to create content. You make the model in for instance Sketchup, through a computer monitor, and then you load the model into a different program which allows you to view it through VR or AR. Because VR and AR are just display systems through which we communicate with the computer, just like the monitor is, it is also possible to do 3D modeling directly in VR or AR. This would essentially cut out the middle man, which in this case is the monitor.
In fact, there are already a few applications that allow for 3D modeling directly within VR. Google Blocks is a very good modeling program that actually works very intuitively. It feels a lot like Sketchup in that regard. Also Unreal Engine 4, a game engine (which we will discuss later), is developing 3D modeling capabilities within the engine that allow you to 3D model within VR.
There are also some 3D modeling applications that use AR, but these are all still very basic and limited.

It will however take some time before the architect starts 3D modeling solely in VR or AR, as the interaction with the computer first needs to become a lot smoother and user-friendly. Given that this only takes time, the future design environment will most likely have the 3D modeling capabilities integrated in the VR or AR.

2.5 | BIM-modeling

As building projects became more and more complex the need for better collaborative building software arose. This is where BIM, Building Information Modeling, come in and gave the industry a new way of collaboration throughout the building development process.
BIM allows people from different disciplines to work together on one model that can represent both the physical and intrinsic properties of a building (Quirk, 2012a). So it is an object-oriented model that is tied to a database of background information. This makes it possible to add layers upon layers of additional information, which are desperately needed in large scale projects.
Another feature of BIM is that all drawings are linked. So that as the model is developed, all drawings within the project are automatically adjusted accordingly (Quirk, 2012a), reducing the amount of inconsistencies in the different drawings.

BIM represents a new way of structuring the building development team, as 3D drawing information can be shared between multidisciplinary teams, potentially in different parts of the world (Bernie, 2010, p. 15). The flexibility it gives to the process, the efficiencies it provides and the opportunities it offers to resource management are fairly obvious. However, BIM is not entirely good for the design process. There are some disadvantages to working with BIM that need to be taken into account.

The first is that it changes the way we think about scale in a project. The sequence of drawing from rough sketch to material detail represents a way of thinking where different scales reflect different scales of thinking (Bernie, 2010, p. 15). BIM forces designers to go into more detail and lower scales, making it tough for designers to keep their focus on their current scale. For example, drawing a wall on paper with a thick marker makes you think about how that wall will impact the space, while drawing a wall in BIM software makes you think about the properties of that wall as it forces you to immediately type in the thickness, material, cost, etc.

A second concern that people have with BIM is that as the software becomes more complex a designer's ability becomes more about how well they are with the program, rather than with design itself (Quirk, 2012a). This would make a novice designer that knows the program 'better' than a highly educated and experienced architect who has yet to touch the program.

A third disadvantage that using BIM has is that it is based on existing building stock and common industry standards (Quirk, 2012a). If you want to make a rectangular building with standard façade elements and

a simple roof construction, then BIM is your software. But if you want to deviate from the standard then BIM will probably give you a headache. Therefor a project made with BIM will most likely reinforce the existing paradigms, rather than encourage new ones.

For an architect BIM is a necessary evil. It makes collaboration with the rest of the building development team significantly more efficient and effective, but it also disrupts the creative process. So the lesson that can be taken from this to the virtual design environment is the same as for the 2D CAD drawing; necessary, but should take place in the background as much as possible.

2.6 | Rendering

Renders allow us to transform an abstract drawing into something tangible. By introducing light, color and texture we are able to give a concreteness to the imagined place (Bernie, 2010, p. 61). They allow us to investigate architectural experiences and show the imagined spatial qualities. These 'early renders' are part of the design process, unlike the 'final render', which should be the result of the design process. The difference between these two kinds of renders is rather important to know, because they are often misused. When making a render that is used to explore, evaluate and suggest certain architectural experiences it is important to leave a level of abstraction to the image that can engage viewers and encourage them to build upon it, like the image below. Some designers like to use photorealism in making these renders, but that would only discourage further design work, as it does not leave much open for creative input.

By contrast, the final render should show the imagined building as how it is going to be built, as it is often the most important image in the communication of an architectural proposal (Bernie, 2010, p. 61). Because these are often so important in selling an architectural proposal, a lot of architects choose to make artistic renders that evoke certain emotions. Bernie also pleads for less photorealistic imagery in order to convey the essential character of the proposal more effectively (Bernie, 2010, p. 17). This is only natural, as presenting the building this way has proven to be more effective in convincing architectural lay-people. This is because they are not so much drawn to the building, but rather to the life, the people, and the atmosphere (Quirk, 2012b).

Figure 15: Example of an ‘early render’.

Figure 16: Example of a ‘final render’.

However, in my opinion, this is a deception. The rendering has become what pornography is to a teenage boy; something that is shopped and enhanced to cater to the fantasies of the reader (Quirk, 2012b). The danger of this deception is that the rendering becomes the final product, instead of a representation of a future building. In that case the image becomes independent of the concept, and architecture becomes nothing more than graphic design (Quirk, 2012b).

In order to make sure that architecture does not become a practice that sells images, but rather actual buildings, we need to visualize our buildings as they are going to be built in the real world. With today's technology it is possible to allow renderings to become so realistic that they become indistinguishable from reality. But, in my opinion, that is still not realistic enough, because you would still be able to precisely choose the perfect angle, show the best properties and hide the compromises. This is why I believe that the final render should make place for a final VR and AR, allowing the public to investigate every aspect of the interior and exterior, the good and the bad. That way not only the public, but also the architects themselves will not be surprised by or disappointed with the finished building.

And if the building is designed well, the final VR and AR will still evoke the emotions that were set out to achieve with the early render images, but then because of the architecture, and not because of some graphic wizardry.

2.7 | Game engines

In the last few decades the most popular architectural visualizations took shape in the form of computer generated renderings, using software like Maya, 3DS Max or V-Ray. In making these renderings it was not uncommon to have to wait several hours for the computer to finish a single image. The result however was a high quality and very photorealistic rendering.
Around the same time that we were trying to make rendering software faster and better, game engines made big advancements as well. But during these developments architecture firms would never use game engines to visualize their designs, because the graphic quality was still much too low. Over the last few years however the graphics of games have become better and better, to the point that they are at the same level as architectural renderings. This is an astonishing development, because game engines are designed for 'real-time rendering', meaning that, instead of taking several hours, they render nearly instantly. This provides architectural visualizers with big advantages as they can now create stunning images very fast and with a lot more control.

But this is not the only big impact game engines have on architectural visualization. Suddenly it is also possible to create high quality animations and movies of the design, or even walk through a fully rendered building without any pre-rendering (except for light-building maybe).
With this game engines open up a whole new range of possibilities for architectural visualization, with VR being the most intriguing at the moment. And as more and more architecture firms adopt game engines in their workflow, VR also becomes more accessible.

At the moment there are a few notable game engines available to the architect. The most popular ones are Unity and Unreal Engine 4, of which the latter is arguably the most suited for architectural visualization. Another one that is particularly interesting for architects is Stingray, Autodesk's own game engine. This engine is interesting because of its compatibility with other Autodesk software, like Revit and 3DS Max. During their Live Event on the 1st of June 2017 in Eindhoven they demonstrated what that workflow would look like (Gastel, 2017).

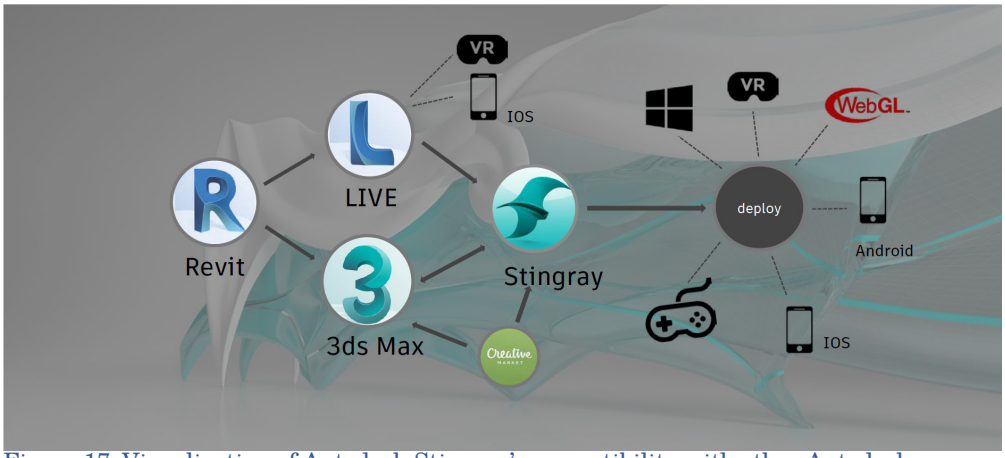


Figure 17: Visualization of Autodesk Stingray's compatibility with other Autodesk Software and different devices.

In the image above you can see that in this example the model is made in Revit and from there it either goes through Revit Live or 3DS Max. Afterwards the model is imported into Stingray. Revit Live is Autodesk's connection service to the 'cloud'. The advantage of using Revit Live is that it creates a direct link with Stingray, meaning that any changes done in Revit are automatically also applied in Stingray (Gastel, 2017). This can significantly improve the efficiency of the workflow and provides constant access to VR.

What this shows is how companies are trying to adapt game engines to fit the needs of the architect, as game engines were initially not designed

for architectural visualization. They were designed to build games. This is why they also contain a lot of tools to create animations, dynamics and interactions. But even though these tools are not meant for architectural visualization, they can still be used for it. In fact, it can be very useful and insightful to have an architectural model that you can interact with, whether it is simply to switch on a light in a virtual room or to see the virtual shading system operate. It also allows the viewer to alter the model itself, for instance by moving the furniture pieces around or quickly re-paint the walls. But these interactions are still very basic. When we look at the dynamics of serious games that these game engines produce, we can see that the possibilities are nearly endless, and by extension allow for endless possibilities in VR and AR.

The game engine will probably play a central role in the creation of a VR/AR Workspace. It would most likely be the basis for the architecture of the software for the workspace. Eventually however the game engine would need to be reviewed in order to better fit the specific demands of a virtual design environment in VR or AR. When that happens we would end up with a true virtual design environment that is custom tailored for the architect.

2.8 | Virtual Reality

Up until now this thesis has taken a very theoretical approach to the impact of VR and AR in the architectural design process. This is of course inevitable, because we are trying to explore the future of architecture and the usage of VR and AR in it. But VR and AR do not only have an impact on the future of architecture. Architecture firms are already using them in the present, making them a part of the tools and media that make up the current design environment. This is why I would like to discuss them as contemporary design tools as well.
In order to research this I went to two renowned architecture firms that are also known for using innovative ways of designing, namely Mecanoo and Benthem Crouwel. There I interviewed their respective VR-specialists, which are Johan Hanegraaf for Mecanoo and Ton Deuling for Benthem Crouwel. In the appendix you can find the entire interviews that I had with them (Hanegraaf, 2017) (Deuling, 2017).

BNTHMCRWL

Figure 18: Benthem Crouwel Logo

mecanoo

Figure 19: Mecanoo Logo

For an architecture firm it can be very difficult to invest in new tools or ways of designing. Because the firm is a place where projects have fast deadlines and employees are expensive, time is very valuable. Besides that, architects are usually not particularly well with computers. They know certain software very well, but only because they have to. This means that experimenting with new software would require investing a lot in knowledge and expertise, making it hard to explore new technologies when there is no clear profit or benefit yet in sight.
Fortunately for Mecanoo they have employees who were willing to experiment with VR in their own time, making it a safer investment once the knowledge and expertise are already in house. For Benthem Crouwel it was also a matter of business philosophy to look into VR, as they see their firm as laboratory for exploration and experimentation, which is why they named their building the 'Benthem Crouwel Lab'.
Both firms started out with VR by putting a phone in a headset and look at a panoramic rendering of their design. This is a very low investment step that requires very little time, effort or expertise. This step was however essential in order to realize the potential that VR could offer, because it was the first contact with an 'immersive experience'. After that it is not hard to imagine the potential benefits of being able to walk through the building with high quality graphics.

Nowadays both firms use VR early on in their design process. For them the main advantages of using VR are to be able to experience the design in an immersive way and to compare different spatial qualities, but most of all to convince the different parties of certain ideas and seduce potential clients. For an architecture firm this is of course the main reason to implement technologies like VR, because it generates business.
Both firms are also trying to develop new ways of using VR, but they take different approaches. Hanegraaf of Mecanoo is developing software that allows architects to create 3D models within VR. He believes that the tools we use now are very unintuitive, while design is something that happens out of intuition, and that VR has the potential to bring back a lot of the intuitive ways.
Benthem Crouwel focuses more on developing the interface of VR. For instance, how to show certain aspects of the design, what should be visible and what should be hidden, how to make marks and annotations within the view, etc.

They are however well aware that there is no point in investing a lot of resources in these developments, because of all the fast developments coming from other industries. Architecture firms could simply not develop as efficient and effective as an engineering firm or software company could, simply because they do not have the resources and frankly have other things on their minds.

This ultimately means that the architecture industry is largely dependent on other industries in order to innovate itself in this regard. Unfortunately this is something that we probably cannot do anything about. On the other hand this might not even be such a bad thing. Let the other industries provide us with the opportunities to innovate and we will decide which ones we adopt and which we do not. That way architecture can focus its efforts on designing architecture.

2.9 | Augmented Reality

So Virtual Reality is still young and needs a lot more development before it can be adopted into the mainstream architecture practice. However, compared to Augmented Reality it is already old technology. AR in architecture is in its infancy. This is why architecture firms like Mecanoo and Benthem Crouwel have yet to find a good 'business friendly' application for it. Both firms have experimented with the technology as a way of checking on how far the technology has come, but both came to the conclusion that it still has a long way to go.

Something that both Hanegraaf and Deuling are convinced of is that AR will most likely become more relevant in the future. Hanegraaf sees a lot of potential in the use of scale models through AR, which can give quick, easy and clear overviews of the design.
Deuling sees the same potentials for AR. He argues that we will see AR easily overtake VR in adoption in the next five years. Personally he is convinced that VR is just a go-to step towards developing a good AR.

For now, however, the quality of the technology behind AR is simply too low for architecture firms to even think about investing in it. When the AR development industry comes with a 'plug-and-play' application with a high enough resolution, then firms can start to adopt and invest in it.

2.10 | The ideal workspace

As we discussed in the beginning of this section the ideal workspace needs to have a balance between reality, media and mind. Augmented Reality has the potential to do that. It can display every virtual design tool and media, while also involving every non-virtual design tool and media. With AR you are able to have media interact with reality, mind with media and consequently increase the interaction between mind and reality.

Looking back at the different tools and media that we discussed in this section there are those that need more emphasis and those that need less. AR has the capability to strengthen and emphasize the different tools and media in multiple ways. It is up to us to choose which ones we would like to see more of in the virtual design environment. If it were up to me I would agree with Stellingwerff's position on having more design media that can enhance creativity, instead of tools that can enhance productivity (Stellingwerff, 2005, p. 117). This would mean more emphasis on drawing and model making (both analogue and virtual), and less on 2D CAD drawing and BIM.

What is clear is that in order to turn the virtual design environment into the ideal workspace it will need media that supports creativity, a balanced alternation between reality, mind and media, and AR as the ultimate display.

Section 3 | The Workspace of the Future

Up until now we have discussed how VR & AR could theoretically benefit the architectural workflow and workspace. During this I might have mentioned a 'virtual design environment' a few times. Alright, maybe a bit more than a few times... But this is because I believe that a virtual design environment is the inevitable conclusion VR & AR will make in their integration with the architectural design process.
As VR & AR become more integrated into the architectural design process it would make more sense to use them as a design environment, rather than as separate tools. By housing all the different architectural tools and media under one roof, we unify them into one language – *the manifestation of the architectural syntax.*

This third section is entirely devoted to describing a personal view on how the virtual design environment could take shape, and substantiating why, using the information gathered in the first two sections.

3.1 | Fundamentals

At the end of the previous section we concluded that the design environment needed media that support creativity, a balanced alternation between reality, mind and media, and AR as the ultimate display. These are the abstract goals that we hope to have achieved in the end. However, in order to design the design environment we need to start with the fundamentals.
The first fundamental aspect is the context, which in this case is the place the architect works in. In general an architect works at his/her desk, but he/she is also needed at the conference table or at the site of the build.
The second aspect we need to look at is the activities that the architect performs at these workplaces. These can be divided into two main categories, 'creation' and 'evaluation'. It is important to make a distinction between the two because they require different thinking styles, as we discussed in chapter 1.1. The design environment needs to support those thinking styles during these activities.
A third fundamental aspect is individual versus collaborative work. As we discussed in chapter 1.3, VR and AR allow for new ways of collaboration among colleagues and other interested parties. A collaborative workplace is however fundamentally different than an individual workplace. This needs to be taken into account when designing the design environment.
A fourth is the perspective of the architect. One of the greatest advantages of using VR & AR during the design process is to be able to view the design at a human scale. However, an architect also needs to keep track of the bigger picture, which is why it is important to be able to easily switch between an immersive view and an overview.

There are, without a doubt, more fundamentals to discuss, but for now (to keep it relatively simple) I would like to discuss how these four fundamental aspects relate to each other and take shape at the workplace.

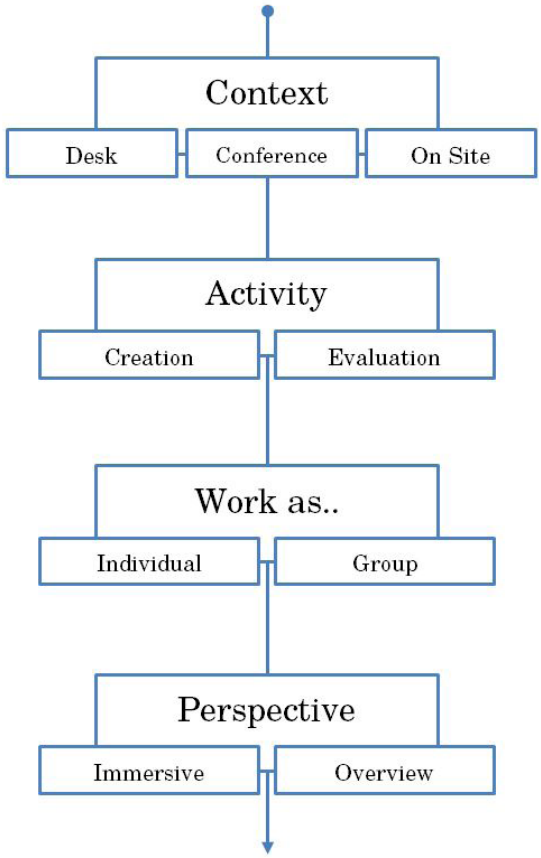


Figure 20: Four fundamental aspects of the design environment.

This diagram shows the different fundamental aspects that together make up certain modes of the virtual design environment. If we were to sum up the amount of modes that these four aspects would produce, we would end up with twenty-four. This seems like a lot, but they are actually a lot alike as they can only differ in four ways at most.
I could explain all twenty-four modes separately, but it is probably better and more enjoyable to explain what it is like to use this virtual design environment by describing a few scenarios:

At the desk

Frank is an architect designing a museum somewhere in Spain. Using the virtual design environment he sits behind his desk making several design iterations of a double curved façade element. Intuitively he builds up the hologram of his façade design using 3D modeling tools combined with hand gestures. After creating a small 300 alternatives he decides to evaluate his work and switch to evaluation mode, which puts the different designs next to each other on the table and allows Frank to make notes, put in annotations, investigate sections, etc.

Looking at one of his more peculiar designs he wonders what it would look like on a human scale. He places a little figure of himself inside the hologram and suddenly changes his perspective to that of his little self. While walking through his design he makes some more notes and annotations, and then goes back to the overview. Frank likes the design but questions whether his design is actually buildable. He decides to call Roger, his engineer, from within the design environment. Because Roger is also wearing AR glasses he can view the same hologram of the design that Frank is seeing. Together they investigate the design behind their own desk as if they were looking at two exact copies of the same physical model. Roger notices a few design aspects that would be expensive to build, and suggests an alternative that would be a lot cheaper. Frank is pleased to hear that his design is buildable and is confident that his client would like it.

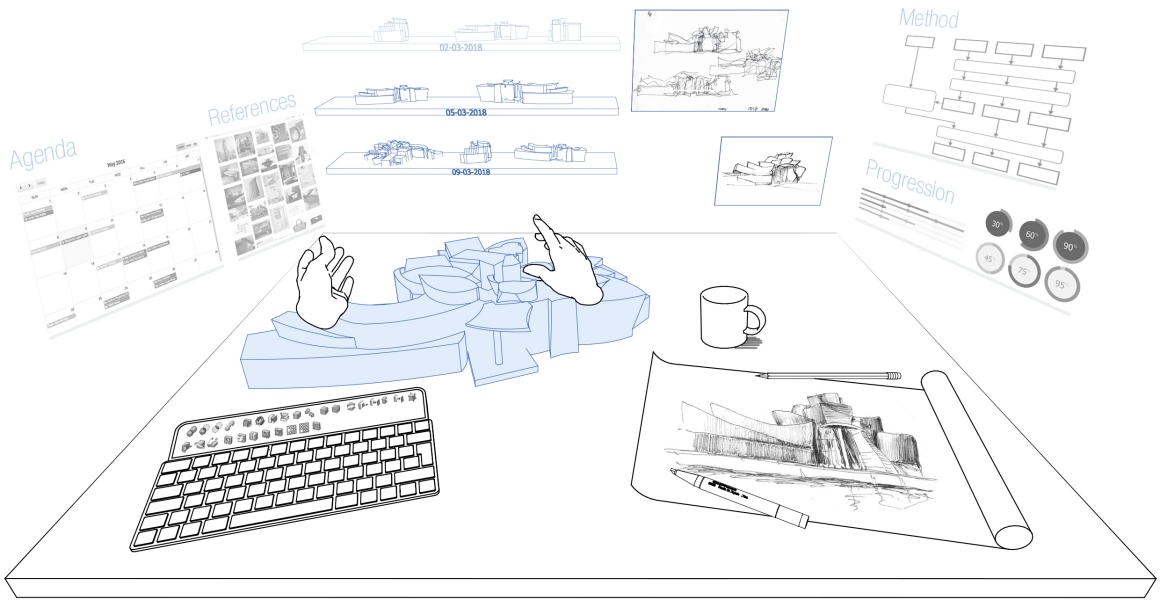


Figure 21: Illustration of the ‘ at the desk’ scenario. (Everything blue is virtual)

At the conference table

As all the stakeholders take their place around a big oval table a hologram of the design appears in the middle of the table. Frank starts his monologue about swirling forms and captivating materiality, and to support his story the different design elements in the hologram light up one by one. He goes over the construction as the stakeholders see a miniature version of the building process take place in front of them. Red and blue animated arrows demonstrate how the air flows through the building as it is ventilated. Crowds of small animated museum visitors walk through the building, showing the principles of the routing throughout the building. Frank then picks one of the virtual museum visitors and suddenly he and the other stakeholders take on the perspective of the visitors, allowing them to experience the building in real-life scale.

Finally Frank invites the stakeholders to join the discussion on the design. (Even though he will probably disregard everything, because obviously the design is already perfect,) He allows them to give their remarks, show their own ideas and make alterations to the design. The hologram is constantly changing as the discussion progresses, giving everyone a clear understanding of everyone's design ideas and an intuitive way of showing their own.

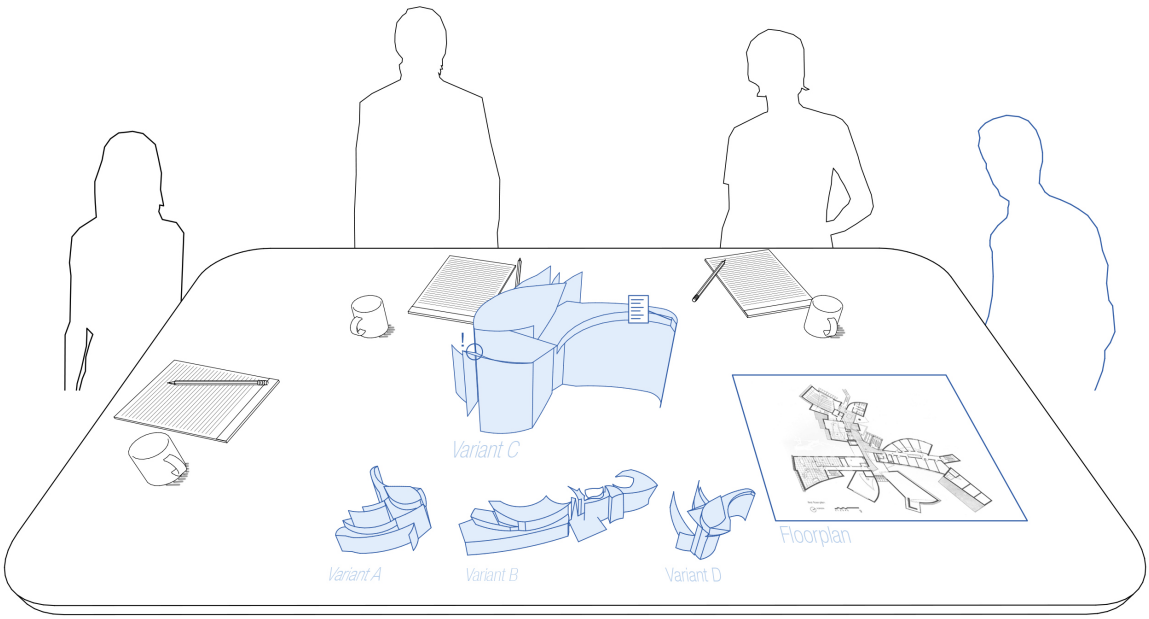


Figure 22: Illustration of the ' at the conference table' scenario. (Everything blue is virtual)

At the site

Full of confidence Franks design team goes to the waterside where the museum is going to be built. Everyone puts on their AR devices and beholds the great design in real-life scale, in the context it is meant to be in. The design team starts walking around the site so that they can inspect it from every angle. As they get closer it becomes clear how fascinating, but also intimidating, the façade actually is. Frank makes a virtual note and sticks it onto the façade for later discussion.

Roger, the engineer, notices how hot it is on the south side of the building and is worried that the material Frank has chosen for the façade could become so hot that visitors can burn themselves if they touch it. Frank agrees and suggests that they should look into that.

The design team then decides to go look at the design from the inside and enters the building site. One of the things that they pay attention to is the view that they would see looking through the openings in the façade. One of the interns notices that one of the façade openings looks out over some heavy traffic and could distract the visitor from the art exhibition. Frank gives her a thumbs-up and feels a little embarrassed that he did not notice that earlier.

After a day of walking around and through the design under the scorching Spanish sun, they conclude that they are very satisfied with the result and can't wait for the virtual sun shading to become real.

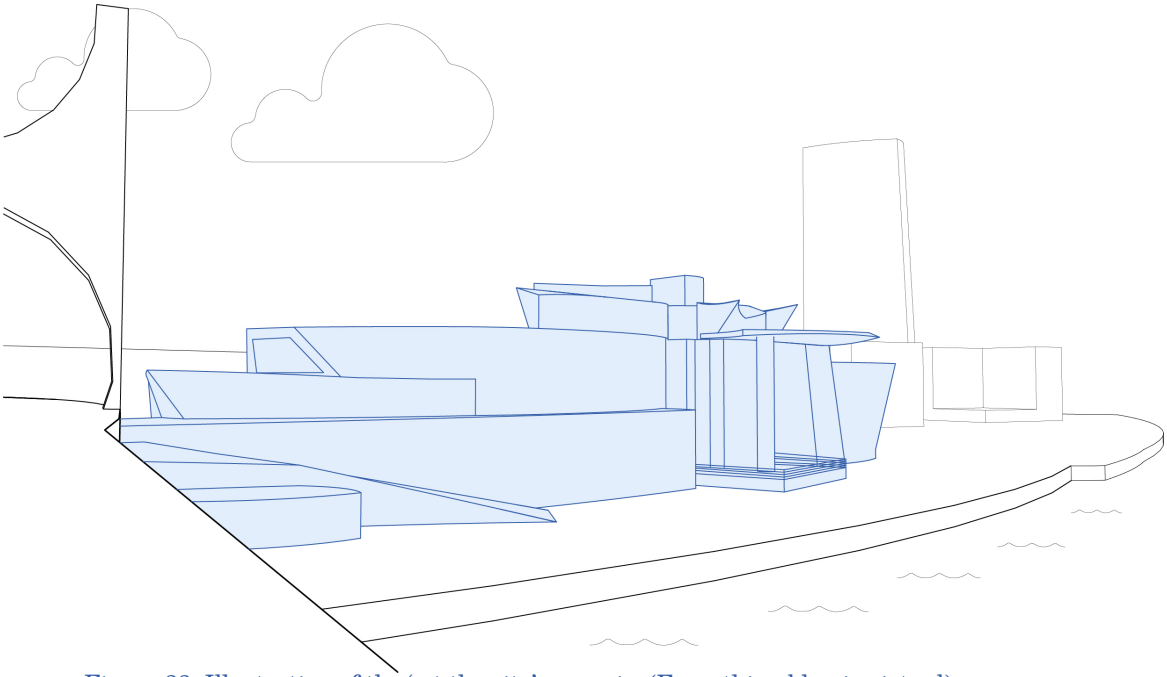


Figure 23: Illustration of the ' at the site' scenario. (Everything blue is virtual)

3.2 | A personal design assistant

The scenario in the previous paragraph describes what the virtual design environment would look and feel like on the surface, but in fact most of the functionalities would happen in the background. Functionalities like gathering and organizing information, automatically creating technical drawings, keeping track of deadlines and appointments, providing the designer with the right tools at the right time, making sure every stakeholder gets the right files, etc. These functions are what would make the virtual design environment such a valuable workspace, because they allow the architect to focus on design, rather than on trivial side jobs. This is why I also like to see the virtual design environment as a collective design assistant, but which behaves as and feels like a personal design assistant.

The functionalities that the virtual design environment fulfills as a design assistant are stated throughout the thesis. There are without a doubt more functionalities to think of, and will be thought of as the work of the architect changes over time. Below I will give a quick summary of the functionalities discussed in this thesis:

- Helping to choose an architectural design method (and sticking to it), which in turn help to;
  - Structure content, tools, types of information.
  - Suggest thinking styles, location of judgment, points of decision-making.

- Keeping track of the framing position, starting biases, judgment criteria and all the decisions made along the way.

- Encouraging the right thinking style at the right time:
  - Encourage exploration, and discourage evaluation, during divergent phases.
  - Encourage evaluation, and discourage exploration, during convergent phases.

- Providing a library of 3D reference material.

- Automatically generating 2D drawings, like:
  - Floor plans,
  - Sections,
  - Elevations,
  - Technical drawings.

- Taking care of BIM activities in the background.

3.3 | A collaboration facilitator

As we have discussed in the collaborative design chapter (1.3) VR and AR have the potential of becoming a great collaborative design platform. This is why one of the fundamental aspects of the virtual design environment is to be able to switch between an individual and collaborative work style.

Figure 24: Collaborative design session using SketchUp Viewer with Microsoft Hololens.

3.4 | A game of architecture

In chapter 1.4 we discussed the benefits of using gamification principles in the design process and how that could guide us into a state of mental focus. But what would this look like in the virtual design environment that we have discussed so far?

The first gamification principle of the chapter was 'choices', and how choices also play a central role in the architectural design process. This principle would be most beneficial during creation phases where imagination and idea generation are most important. The goal of 'Gamifying' this phase would be to encourage architects to try out more design ideas, whether they are good or bad.

A simple way that the design environment would go about to do this is to present the architect with a dozen empty slots that need to be filled with design ideas. The goal then becomes to fill every slot, instead of looking for good design ideas. That way you are encouraged to also explore bad ideas, as it is more important to fill the slots then to come up with a good design

idea. By also exploring the bad ideas you make way for good ideas or a bad idea might give inspiration for a good idea, but most importantly, you get your creativity rolling.

The second principle we discussed was 'feedback', which allow us to understand the consequences of our actions and choices. Feedbacks in games try to answer three questions. "Where am I going?", "How am I doing?" and "Where do I go next?". These questions can also be applied to the design process in order to give the architect a grip on the choices he has made and the progression of the design process. I will give an example of how the virtual design environment could provide this feedback per question.

1. "Where am I going?" is a question of relating design choices to your 'framing position', 'starting biases', 'judgment criteria' and 'program of requirements'. During evaluation phases it is important to test your design ideas to these starting positions, criteria and wishes. To help with this the design environment can ask you to rate the different design ideas and keep track of those ratings for you. This also forces you to make sure that you have all your starting positions, criteria and wishes for the project in order before you start designing.

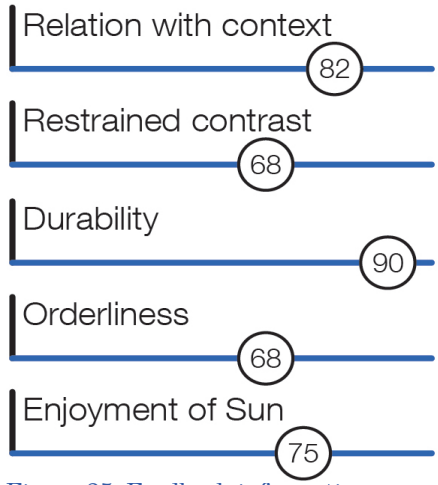


Figure 25: Feedback information relating back to your starting positions, criteria and wishes.

2. "How am I doing?" is a question that can be answered by showing how far along the architect is in the process. Showing this per aspect or domain of the design would be even better. For example, the design environment can show to what extent a domain is worked out through a simple progress bar, like games use for levels or skills. You could also provide the progress bar with a secondary bar that shows the quality of the design of that aspect, based on the ratings given during evaluations.

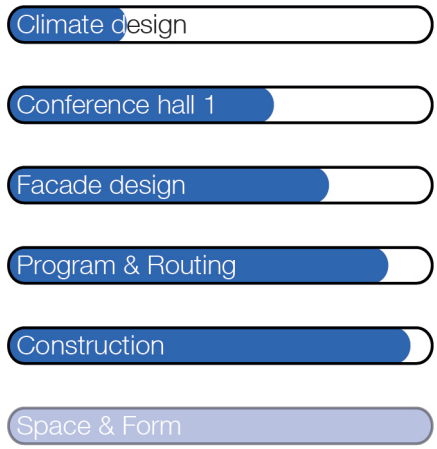


Figure 26: Feedback information showing the progress of different aspects or domains.

3. “Where do I go next?” is a question that can be answered by combining an overview of the progression bars, an overview of the different phases of the design process and perhaps an agenda with the deadlines for the project. That way you know at all times which aspects need your attention the most.

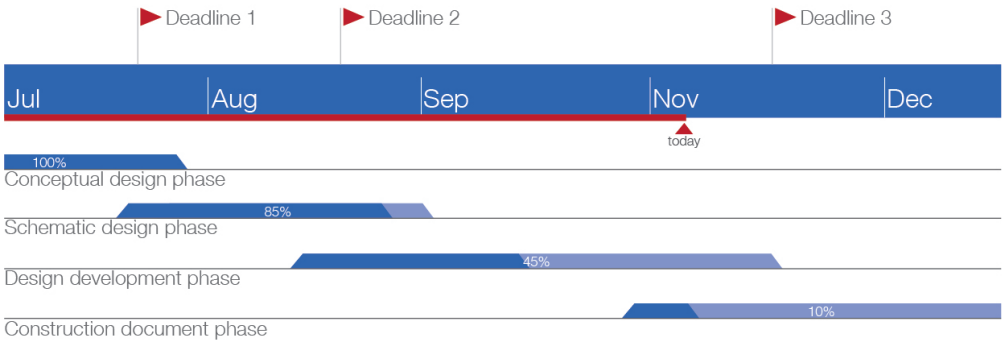


Figure 27: Feedback information on the entire process.

‘Pacing’ is another principle of gamification that the virtual design environment could incorporate. The goal of pacing here is twofold. Firstly it is about excitement, where pacing the engagement with the design environment in peaks and troughs can help to keep the work exciting. For example, during a creation phase there will be moments where you take in information, moments where you draw or model a lot, and moments where you just think. As you take in information you have an average engagement with the design environment, while modeling a high engagement, and thinking a low engagement. By having the presence of the design environment follow the level of engagement you automatically create peaks and troughs in the workflow, which (hopefully) make using the virtual design environment more engaging.

Secondly pacing is about making design environment adaptable to the architect’s work efficiency, and provide the right kind and amount of information accordingly. As one architect works faster, or in more domains simultaneously, than another it is important that the design environment does not restrict or push an architect’s ability.

What all of these principles come down to is to put the designer ‘in the zone’, the sweet spot between boredom and frustration, where we work at our best and enjoy our work the most. How the virtual design environment does this exactly would first require a lot more research, experimentation and prototyping. However, I hope that the given examples start to picture what a ‘gamified’ design environment might look like.

3.5 | Conclusion

The virtual design environment that is envisioned here is of course just an example of one student imagining what such an environment would look like. So whether this particular design environment will come to fruition is impossible to say. However, looking at the speed and scale that these technologies are being developed at, and the advantages of using AR for architecture in this manner, makes it very likely that a virtual design environment will become a reality fairly soon.

What I hope to have made clear in this section, besides the possibilities that this development poses, is the impact that it will have on the architectural practice. This is why I hope that the companies that end up developing AR software for the architectural practice try to make a design environment that focuses on media that support creativity, rather than tools for productivity, and strive for a balance between reality, mind and media. Then we can truly create an *Augmented Design Space*.

Section 4 | VR & AR experiments

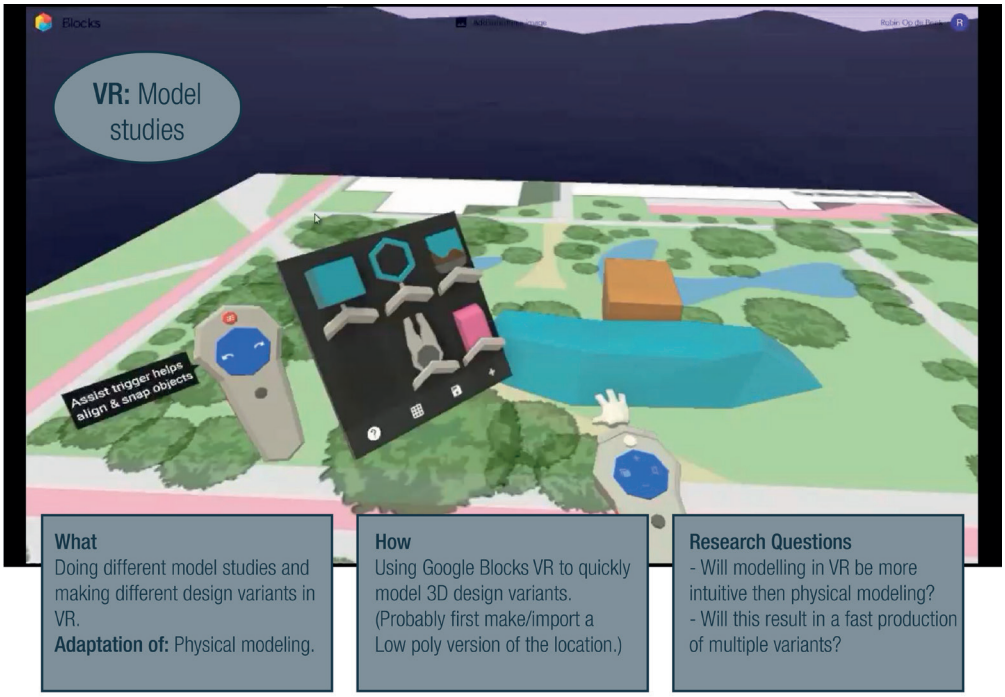
This thesis is one of the three major parts of which the graduation project consists. For the second part of the project I will be designing a 'University Forum for the TU Delft'. The design of this building is not only something that I find an intriguing building concept and a very relevant addition to the university, but it also functions as a case study for the third part of the project, which is testing aspects of the 'Workspace of the Future' through VR & AR Experiments.
In order to support the theoretical framework that this thesis has given so far, I also wanted to give a practical framework. This is where the VR & AR experiments come in. By forcing VR & AR into my own design process I hope to find out what kind of usages of these technologies would be desirable, and which not.

In this chapter I will present my findings in the form of a comparison between the 'traditional' design process and the 'augmented' design process. These findings are of course based on personal experience, so it could be that someone might view things differently. That being said, the comparisons are overall pretty straight forward, so it is not very likely that someone would see things entirely different.
First we will discuss a few different examples of the experiments that were done. Secondly, the findings are presented in the form of a comparison between the 'traditional' design process and the 'augmented' design process. And to conclude I will reflect a little bit on the process of doing the experiments.

4.1 | Experiments

I will start by giving an example of the experiments that were done during the design process (the rest of the experiments can be found in the appendix). The pages describe the following information:

- What is done in the experiment.
- How the experiment is done.
- The research question(s) behind the experiment.
- The likes and dislikes of doing the experiment.



VR: Model studies

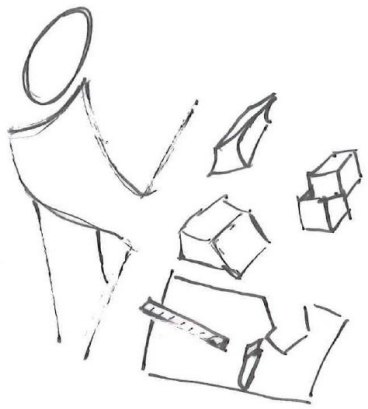
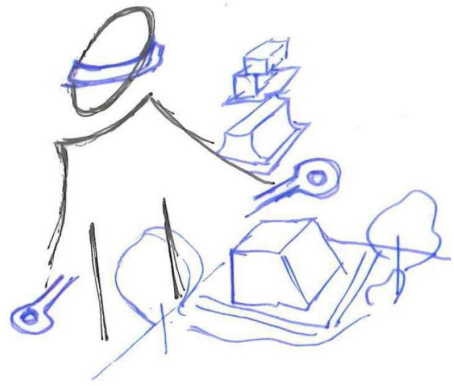
The purpose of this experiment was to see what it was like to do model studies in VR, in comparison with physical modeling.

+ Intuitive scaling, rotating and moving.
+ Very playful.
+ Combines Sketchup with physical modeling.
+ Easy to change colors.

– Difficult to be precise.
– Hard to get a hang of the controls.
– Misses functionalities of other modeling software.
– Misses tangibility

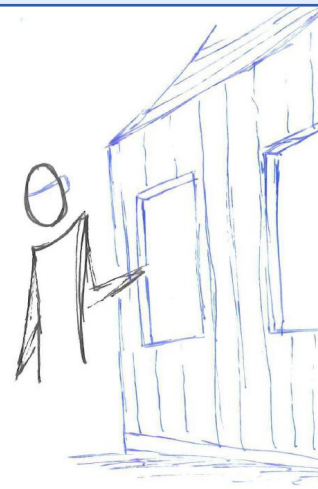
4.2 | Findings

During the experiments there were a lot of moments where I was either pleasantly surprised, or just utterly frustrated with having to use VR and AR in the design process. Sometimes it would give insights that normally would never have been seen, and other times I wished that I could go back to my old workflow. There are a lot of differences between the 'traditional'- and the 'augmented' design process. This chapter is devoted to those differences by comparing the two design processes per experiment.

Traditional Design Process	Augmented Design Process
VR: Model studies	
	
• Use modeling materials, like cardboard, foamboard or wood. • Shaping is limited by material and production techniques. • Can be seen/evaluated by others. • Add abstract tree models. • Test lighting using a lamp setup. • Has a fixed scale. • Variations require new models. • Has tactile qualities.	• Can have any material, color or transparancy. • Shaping is limited by software tools. • Only seen by people in VR. • Add virtual tree models. • Test lighting by simulating sun movement. • Freely scalable (also to 1:1 scale) • Variations can be done by copying and then editing. • Has no tactility.

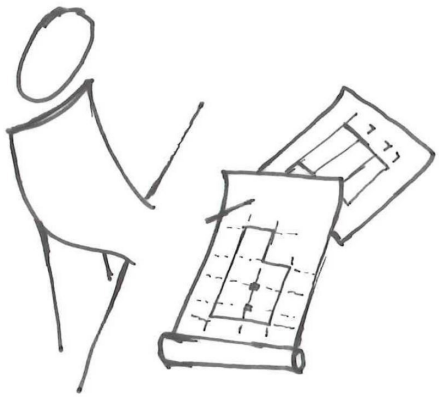
VR: Materialisation

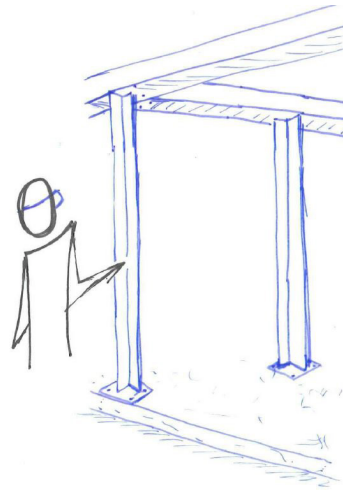
- Use hatches or photoshop to visualize materialisation on 2D drawings.
- Use material samples for reference.
- Able to test the feel of materials with the samples.
- Quickly test different compositions with sketchpaper.
- Evaluating the impact of certain materials on the form and space is done in the mind of the architect.
- Focus on the macro-scale.



- Use photorealistic materials wrapped around the 3D model.
- Use online material library for reference.
- Unable to touch materials.
- Quickly change material of objects, but harder to change compositions.
- The impact of certain materials on the form and space is evaluated in the VR.
- More focus on the micro-scale.

VR: Construction





• Draw constructional elements on floorplan or section. • Judge construction using measurement, calculation and experience. • More focus on macro-scale. • Quickly draw multiple configurations. • To evaluate corner connections you need XY-, YZ-, and XZ-view drawings. • Have to actively look for constructional issues.	• Insert constructional elements from 3D modeling software to VR. • Adds intuition to judging construction. • More focus on micro-scale. • Need to move everything around in order to get a different configuration. • To evaluate corner connections you need one 3D model. • Often incidentally confronted with constructional issues.

VR: Functional program

• Draw functional elements on floorplan or section. • Judge functional layout by using measurement, calculation and experience. • More focus on basic principles • Quickly draw multiple configurations. • Hard to quickly edit drawing. • Unable to change colors or transparancy of objects.	• Insert constructional elements from 3D modeling software to VR. • Adds intuition to judging functional layout. • More focus on spatial relationship. • Need to move everything around in order to get a different configuration. • Easy to quickly edit the model by scaling, moving or rotating. • Freely use colors, textures and transparancy.

VR: Form & Space

• Evaluate spatial qualities using a physical model. • Has a fixed scale. • Rotate the model around on your hand and imagine what the scale would be in reality. • Add a scale person to help with getting a feeling for scale. • Shaping is limited by material and production techniques.	• Evaluate spatial qualities using a virtual model. • Freely scalable (also to 1:1 scale). • Walk around the building and experience the real scale. • Add a virtual person to the VR to help with the feeling for scale. • Shaping is limited by software tools.

VR: Climate design

- Evaluate climate design through floorplans and/or sections.
- Gives a clear picture of the basic principles of the climate regulation.
- While using only floorplans and sections you are bound to miss some corner connections.
- Colored arrows indicate air- or heat-flows.
- The size of ventilation systems are not very obvious.

- Evaluate climate design while walking through the VR.
- Harder to understand the basic principles.
- Every corner connection is viewable.
- Arrows can be animated to make it clearer.
- Immidiately confronted with the size of the ventilation systems.

VR: Interior design

- Draw interior design configurations on sketchpaper.
- Hard to quickly edit drawing.
- Quickly draw multiple configurations.
- Dimensions need to come from a book.
- Editing colors or materials require a new drawing.

- Use modelling in VR to draw interior design configurations.
- Easy to quickly edit the model by scaling, moving or rotating.
- Need to move everything around in order to get a different configuration.
- Dimensions can be tested intuitively.
- Quickly edit colors or materials

VR: Design Evaluation

- Evaluate the design through floorplans, sections, 3D drawings and physical models.
- Requires the mind of the architect to fill in the blanks.
- Multiple products telling different chapters of a story.
- Different products highlight different aspects of the design.
- Evaluate specific things.

- Evaluate the design through VR.
- Almost no blanks to fill in.
- One product telling the entire story.
- Hard to highlight single aspects of the design.
- Evaluate the whole.

AR: Floorplan & Section

- Evaluate floorplans and sections on paper.
- More focus on basic principles.
- The lines do not seem very significant.
- Write down notes or make side drawings on the drawing.

- Evaluate floorplans and sections on site in 1:1 scale.
- More focus on spatial relationship with surroundings.
- The lines show the impact on the site, which give them extra weight intheir significance.
- Notes have to be memorised or recorded by audio.

AR: Form & Space

- Evaluate spatial qualities using a physical model.
- Has a smaller scale.
- Navigate through the model by moving and rotating it around.
- Has no context (unless it has also been modelled)
- White foam material gives a good indication of spatial aspects.
- Shaping is limited by material and production techniques.

- Evaluate spatial qualities using a virtual model on site in 1:1 scale.
- Has a fixed 1:1 scale.
- Navigate through the model by walking from one side to another.
- Sits on the actual site.
- White color makes it feel very massive and disproportionate.
- Shaping is limited by software tools.

AR: Construction

- Evaluate constructional elements on floorplan or section.
- Judge construction using measurement, calculation and experience.
- Gives little sense of the implications for the site.
- To evaluate corner connections you need XY-, YZ-, and XZ-view drawings.
- Have to actively look for constructional issues.

- Evaluate constructional model on site in 1:1 scale.
- Adds intuition to judging construction.
- Gives a good impression of what the building site would look like if it would be built.
- Corner connections are readily viewable.
- Often incidentally confronted with constructional issues.

AR: Materialisation

- Use hatches or photoshop to evaluate materialisation on 2D drawings.
- Photoshop the drawing into a photo to evaluate the design in its surroundings.
- Write down notes or make side drawings on the drawing.
- Watching different sides of the building requires different drawings.

- Use photorealistic materials wrapped around the 3D model, and view it on site in 1:1 scale.
- Walk around the building to view it in its surroundings from all angles.
- Notes have to be memorised or recorded by audio.
- Walk to the other side to see a different side of the building.

AR Design evaluation

- Evaluate the design through floorplans, sections, 3D drawings and physical models.
- Requires the mind of the architect to fill in the blanks.
- Multiple products telling different chapters of a story.
- Different products highlight different aspects of the design.
- Evaluate specific things.

- Evaluate the design using a virtual model on site in 1:1 scale.
- Almost no blanks to fill in.
- One product telling the entire story.
- Hard to highlight single aspects of the design.
- Evaluate the whole in its actual surroundings.

4.3 | Reflection

Looking back at this research I have to admit that it was a pretty big undertaking. Especially acquiring the right hardware and software took a lot of time and effort. In that regard the VR experiments were easier to setup thanks to the VR lab at the faculty, which had the hardware readily available, and my knowledge on Unreal Engine 4, which I had a few years of experience with. The AR experiments however were a lot more difficult to setup. At the start of the graduation project there was no hardware, no software, and no knowledge on using AR.
So first I started with finding the right hardware. I tried to acquire Microsoft's Hololens through the university, but was unsuccessful. Then Apple's ARKit came out, but this required a new MacBook to work, which I did not have (and was unsuccessful to borrow one from the university). Then Google's ARCore came out, which I could develop for from my own computer. However, this required a newer Android phone. That is when I gave in and just decided to buy a new phone.
Secondly there was software. Over the span of the graduation project I tried several programs. Sketchfab, Augment, Unity and Vuforia were ones that I had some success with. Fortunately, one year into the project, Unreal Engine 4 started supporting ARKit and ARCore, which opened a lot of possibilities and allowed me to bring the AR experiments to the next level.

Even though there were some frustrations with setting up the experiments, performing the experiments was mostly a lot of fun. Exploring the nearly endless possibilities that VR & AR had to offer gave a lot of motivation and gratification.
Unfortunately, because the AR setup took so long, I had to leave out a few experiments. These were the ones that would be at the start of the design process, because the design of the 'University Forum' had to move forward. The experiments that were left out were 'AR: Analyses on location' and 'AR: Functional program'.

There are a lot more experiments that can still be done, with AR as well as with VR. Also the experiments done here can be done with different designs, perhaps resulting in more or different insights. These technologies are still very new and therefor provide a whole new field of study, and as they become more and more accessible so will the experiments become more and more elaborate.

Conclusion

As a practice of visual imagination architectural design can be augmented through technology. Especially through technology that can aid us in visual perception, like Virtual Reality (VR) and Augmented Reality (AR). If we truly want to augment the architectural design process with VR or AR, than this would mean that VR or AR will need to facilitate our design environment. That way it becomes more than just a tool or a medium, but rather an environment that encapsulates all tools and media. This is why the main research question for this thesis uses 'VR & AR as the workspace':

What are the implications of using VR & AR as the workspace in the architectural design process?

The short and blunt answer to this question is that VR & AR provide more *immersion* and *communication*. In order to clarify this answer we will discuss both these implications more elaborate.

Immersion

Practicing architecture is a reflective conversation between the architect and the situation, where the more you 'talk', the clearer the goal becomes. And the more experienced you are as a designer, the more effective you are at steering the conversation the right way.
This conversation between architect and situation can only work through a medium. This medium takes form in the tools and media that architects use to produce representations of their ideas and designs, like sketching and modeling. The collection of these tools and media, together with the environment in which they are used, is what I call the 'workspace' of the architect.
So the workspace is not just a laboratory for experimentation, but is also the means, through which an architect speaks. The different tools and media are the different ways of saying what is on the mind of the architect, and by housing all of them in one environment you unify them into one language - *the manifestation of the architectural syntax*.
In other words, the workspace acts as a mirror for the mind of the architect. In order to find the ideal workspace we need to have a balance between reality, media and mind. Augmented Reality has the potential to do that. It can display every virtual design tool and media, while also involving every non-virtual design tool and media. With AR you are able to have media interact with reality, mind with media and consequently increase the interaction between mind and reality.

The unique ability of VR & AR to immerse the architect into his/her design on a 1:1 scale humanizes the design process. It adds a much needed perspective to bring the architect closer to reality, and it sets the aim for architecture to design buildings for the human experience, rather than for what looks good on a competition poster.

Communication

Whereas the immersive qualities of VR & AR provide a mirror for the architect to reflect design ideas, so do the communicative qualities provide a window for other stakeholders to understand the architect's thought process. The building development process involves a lot of people who all have something to say about the design, and it is up to the architect to make sure everyone is on the same level of understanding. VR and AR can become the ultimate media to make sure that happens, because these technologies can show the future building without leaving much open for individual interpretation. This is not only good for the outward communication towards the client and end-users, but also good for internal communication between other designers and technical advisers.

Besides communicating design ideas, VR & AR allow for another potential, namely 'collaborative design', where the design ideas are generated in collaboration. In a collaborative design process it is not the individual architect that designs the different iterations, but a group of designers and other stakeholders working simultaneous. As you can imagine collaborative design can greatly improve and speed up the consensus on a design project amongst the different stakeholders. Unfortunately, traditional design tools and media can be hard to read, open for interpretation, or complicated to use. VR & AR have the potential to solve these problems. Because they present the design as close to reality as you can get, they do not require any reading or interpreting. So in order to become a facilitator for a true collaborative design process they only need to find a way to make it easy to work with, while not being too restrictive in its possibilities.

By making design ideas tangible and understandable for everybody, including non-professionals, everybody will be able to follow the design process alongside the architects. This could lead to more appreciation of the architecture, but it could also lead to more critique. It could lead to more input for design ideas, but it could also lead to more misunderstandings. As more people get involved with the process the design tends to be more well-considered, but it also complicates decision making.
So something that could happen is that the architectural practice shifts from an aristocracy to a democracy – *the democratization of the design process*.

Virtual Design Environment

This thesis shows that the most likely future role of VR & AR in architecture will be to facilitate the architect's workspace. The reasoning for this can be found throughout sections 1 and 2. Section 1 shows that a virtual design environment can benefit the fundamental aspects of architectural design, it can play a beneficial role throughout all of the phases of the design process, it can facilitate collaborative design, it can allow for gamification elements and it could democratize the design process. Section 2 shows how the tools and media of the contemporary architect would fit into a virtual design environment. An important conclusion of this section is that VR would not be able to facilitate a virtual design environment as it would disregard non-virtual tools and media, like physical drawing and modeling. AR however would be capable of this, as it can display virtual design tools and media, while also involving every non-virtual design tools and media. Other important conclusions of this section are that the virtual design environment should strive for more design media that support creativity, rather than tools that can increase productivity, and for a balance between reality, mind and media.

Section 3 describes a personal view of a virtual design environment to give an image of what such an environment would look and feel like. The goal of this section is to make clear, besides the possibilities that this development poses, is the impact that it will have on the architectural practice.

Future recommendations

VR & AR are technologies that are still in their infancy, so there is a lot of research that can still be done in regard to their impact on the architectural practice. Especially research into AR would have priority, seeing as it is even younger and will have a bigger impact than VR. As far as research recommendations go, I would argue that it is best to follow the latest tech-news and adapt your research goals to that, because any recommendations I would give you here will probably be outdated in a few months' time.

Hopefully reading this thesis has at least given you some inspiration for future research, or allows you to kickstart your current research.

References

Literature

Autodesk. (2017). VRED Overview - 3D Visualization and virtual prototyping software. Retrieved from http://www.autodesk.com/products/vred/overview

Bernie, D. (2010). Architectural Drawing: Laurence King Publishing.

Broll, W., Lindt, I., Ohlenburg, J., et al. (2004). ARTHUR: A Collaborative Augmented Environment for Architectural Design and Urban Planning. Journal of Virtual Reality and Broadcasting, 1(1).

Bye, K. (2015). #224: Arch Virtual says VR could transform the entire Architecture Industry. Retrieved from http://voicesofvr.com/224-arch-virtual-says-vr-could-transform-the-entire-architecture-industry/

Conti, M. (2017). The incredible inventions of intuitive AI: TED.

Deuling, T. (2017) Interview with Ton Deuling of The Benthem Crouwel Lab on VR & AR in Architecture/Interviewer: R. o. d. Beek. Delft.

Dooren, E., et all. (2014). Making explicit in design education: Generic elements in the design process. . International Journal of Technology and Design Education, 24(1).

Dunn, N. (2010). Architectural Modelmaking. London: Laurence King.

Fröst, P., Warren, P. . (2000). Virtual Reality Used in a Collaborative Architectural Design Process. Proceedings of IV2000 IEEE International Conference on Information Visualization, 568-573.

Gastel, J.-P. v. (2017). Live Design Ecosystem. Paper presented at the Autodesk Live Event Eindhoven.

Halsey, E. (2016). 5 Reasons to add Virtual Reality to you Workflow. Retrieved from http://www.archdaily.com/787137/5-reasons-add-virtual-reality-to-architecture-workflow

Hanegraaf, J. (2017) Interview with Johan Hanegraaf of Mecanoo Architects on VR & AR in Architecture/Interviewer: R. o. d. Beek. Delft.

HMH Architecture. (2017). The Design Process: Standard Phases. Retrieved from http://hmhai.com/design-phases/

Hubers, J. C. (2008). Collaborative Architectural Design in Virtual Reality. (PhD), Delft University of Technology, Delft.

Kapp, K. (2012). The Gamification of Learning and Instruction: Game-based Methods and Strategies for Training and Education: John Wiley & Sons.

Kelly, K. (2016). The untold story of Magic Leap, the world's most secretive startup. Retrieved from https://www.wired.com/2016/04/magic-leap-vr/

Lawson, B. (1979). Cognitive Strategies in Architectural Design. Ergonomics, 22(1), 59-68.

Mahon, C. (2016). 4 ways Virtual and Augmented Reality will revolutionize the way we practice Architecture Retrieved from http://www.archdaily.com/783677/4-ways-virtual-and-augmented-reality-will-revolutionize-the-way-we-practice-architecture

Martín, N. (2016). VR Architecture: Why the next design frontier will be in Virtual Spaces. Retrieved from http://www.archdaily.com/781391/vr-architecture-why-the-next-design-frontier-will-be-in-virtual-spaces

Myers, B. (2016). Real-, Virtual-, Mixed-, Augmented- That's a lot of reality. Here's how to keep it all straight. . Retrieved from https://www.wired.com/2016/04/magic-leap-vr/

Plowright, P. (2014). Revealing Architectural Design: Methods, Frameworks and Tools. New York: Routledge.

Quirk, V. (2012a). A brief history of BIM. Retrieved from https://www.archdaily.com/302490/a-brief-history-of-bim

Quirk, V. (2012b). Rendering/CLOG. Retrieved from http://www.archdaily.com/310498/rendering-clog#_=_

Routledge, H. (2016). Why Games are good for business: How to leverage the power of serious games, gamification and simulation: Palgrave Macmillan.

Schnabel, M., Tian, S., Aydin, S. (2014). Gamification and rule based design strategies in architecture education. DesignEd Asia Conference.

Schön, D. (1985). The Design Studio: An Exploration of its Traditions and Potential. London: RIBA.

Schön, D. (1987). Educating the Reflective Practicioner: Toward a new design for Teaching and Learning in the Professions. San Francisco: Jossey-Bass.

Stellingwerff. (2005). Virtual Context. (PhD.), Delft University of Technology, Delft.

Stott, R. (2015). The Computer vs The Hand in Architectural Drawing: ArchDaily Readers Respond.

Sutherland, I. (1963). Sketchpad, a man-machine graphical communication system. (Doctor of Philosophy), Massachusetts Institute of Technology, Massachusetts.

Sutherland, I. (1965). The Ultimate Display. Proceedings of IFIP Congress, 506-508.

Valdes, G. (2016a). Getting Started with Virtual Reality and Immersive Review. Retrieved from http://blog.irisvr.com/blog/category/getting-started-virtual-reality-immersive-review

Valdes, G. (2016b). Immersive Design and Immersive Review. Retrieved from http://blog.irisvr.com/blog/category/immersive-design-and-immersive-review

Valdes, G. (2016c). Quality Assurance and Control with Virtual Reality. Retrieved from http://blog.irisvr.com/blog/category/quality-assurance-and-control-with-virtual-reality

Webster, A., Feiner, S., MacIntyre, B., Massie, W., Krueger, T. (1996). augmented reality in architectural construction, inspection, and renovation. Proc. ASCE Congress on Computing in Civil Engineering, 913-919.

Figures

1. Myers, B. (2016). Real-, Virtual-, Mixed-, Augmented- That's a lot of reality. Here's how to keep it all straight. (pp. Real Virtual and Augmented Reality): Wired.

2. Plowright, P. (2014). Revealing Architectural Design: Methods, Frameworks and Tools (pp. Diagram of Durand's design method). New York: Routledge.

3. HMH Architecture. (2017). The Design Process: Standard Phases (pp. Architectural design phases of HMH Architecture.).

4. Budhrani, D. (2017). Virtual Reality #3 - Hardware options: displays.

5. Broll, W., Lindt, I., Ohlenburg, J., et al. (2004). ARTHUR: A Collaborative Augmented Environment for Architectural Design and Urban Planning Journal of Virtual Reality and Broadcasting.

6. Routledge, H. (2016). Why Games are good for business: How to leverage the power of serious games, gamification and simulation (pp. Pacing in movies, like Star Wars.): Palgrave Macmillan.

7. Routledge, H. (2016). Why Games are good for business: How to leverage the power of serious games, gamification and simulation (pp. Pacing in games, like Assassin's Creed.): Palgrave Macmillan.

8. Self-Made. (2017). Co-ordinate system to compare different design media.

9. Stellingwerff. (2005). Virtual Context Architecture (pp. Six different design media in the co-ordinate system.). Delft: Delft University of Technology.

10. Bernie, D. (2010). Architectural Drawing (pp. Generative Drawing): Laurence King Publishing.

11. Bernie, D. (2010). Architectural Drawing (pp. Analytical Drawing): Laurence King Publishing.

12. Bernie, D. (2010). Architectural Drawing (pp. Illustrative Drawing): Laurence King Publishing.

13. Ram, N. (2017). Google's Tilt Brush is the future of Arts (pp. Generative Drawing in VR using Tilt Brush).

14. Fairs, M. (2013). augmented 3D printing (pp. Physical model with an AR overlay of the direct context.).

15. Bernie, D. (2010). Architectural Drawing (pp. Example of an 'early render'.): Laurence King Publishing.

16. Mothe, P. (2015). Design of new Emily Carr University campus unveiled as construction begins at False Creek Flats (pp. Example of a 'final render'.).

17. Gastel, J.-P. v. (2017). Live Design Ecosystem Autodesk Live Event (pp. Visualization of Autodesk Stingray's compatibility with other Autodesk Software and different devices.). Eindhoven: Autodesk.

18. Architects, B. C. (2018). BNTHMCRWL Logo (pp. Benthem Crouwel logo): Google.

19. Architects, M. (2018). Mecanoo Logo (pp. Mecanoo Logo): Google.

20. Self-Made. (2018). Four fundamental aspects of the design environment.

21. Self-Made. (2018). Illustration of the ‘ at the desk’ scenario.

22. Self-Made. (2018). Illustration of the ‘ at the conference table’ scenario.

23. Self-Made. (2018). Illustration of the ‘ at the site’ scenario.

24. Lynch, P. (2016). Trimble’s SketchUp Viewer Allows You To Manipulate Hologram Models in the Real World (pp. Collaborative design session using SketchUp Viewer with Microsoft Hololens.).

25. Self-Made. (2018). Feedback information relating back to your starting positions, criteria and wishes.

26. Self-Made. (2018). Feedback information showing the progress of different aspects or domains.

27. Self-Made. (2018). Feedback information on the entire process.

Interviews

Ton Deuling - Benthem Crouwel

R: Laat ik eerst even uitleggen wat ik nou precies aan het onderzoeken ben...
T: Wat is de afstudeerrichting die je doet?
R: Architectuur bij de studie ExploreLab, waar ik dus compleet mijn eigen richting mag kiezen.
T: Ik weet dat ze inderdaad erg druk bezig zijn op bouwkunde met VR. Tijdens de BAU lieten ze ook van die rugzakken zien waar dan goede computers in zitten, zodat je kunt rondlopen met de VR-bril. Ze vertelde dat ze ook meer van dat soort setups wouden maken. Maar dat dit op de faculteit nog wel aardig anoniem is.
R: Ja klopt. Er is één keuze vak in de master waarbij je ermee wordt geintroduceerd. Los daarvan is er nog niet veel waarbij je in contact kunt komen met deze nieuwe technologie.
T: Ik begrijp ook dat het nog niet zo erg gewaardeerd wordt door alle professoren.
R: Ja, dat is ook iets wat ik probeer te bereiken met mijn onderzoek, namelijk om te overtuigen dat VR en AR meer zijn dan een simpele gimmick en dat het veel meer kan betekenen voor de architectuur.

1. Wat is het precies waar u VR en AR nu voor gebruikt?
T: We hebben op het moment wel een beetje AR gebruikt, maar nog niet heel veel. De mogelijkheden met AR zijn toch nog erg gelimiteerd.
VR gebruiken wel al best vroeg in het ontwerpprocess. Vooral ook mensen te overtuigen en mee te krijgen in ideeën. We gebruiken het wel voornamelijk bij projecten die we al binnen hebben. Dus niet om mensen te verleiden tijdens een competitiefase.
We gebruiken het voornamelijk om mensen te overtuigen van een ruimtelijke kwaliteit. Als architect ben je natuurlijk ook heel erg op zoek om jou ideeën te verkopen en die moet je dan op een bepaalde manier overbrengen aan je opdrachtgever. Opdrachtgevers bij competities zijn vaak juryleden en dat zijn vaak geen architecten. En die hebben vaak een minder ruimtelijke verbeelding.
R: Vaak zit er toch wel één architect bij de jury?
T: Nou.. Vaak zit er wel een of twee bij, maar de meeste zijn het niet. Het zijn vaak wel mensen die verstand hebben van bouwen. Zeker omdat wij vaak te maken hebben met grote opdrachten en weing particuliere opdrachten.

R: Dus ze weten wel een beetje waar ze naar moeten kijken.
T: Ja, maar ze zijn dan nog steeds geen architect. En het verschil daarin is dat een architect de waarde van een mooie ruimte kan inzien. Hoe maak je dat dan duidelijk? Zeker als je dan ook alternatieven wilt aandragen. Daarin zie wij dat VR erg belangrijk is. Zo kunnen we met een opdrachtgever een ontwerp doorlopen en dan atelier A, B en C laten zien en zo het verschil in ruimtelijke kwaliteit aantonen. Als architect is dat heel moeilijk om dat uit te drukken in geld. Als je bijvoorbeeld een lagere verdiepingshoogte neemt kan dat in de kosten heel veel schelen, maar om dan duidelijk te maken wat daarvan het effect zal zijn op de beleving moet dan ook overwogen worden. Dat soort zachte kanten van een ontwerp kan je veel meer toetsen met VR. Zeker omdat je met VR er echt in zit. Met AR houdt je dan toch die afstand.

2. Welke programma's gebruikt u hiervoor? En leggen die ook de link met de andere CAD en BIM programma's?
T: Wij gebruiken nu veel Rhino. Zeker in het begin van het process. Wanneer we het dan verder uitwerken gebruiken we Revit. Vervolgens brengen we het naar 3DS Max voor het renderen.
R: Zijn 3DS Max en Rhino niet een beetje gelijkwaardig op dat gebied?
T: Als je naar de core kijkt zijn het natuurlijk andere modelleer programma's. De een gebruikt NURBS en de andere polygonen. Maya kan bijvoorbeeld allebei.
Maar wij kopen een Revit pakket en daar zit automatisch 3DS Max bij. Voor ons is dat nu ook het snelst, want wij hebben visualizers die daarin getraind zijn.
Dus wij modelleren in Rhino en Revit, vervolgens gaat het naar 3DS Max en vanuit daar brengen we het naar Unreal Engine. We kunnen het ook direct vanuit Revit naar Unreal brengen, maar als we meer kwaliteit willen gaat het eerst langs 3DS Max.
Wat wij dus ook al zeiden bij het Autodesk Live Event is dat wij niet alles materialiseren tot in de puntjes. Wij zitten veel meer in een dynamisch process, waarbij een opdrachtgever vaak veranderingen wilt doorvoeren. Dan kost het veel te veel tijd om alles nogmaals te materialiseren. Door alles simpel te houden kunnen we veel efficienter werken.
R: En het lijkt me ook beter om een niveau van abstractie te houden zodat het makkelijker is om op voort te borduren.
T: nou.. Je hebt inderdaad wel dat mensen het gevoel krijgen bij een strakke tekeningen dat er geen veranderingen meer mogen plaats vinden. Maar dat wordt wel steeds minder een issue, omdat het steeds makkelijker wordt om te renderen.
R: Mensen worden zich ervan bewust dat, doordat alles steeds sneller er mooi uit ziet, dat veranderingen mogelijk blijven?
T: Waarbij je 3-4 jaar geleden met gelikte plaatjes kwam dan dachten

mensen van 'oh hier kan ik niks meer aan doen, want het is gewoon klaar', denken mensen dat nu niet, want iedereen komt met die plaatjes en iedereen begrijpt dat het niet meer zoveel moeite is als toen.
R: Bij het Autodesk Live Event hadden ze het ook over de workflow van Revit naar Revit Live naar Stingray. Hebben jullie daar ook over nagedacht?
T: Er zijn wel mensen binnen het bureau die vinden dat we daarnaar moeten kijken. Maar binnen een bureau heb je gewoon mensen die bepaalde expertises hebben en bij ons zijn de 3D'ers ervan overtuigd dat UE4 een veel hogere kwaliteit geeft dan Stingray.
Daarnaast zijn er veel dingen met die Revit Live update zijn nog steeds lastig. Ze presenteren het alsof het flawless werkt en geen problemen opleverd. Maar dat zijn allemaal afgesloten use-cases waarbij geen veranderingen plaatsvinden. Je hebt een huisje in revit en link ik direct naar Stingray en dat is het.
R: En als ik dan een muurtje verplaats in Revit dan gebeurt dat ook gelijk in Stingray.
T: Ja een muurtje verplaatsen is een ding, maar dat is niet wat wij doen. Wij willen graag ons hele project kunnen omgooien. Is het dan nog steeds fijn om op die manier te werken? Dan moet het ook zo simpel worden dat iemand die in Revit werkt ook gelijk in Stingray kan werken. Maar binnen het bureau heb je mensen die werken in Revit en mensen die werken in de game engine.
R: Ieder heeft zijn eigen expertise en houdt zich bezig met zijn eigen taak/ tekenprogramma.
T: Ja, en nu is er gewoon nog teveel expertise nodig om op die manier met Stingray te werken.

3. Hoe benadert u VR en AR onderling? Kijkt erg verschillend naar de twee, of ervaart u ze eerder als gelijk?

T: We hebben wel eens wat geprobeerdt met AR. Cadac is wel eens langs geweest met een Hololens. Als je bijvoorbeeld dat station neemt die ze lieten zien op het Autodesk Live Event dan is het leuk en aardig dat je een maquette ziet van het station, maar dan? Wat is dan de toegevoegde waarde daarvan? Waar ik dan de toegevoegde waarde graag in zou willen zien is dat je dan dingen in die hologram kunt highlighten. Zoals interessante punten, bepaalde routing, hoe komt alles bij elkaar, beter uitleggen hoe de isolatie werkt. Dat zijn dingen die handig zouden zijn in AR, maar die staan nog te veel in de kinderschoenen. Daar moet je dan zoveel in investeren om er wat uit te kunnen halen.
Als je kijkt naar zo'n bedrijf als Royal Haskoning die zijn veel groter en kunnen zich dat veroorloven.
R: Die kunnen daarin innoveren.
T: Ja ook nu al inderdaad. Zij zitten ook op een ander gebied en zien in dat gebied ook al ander soort mogelijkheden, zoals controles, bouwchecks

of voor bouwvakkers op locatie. Dat zijn toepassingen die nu al zouden kunnen werken. Maar als architect moet je kunnen verleiden en als AR dan komt met een schokkerige hologram dan kun je beter een echte maquette bouwen, want dat doet veel meer.
Op dat gebied moet eerst nog een slag geslagen worden wil je het interessant maken voor de architect.
R: Je hebt nu wel een hoop bedrijven die komen met AR technologiën die al een stuk beter werken, zoals Google Tango of de Apple ARKit. Die lijken best aardig goed te werken.
T: Ze lijken inderdaad goed te werken, maar vaak is in de praktijk dat niet het geval. Het is ook zeker interessant voor jou onderzoek om te kijken hoe dat in de praktijk in zijn werk gaat. Het verhaal van 'ik moet binnen zes weken een project afhebben en daar moet ik niet alleen mooie plaatjes, maar ook plattegronden en doorsnedes voor hebben' hoe ga je dan de opdrachtgever verleiden? Die kant van het verhaal is er ook. Daarom gebruiken wij tijdens de overleggen voor een prijsvraag ook graag VR, want dan kunnen we goed laten zien wat er mogelijk is en kunnen we mensen mee krijgen met een bepaald idee.
Daarnaast is het zo dat heel veel prijsvragen en tenders het niet toe laten dat je dit soort dingen gebruikt.
R: Ze willen vaak gewoon één poster met bepaalde producten zien?
T: We doen veel projecten in Duitsland en daar is de markt erg dicht getimmerd. Dus dan is niet alleen de hoeveelheid posters, maar ook wat erop komt, in welke schaal, etc. Een vereiste. Je kunt dan wel extra dingen opsturen, maar alles wat in eerste instantie niet gevraagd is wordt gewoon afgeplakt. In Nederland zijn ze wel iets vrijer daarin.
Maar ja, je moet je ook wel afvragen of ze open staan voor VR. Als je daar bij een jury staat en je hebt maar 5 minuten, zijn ze dan bereid om zo'n bril op te zetten.
R: Je kunt het dan natuurlijk ook alleen via een scherm doen. Dat zou je ook kunnen zien als een soort VR.
T: Ja klopt, alleen heb je dan niet die immersiveness.
Wat dan ook heel interessant is om te kijken naar hoe VR zich manifesteerd in bedrijven, maar ook binnen architectuur. Je merkt het ook al wanneer je een render maakt. Je wilt gewoon een bepaalde kwaliteit hebben. Wanneer je een resolutie van 400x600 eruit haalt dan kun je daar vrij weinig mee. En dat is een beetje wat Hololens nu bied. In die zin is het daarom nog heel moeilijk om als architectenbureau te investeren in AR.
R: De kwaliteit is gewoon nog te laag om nu wat mee te kunnen.
T: Ook als je kijkt naar de Oculus of de Vive dan heeft dat ook nog even geduurd voordat dat de gewenste kwaliteit had behaald.
R: Dat lag natuurlijk ook heel erg aan de sterkte van de videokaarten.
T: Tegenwoordig is de kwaliteit acceptabel, maar kan zelfs nog wat verbeterd worden.

R: Uiteindelijk zal die kwaliteit ook naar AR komen, maar dat is er voorlopig nog niet.

4. Wat heeft u ertoe geleidt om met deze technologiën aan de gang te gaan?

T: Je bent natuurlijk constant bezig om nieuwe middelen te zoeken om je ideeën beter mee te verkopen. En dit is ook niet om iets te vervangen. We zien het ook meer als een toevoeging. We zullen bijvoorbeeld niet afstappen van het maken van maquettes omdat we nu door een VR model kunnen lopen. Maar VR is wel een goede toevoeging om bepaalde ingrepen binnen een project beter te onderbouwen. Dat is dus het eerste punt waarom we ermee zijn begonnen.

Ten tweede was het ook gewoon een experiment. We begonnen met zo'n bril waar je je telefoon in kunt stoppen en dan maak je een simpele panorama render en dan kom je er pas achter wat de kracht is van immersiveness. Zo'n headset voor je telefoon was dan wel een makkelijk opstapje. Vervolgens kom je erachter dat je ook met goede kwaliteit er ook echt doorheen kunt wandelen en toen zijn we gaan kijken hoe we dat zouden kunnen implementeren in het bureau en wat zouden daarbij dan de investeringskosten zijn.

R: Op zich best lage instapskosten dus.

T: In het begin wel ja, maar op het moment dat je gaat kijken naar het echte implementeren moet je vooral kijken naar hoeveel tijd je eraan kwijt bent. Als er iemand een dagje mee bezig is, heb je in principe al gelijk 800 euro als bedrijf erin geïnvesteerd. En als hij een week ermee bezig is ben je al 4000 euro verder. Die bedragen lopen best snel op. En dan heb je in feite nog niks gekocht.

Gelukkig had iedereen hier wel door dat dit iets was waarin we moesten in investeren, omdat het iets is wat je helpt in het overtuigen van mensen.

R: En ook iets is wat helpt ten op zichte van de concurrentie.

T: Ja ook inderdaad. We noemen on bureau ook het Benthem Crouwel Lab, omdat we ook graag experimenteren, onderzoeken en steeds nieuwe dingen willen proberen. Daarbij hoort VR ook bij.

5. Wat hoopt u te bereiken door gebruik te maken van deze technologiën?

[Overgeslagen]

6. Websites als ArchDaily beweren dat VR en AR de wereld van architectuur zullen veranderen als nooit tevoren. Bent u het daarmee eens? Waarom, of waarom niet?

T: Ze zullen natuurlijk wel ons beroep veranderen. Zo is het al niet meer zo dat we twee uur moeten wachten op een render, maar kunnen we nu de game engines gebruiken voor real-time rendering. Bij het Autodesk

Live Event had je bijvoorbeeld ook die man van Soluis die daar heel erg mee bezig was. Zij bieden VR aan op de hoogste kwaliteit en daar betaald men dan ook grof geld voor. Zij zijn daarom ook koplopers op dat gebied. Langzaam zal dat wat zij doen ook worden overgenomen door de rest.
Wat websites als Archdaily promoten is dat je kunt ontwerpen in VR en dat je dan daarnaast niks meer nodig hebt. Maar ik denk dat dat wel iets is wat niet zo snel zal gebeuren. Zeker bij projecten die wij doen, die super complex zijn. Het draait dan vaker om het overview dan om de menselijke ervaring. De vraag is dan of VR het beste middel is. Je hoeft namelijk niet bij alles in de ruimte te staan. Wij doen bijvoorbeeld op schiphol een project waarbij het veel gaat om passagier-stromingen en dan is het niet voordeliger om in de ruimte te staan. Dan is een 2D plattegrond makkelijker.
Daarnaast is ook maar de vraag hoe ver je daarin kunt gaan. Een muurtje neer zetten is een ding, maar kan ik hem dan ook detailleren en custom-made maken. Architecten willen altijd net weer iets anders. In de filmpjes die nu worden weergegeven worden vaak maar hele simpele dingen voorgedaan. In het begin is dat misschien handig, maar al snel wil je meer in detail werken.
Het zal in ieder geval nog even duren voordat we op zo'n manier zullen werken.
Als kijkt naar hoe de computer ons vak heeft verandert dan heeft dat ook veel impact gehad en VR zal ook wel een zelfde soort impact hebben, maar dat zal zeker nog wel even duren.

7. Ontwikkelen jullie ook software waarmee je kunt modelleren in VR? (Zoals Johan Hanegraaf doet bij Mecanoo)

T: Bij ons zit de ontwikkeling veel meer op het interface gebied. Dus hoe krijgen we bepaalde interfaces bij onze VR views. Dus veel meer op het gebied van wat we wel en niet willen laten zien en hoe we door de ruimte bewegen. Dus we zijn op het moment niet echt bezig om te creeëren in VR. Het is wel interessant dat te doen natuurlijk. Zeker tijdens bijvoorbeeld een meeting waarbij je snel wat dingen zou willen aanpassen. Het probleem daarbij is dan voor nu nog dat er maar één iemand in die bril zit.
R: Dus jij zegt dat er eerst een soort 'collaborative function' aan moet komen?
T: Ja, want als ontwerper maak je je gebouw en dan laat je het zien in VR. De kracht zou dan kunnen zijn, dat je dat even snel wat kunt veranderen tijdens de meeting, zodat je niet eerst terug naar de computer hoeft en een nieuwe meeting moet inplannen. Vaak komen er wel tot zeven mensen kijken bij zo'n meeting en dan moet iedereen kunnen mee doen. Als dat zou kunnen dan heb je een heel erg krachtige tool voor tijdens die discussies. Zeker voor discussies die intern plaats vinden. Bij externe meetings wil je het vaak wat beter controlleren.
R: IrisVR is een bedrijf dat hun software voor dat soort doeleinden aanbied,

waarbij ze een setting creeëren waar één iemand een bril op heeft en de rest mee kijkt op een scherm ernaast.
T: Ja, dat is iets wat wij hier ook kunnen doen. In de kamer hiernaast hebben we dan een grote biemer met een grote wand waar we dan de beelden op projecteren. Dan heeft één iemand inderdaad de bril op en de rest kijkt mee. Want je wil als persoon niet niks kunnen doen tijdens zo'n meeting. Iedereen moet kunnen participeren.
Dus in die zin denk ik dat het als ontwerptool erg handig kan zijn tijdens meetings, maar het verdere uitwerken sneller zou gaan achter de computer.

8. Waar denkt u dat de 'ultieme' potentie ligt voor VR of AR binnen de architectuur?
T: Waar ik denk dat het heen gaat.. Ik denk dat VR een tussenstap is naar echt goede AR. Want in zekere zin zou AR precies hetzelfde kunnen doen als VR. Ik denk dat het in de toekomst erg toegankelijk zal zijn en dat je dan in het dagelijkse gebruik heel gemakkelijk een hologram van het gebouw kunt plaatsen op de tafel. Maar dan ook gemakkelijk interactie kunt hebben met een hologram. Verder zullen biemers en TV's minder gebruikelijk zijn, omdat je dat ook kunt nabootsen met AR.
Dus ik denk dat er meer toekomst zit in AR dan in VR.
R: Maar voor nu gaat VR nog even voor..
T: Ja, maar ik denk dat de AR wel heel snel gaat en dat we over 5 jaar wel een ander gesprek zouden kunnen hebben. Zeker omdat vooral de grote bedrijven meer zien in AR dan in VR.
R: Vandaar dat de grote er ook zoveel in aan het investeren zijn.
T: Ja, als je bijvoorbeeld naar Microsoft kijkt die gooien alles op AR, net als Apple. En dan heb je ook nog Magic Leap waar iedereen een hoop van verwacht. Daar moeten we ook nog maar op wachten wat daar uit komt.

9. Zouden studenten die nu beginnen aan de faculteit al eerder met deze technieken geïntroduceerd moeten worden?
Ja zeker. Ik vind dat een universiteit gewoon moet vooroplopen met alles. En dat je daarin dan ook alles aanpakt wat je kunt aanpakken. Je ziet gewoon dat die grote bedrijven best wel willen investeren in universiteiten en hun producten willen delen. Zeker omdat de studenten dan later er ook mee zullen werken en dan ook meer geneigd zijn om producten van die bedrijven te kopen. Als universiteit kun je daar op inspelen.
Daarnaast kun je veel meer spelen bij de universiteit, want je bent aan het leren. Je kunt spelenderwijs leren omgaan met deze tools. Dit is iets wat ook toegejuicht moet worden door de docenten en hoogleraren. Nou weet ik dat de faculteit erg veel mogelijkheden bied, maar dat ze niet erg breed worden uitgezet. Dat zal natuurlijk deels te maken hebben met geld, maar dat ligt ook aan het slim leggen van contacten. Je moet je studenten kunnen bieden wat ze nodig hebben om te kunnen experimenteren, onderzoeken

en uiteindelijk te innoveren.
Ik heb zelf ook gestudeerd in Amerika bij een private university en daar was een hele andere sfeer. Alles draait erom wat de studenten nodig hebben en daar speelt geld dan niet echt een rol in. Als iemand wilt 3D printen dan moet er een printer beschikbaar zijn voor die student. Dat maakte het heel laag-drempelig om dingen aan te pakken. En daarmee kun je als universiteit voorop lopen.
Dus ik vind dat nieuwe ontwikkelingen ten alle tijden toegejuicht moeten worden. Al is het alleen maar toejuichen. Wat ik een slechte ontwikkeling vind is dat professoren dingen niet willen beoordelen wanneer het op een andere manier gedaan wordt. Een vriend van mij die nu bijna afstudeert die werd verteld dat hij geeen VR mocht gebruiken, want dat zou niet eerlijk zijn tegenover de rest. Terwijl de rest in principe ook dat zouden kunnen doen. Als hij er de tijd en energie in wil steken dan zou dat alleen maar toegejuicht moeten worden.
R: Ja ben ik het ook zeker mee eens.

Johan Hanegraaf - Mecanoo

1. Wat is het precies waar u VR en AR nu voor gebruikt?
J: Het begon als een soort van studie object, omdat een hoop software het makkelijk maken om 360 images te maken. Die gebruiken we vooral om op dit moment. Dat begon vooral bij de opdrachtgevers als een soort PR tool. Uiteindelijk zagen we ook dat de architecten zelf het ook graag gebruiken tijdens het ontwerpproces. Dit is iets wat gelijk ook zal veranderen, want veel architecten geven niet graag toe dat ze tools als VR of BIM nodig hebben om het ontwerpproces beter te maken. Ze denken dat ze het allemaal al zelf in hun goed weten. Maar de werkelijkheid is dat als jij iets virtueel 3D voor je ziet, kun je het gewoon veel beter inschatten. Hier beginnen de architecten het al te waarderen, maar een hoop denken nog steeds van "ah dat heb ik toch allemaal niet nodig". Langzamerhand beginnen mensen het ook in te zien als ontwerp tool.

2. Welke programma's gebruikt u hiervoor? En leggen die ook de link met de andere CAD en BIM programma's?
J: Grotendeels gebruiken we daarbij de gewone dagelijkse programma's, als Revit, Maya, 3D Studio, Lumion. We zijn aan het testen met game engines. Persoonlijk groot voorstander van game engines. Degene die wij hier het meest gebruiken is Enscape, als plugin op Revit. Verder ben ik nog aan het expirimenteren met UE4 en Unity. Unity is als third party developer namelijk ook wat meer open.
Het zal zeker niet lang meer duren voordat game engines standaard binnen de architectuur gebruikt worden.

3. Hoe benadert u VR en AR onderling? Kijkt erg verschillend naar de twee, of ervaart u ze eerder als gelijk?
J: We gebruiken eigenlijk nog helemaal geen AR. De hoofdreden daarvoor is dat de techniek nog erg achterloopt ten opzichte van VR. Virtual Reality is gewoon Plug & Play en dat is in de commerciele wereld erg belangrijk. Je wilt niet van te voren nog veel moeten investeren om het te kunnen gebruiken. Tot dat er goede tools zijn in AR die heel toegankelijk zijn, zal het bij de architecten bureaus ook wel zo blijven. Daarnaast is het voordeel van VR boven AR dat een architect er veel aan heeft om omgeven te worden door de ruimte. Dat is zou je nooit zo goed kunnen krijgen met een hololens.
R: Uit mijn onderzoek komt nu ook dat VR voornamelijk goed toe te passen is op het interieur, omdat je dan die immersie wilt, en AR meer voor het exterieur.
J: En vooral ook bij de schaal modellen zou AR handig zijn, want dat is ook nog steeds belangrijk binnen de architectuur. Een architect moet namelijk ook het overzicht kunnen zien van het gehele ontwerp, waarbij je kunt zien

waar alles zit, hoe het in zijn context ligt, hoe het concept zich uitstraald, hoe zit het aesthetisch in elkaar, wat zijn de voor- en nadelen..
Dit zijn ook dingen die ik probeer te bereiken met de applicatie die ik nu zelf aan het ontwikkelen ben, zoals makkelijk kunnen switchen tussen het overzicht en de menselijke ervaring.
Het echt in de ruimte rondlopen zie ik niet zo snel gebeuren met een AR-bril.
R: Nee precies, dan is het logischer om gewoon een VR-bril te pakken. Wat ik me dan wel weer kan voorstellen is het weergeven van het gebouw op de bouwplaats en dan het gebouw van veraf in zijn geheel kunt zien.
J: Dat zou inderdaad hele waardevolle informatie opleveren. Zeker als daarbij dingen als leidingen onder de grond en andere dingen die je wilt zien zichtbaar zijn.
R: Zover zijn we helaas nog net niet. Maar is wel interessant om nu al mee bezig te zijn.
J: Dan ga je alleen wel meer de technische kant op waarschijnlijk. Ik weet niet hoe je uiteindelijk je afstuderen gaat vormgeven.

4. Wat heeft u ertoe geleidt om met deze technologiën aan de gang te gaan?
J: Het is grappig, want het is eigenlijk puur ontstaan vanuit de mensen die voor het bureau zelf werken, die een beetje handig zijn met computers. Dus het is niet vanuit de bedrijfsfilosofie van Mecanoo ontstaan. Doordat we op dat gebied een beetje hebben gepionierd hebben we ook de directie kunnen introduceren aan VR en AR.

5. Wat hoopt u te bereiken door gebruik te maken van deze technologiën?
J: Ik denk dat veel dingen nog onduidelijk zijn voor ons. Maar ik denk dat veel vanuit de industrie zelf zal gaan komen. Men zal met nieuwe mogelijkheden komen die de rest de ogen zal openen over het gebruik van VR. Zo krijg ik zelf ook veel aandacht dankzij de filmpjes die ik op internet gooi, en daarbij vind ik het ook gek dat niemand anders met deze toepassing is gekomen. Zo blijkt er ook maar weer dat er nog zoveel dingen nog on-ontdekt zijn bij VR en AR. Dus de komende jaren zullen we nog versteld staan met wat we allemaal ermee kunnen. Voor de architect ligt het geheel aan de hoeveelheid tijd en geld hij willig is om te investeren.
Fun fact: Mecanoo heeft niet zoiets van “Johan ga lekker je gang met het ontwikkelen van je applicatie”. Ik doe dit voornamelijk in mijn eigen tijd. Het is voornamelijk vanuit mezelf gekomen dat we dit doen. Het is dus niet zo dat Mecanoo mij drie dagen op het ontwikkelen van VR applicaties zal zetten. Zo werkt het nou eenmaal niet binnen het bureau. Ik denk dat het voor een engineering bureau interessanter is, omdat die al wat meer specialisten, kennis en middelen hebben. Binnen een architecten

bureau draait het toch meer om het binnen halen van projecten en ontwerpopdrachten, waardoor het een heel snel draaiende wereld is en er geen tijd overblijft om VR of AR applicaties te ontwikkelen.
R: Dus jij denkt dat het ontwikkelen eerder zal beginnen bij de engineering bureau's dan bij de architecten?
J: Nou.. Ja, ik denk dat engineering bureau's er ook veel aan zullen hebben, en aangezien het voor hun makkelijker is om iemand daar een hele dag op te kunnen zetten.
Daarnaast zijn de meeste (oudere) architecten niet persee heel goed met computers. Echt zelf ontwikkelen zal daarom niet zo snel gebeuren bij een architecten bureau.
R: Architecten bureau's moeten het dus echt hebben van iemand zoals jij om daarmee bezig te zijn?
J: Ja inderdaad, ook als je kijkt naar de technische kennis op dat gebied heeft een engineering bureau er veel meer van. Misschien dat dat daarom ook nog wel interessant is om naar te kijken voor je?
R: Op zich wel interessant om naar te kijken, maar ik probeer wel mijn onderzoek te focussen op de architect. Dus ik zal dat nog wel even goed moeten overwegen.
J: Ja snap ik, doe je wel goed aan.

6. Websites als ArchDaily beweren dat VR en AR de wereld van architectuur zullen veranderen als nooit tevoren. Bent u het daarmee eens? Waarom, of waarom niet?
J: Uiteindelijk wel. Maar ik ben het niet eens met alle artikelen op Archdaily eens daarover. Veel wordt gefocust op de visualisatie kant, en dat is ook wel belangrijk natuurlijk, maar ikzelf zie veel meer mogelijkheden in het manipuleren van ruimte met 3D bewegingen. Het intuitief omgaan met modellen is voor mij een hele nieuwe wereld die open gaat. Voor mij gaat het over een nieuwe manier van verbinden met computers. Dit wordt de eerste connectie met de matrix!

7. Waar denkt u dat de 'ultieme' potentie ligt voor VR of AR binnen de architectuur?
De tools die we nu gebruiken vergen veel on-intuitive handelingen, terwijl ontwerpen eigenlijk iets heel intuitiefs is, waarbij we schetsen, modelletjes maken, kijken hoe dingen zitten, kijken hoe licht valt, etc. Dat intuitieve is een beetje weg gegaan in de loop der jaren, voornamelijk door die CAD software. Ik denk dat VR weer een hele hoop van dat intuitieve weer terug kan brengen. Maar tegelijkertijd wel alle voordelen houden van het gebruik van computers, zoals het snel kunnen kopieren, automatiseren, etc. Zo hoef je niet 100 keer hetzelfde schuimblokje te gaan zitten snijden. Dus de computer zal een verleng stuk worden van het intuitive ontwerp proces. Ik ben zelf heel erg van de digitale werkomgeving en zie daar heel veel

potentie in. Binnen het bureau denkt niet iedereen daar zo over trouwens, maar dat maakt het bureau ook divers. Maar de computer kan ons in ieder geval productiever maken.

8. Denk je dat we met VR en AR ook uiteindelijk de kwaliteit van onze gebouwen kunnen verbeteren?

Ik hoop het wel ja. Je merkt het ook al met de BIM werkwijze, waarbij je tegelijkertijd met meerdere mensen aan hetzelfde gebouw kunt werken. Dat haalt zoveel problemen en miscommunicatie weg. Alleen ook daarin worden nog foute keuzes gemaakt in bijvoorbeeld wat voor standaarden we dan zouden moeten naleven. Komt natuurlijk ook omdat de techniek nog erg jong is. VR is in die zin nog jonger. En er zullen waarschijnlijk ook mensen zijn die VR gaan gebruiken tegen het ontwerpproces, bijvoorbeeld door hele hoge onnodige standaarden te verwachten. Dit zal ook wel altijd blijven met techniek.

R: Ik heb nu ook een beetje hetzelfde met renders.

J: Ja, daarin heb je nu ook het probleem dat we de wereld mooier kunnen doen lijken dan het eigenlijk is. En dan kan het gebeuren dat je de klant rommel loopt te verkopen, puur en alleen omdat je het op de computer mooier kunt maken. Het moet uiteindelijk natuurlijk worden gebruikt als simulatie middel om de architectuur te kunnen verbeteren. Het ene architecten bureau gaat anders met deze technieken om dan de ander en het is nog maar afwachten hoe ze het gaan gebruiken.

R: Als ik zo bezig ben met VR en AR zie ik voornamelijk goede dingen voor ogen, maar het moet inderdaad nog maar blijken wat de slechte dingen zullen worden.

J: In het begin zullen het inderdaad meer goede dingen zijn. Mensen die ik nu enthousiast er zie inspringen hebben ook het beste voor met dit soort middelen. Maar ik denk inderdaad dat VR nog best wel eens wat schade kan veroorzaken op sociaal gebied. Maar dat is iets wat nu met alle technologie gebeurd. Daarvoor hoef je alleen maar in de trein te kijken hoeveel mensen ernaar hun smartphone zitten te staren.

R: Zeker met VR ben je compleet afgeschermd van de realiteit. Daarom denk ik dat AR uiteindelijk het zal overnemen, omdat je dan nog wel bent verbonden met de realiteit.

J: Ja zeker, het is ook een stuk minder gevaarlijk. Uiteindelijk zijn we ook gewoon mensen en willen we gewoon kunnen communiceren met elkaar.

R: Ik denk daarom dat VR vooral geschikt is voor architectuur, want daar is het echt nuttig om je in een andere realiteit te bevinden. Zeker om ook je gebouwen te testen, bijvoorbeeld hoe mensen vluchtroutes gebruiken tijdens een brand.

J: Er zijn natuurlijk al meerdere studietjes geweest aan verschillende universiteiten waarbij ze dat soort dingen testen.

9. Zouden studenten die nu beginnen aan de faculteit al eerder met deze technieken geïntroduceerd moeten worden?

J: Ik denk dat dat over het algemeen wel geldt voor technologie. Het is nu vaak zo dat mensen op eigen initiatief zich gaan specialiseren. Ik heb zelf de academie van bouwkunde gedaan en daar draait het ook veel om het artistieke of de geschiedenis van architectuur en niet zo zeer om de nieuwste technologien. Ik weet niet hoe dat bij de TU werkt?

R: Op de bachelor wordt je vooral geleerd om met de hand te tekenen en later krijg je dan les in het 3D modelleren, renderen, etc. Zou je tijdens die introductie ook gelijk al VR en AR les moeten krijgen?

J: Voor universiteiten is het voor alsnog een interassant onderzoeks gebied. Daarbij zijn vaak de onderzoeken terug kijkend en wat mij betreft kan dat wel wat meer naar het vooruitkijkende gaan. Zeker omdat er zoveel uit te halen valt en bij de universiteit heb je de tijd om je daarin te verdiepen.

R: Want als je aan het werk bent, dan heb je daar geen tijd meer voor.

J: Ja precies! Eigenlijk zou ik gewoon moeten tekenen en zou er geen tijd voor mij moeten zijn om met VR bezig te zijn.

Uiteindelijk denk ik wel dat je de mensen (studenten) zelf moet laten kiezen waarin ze zich verdiepen, maar het zou wel meer gestimuleerd mogen worden om de mogelijkheden van de toekomst te laten zien.

R: Dat waren eigenlijk al mijn vragen! en ik denk dat je jullie filosofie hierover goed hebt onder woorden weten te brengen.

J: Ja ik moet zeggen dat ik zelf hier nogal vooruitdenkend daarin. Als je mijn collega's spreekt dan denken die er wel eens anders over. Als ik het zo zwart-op-wit zou zeggen dan zijn het toch de oudere generaties die hier liever niks van willen weten of van werken met computers. De een vind het fijn om alles op de computer te hebben en de ander wil alles vanuit schetsen. Dit bepaald ook het soort architectuur wat eruit voort komt.

R: Dat is ook wat ik zo interessant vind aan het ontwerpproces. Er is niet maar een perfecte manier, iedere architect, ieder gebouw heeft zo zijn ontwerp methodes.

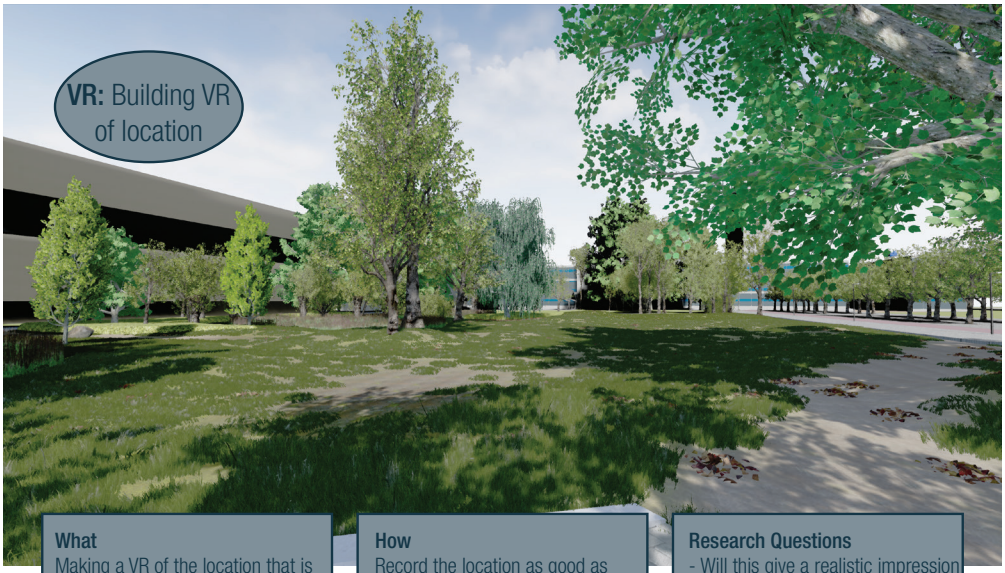
J: Ik vind het ook leuk om mijn collega's daarmee te jennen dat ik het met mijn technieken veel sneller zou kunnen.

Maar als je ook kijkt naar andere architectenbureau's dan vind je ook voorbeelden van prachtige ontwerpen die puur en alleen met papier zijn gemaakt. Zolang er maar passie voor het werk in zit, dan komt het er vanzelf wel uit.

Experiments

Virtual Reality

Augmented Reality

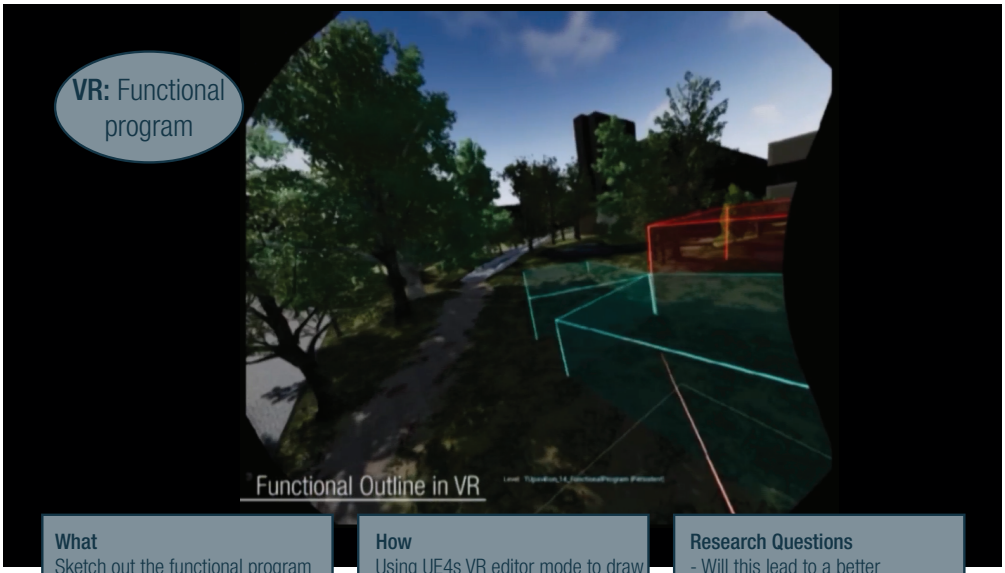


VR: Building

This was initially not meant as an experiment, because it was preperation for the other experiments. However, this could be seen as an adaptation of building a physical model of the location, which is usually done to get a better understanding of the context. Building this in VR really gave me a great understanding of every detail of the site.

+ Intuitive placement.
+ Very gratifying as the quality is so high.

– Takes a lot of time.
– All of the trees and plants require optimization to not put too much strain on the graphics card.
– Requires quite a bit of UE4 landscaping knowledge



What
Sketch out the functional program in the VR of the location.
Adaptation of: Drawing out the functional areas on the floorplan.

How
Using UE4s VR editor mode to draw simple colored blocks to indicate the locations for the different functions.

Research Questions
- Will this lead to a better understanding of the spatial requirements of the different functional areas?

VR: Functional program

The purpose of this experiment was to see if VR could help in finding a functional layout concept.

+ Intuitive scaling, rotating and moving.
+ Very playful.
+ Easy to change colors.
+ Easily switch between human- and birdeye view.

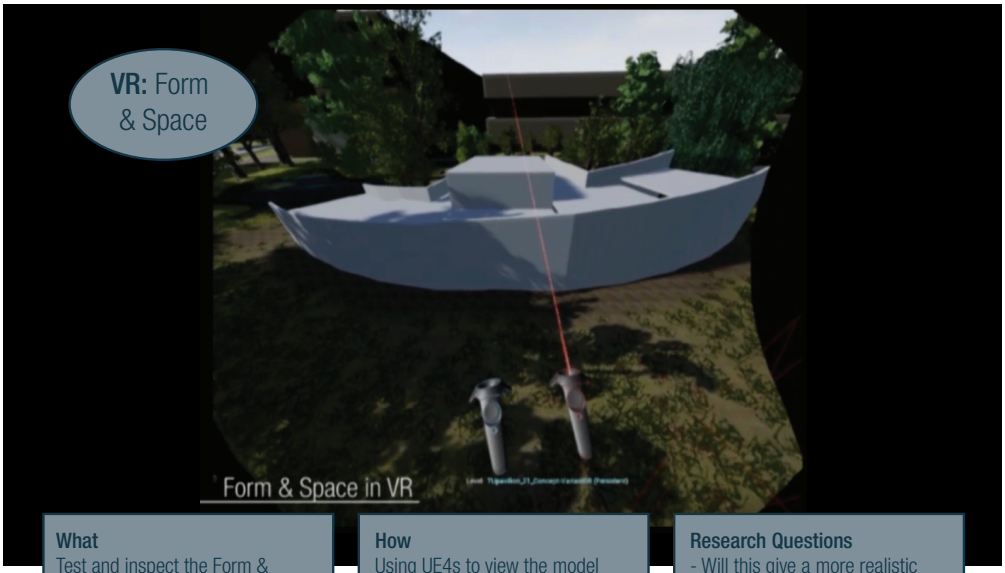
– Difficult to be precise.
– Hard to get a hang of the controls.
– Misses functionalities of other modeling software.

VR: Model studies

The purpose of this experiment was to see what it was like to do model studies in VR, in comparison with physical modeling.

+ Intuitive scaling, rotating and moving.
+ Very playful.
+ Combines Sketchup with physical modeling.
+ Easy to change colors.

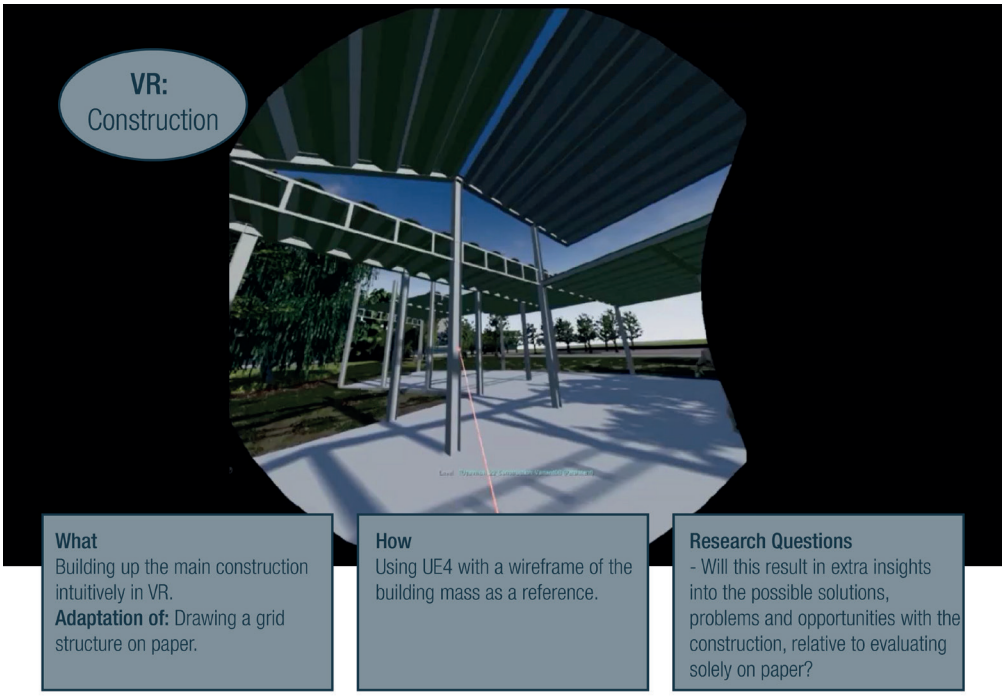
– Difficult to be precise.
– Hard to get a hang of the controls.
– Misses functionalities of other modeling software.
– Misses tangibility



VR: Construction

The purpose of this experiment was to evaluate the Form & Space of the spatial concept.

+ Experience the spatial qualities.
+ Easily switch between human- and birdeye view.
– Without materials the shapes feel very massive.



VR: Construction
The purpose of this experiment was to evaluate the construction through VR.

+ A lot easier to understand the construction.
+ More attention towards detail.
+ Falsehoods make you feel uncomfortable, and want to solve them immidiately.

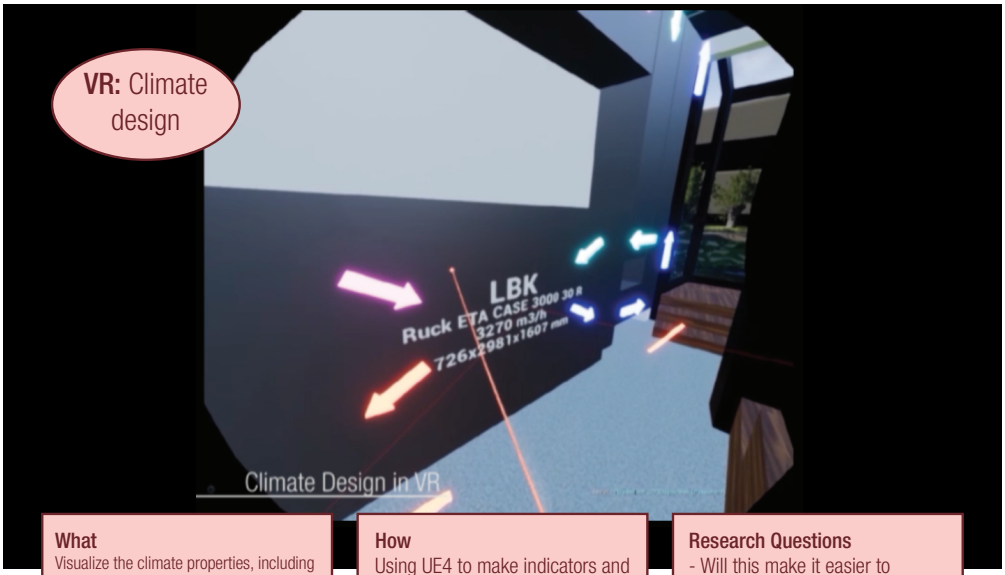
– No gravity, so flying beams are still possible.
– The smallest details draw attention

VR: Materialisation

The purpose of this experiment was to evaluate the material properties of a facade design through VR.

+ Materials in UE4 look very realistic.
+ Immidiately the building came to life.
+ Very insightful in regard to the design, as it the experience was totally different then on paper or screen.
+ More attention towards detail.

– Misses the tangibility you can only get from touching the real material.
– Less attention towards the overall design.



What
Visualize the climate properties, including the airflows, heating / cooling and sun protection. Visualize the climate installations
Adaptation of: Drawing cooling/heating and ventilation arrows on floorplans and sections.

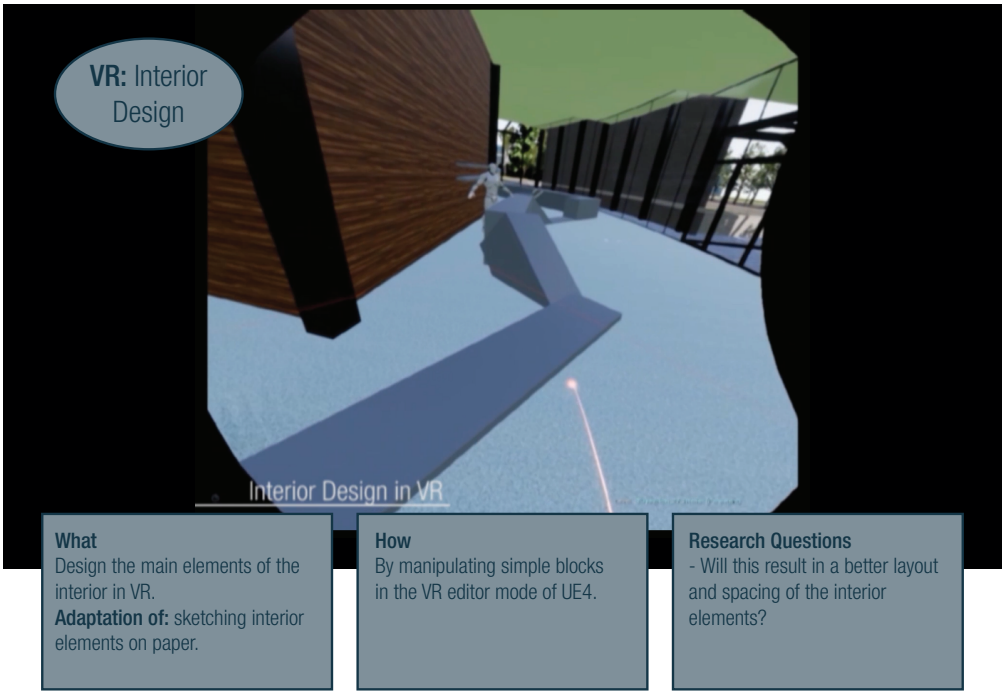
How
Using UE4 to make indicators and animations that visualize the climate design.

Research Questions
- Will this make it easier to recognize possible problems or opportunities?
- Will this make it easier to communicate with other parties?

VR: Climate design
The purpose of this experiment was to evaluate the ventilation system throughout the building.

+ You get a good sense of the airflows throughout the building.
+ Gain much needed respect for the space needed for the ventilation system.

– Still needs a floorplan or section to get the basic principle.

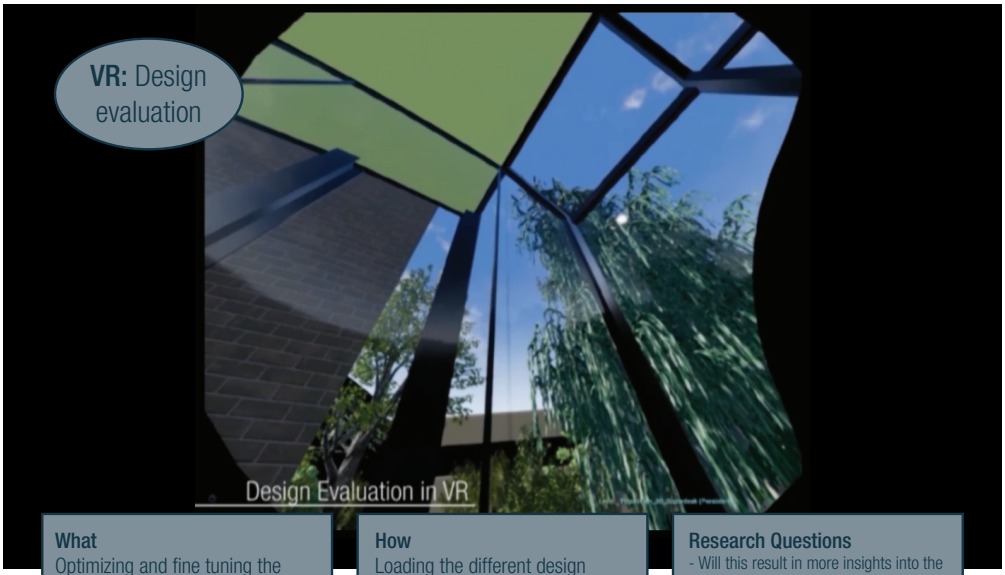


VR: Interior design

The purpose of this experiment was to test different layouts for the interior design.

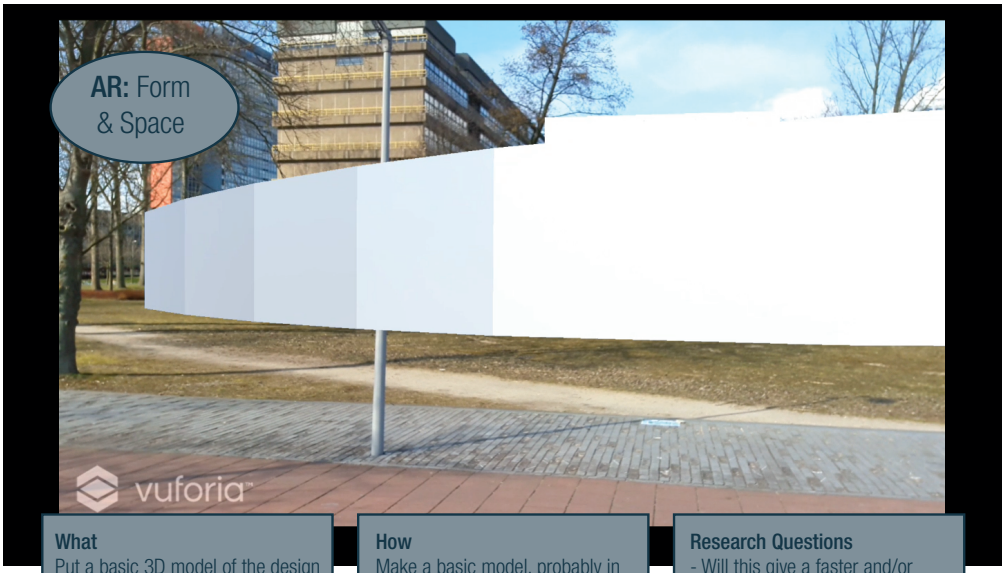
+ Intuitive scaling, rotating and moving.
+ Very playful.
+ Intuitively inspect spatial requirements and measurements.

– Difficult to be precise.
– Hard to get a hang of the controls.
– Misses functionalities of other modeling software.



VR: Design evaluation
This experiment was a recurring one, as I inspected the different design phases in VR.

+ Evaluation becomes very intuitive: If it looks it is good.
+ No detail goes unnoticed, because all of the building is exposed.
– Every detail becomes important, even when they are not required during that stage.



What
Put a basic 3D model of the design on the site on a 1:1 scale.
Adaptation of: Viewing the model on a computer screen.

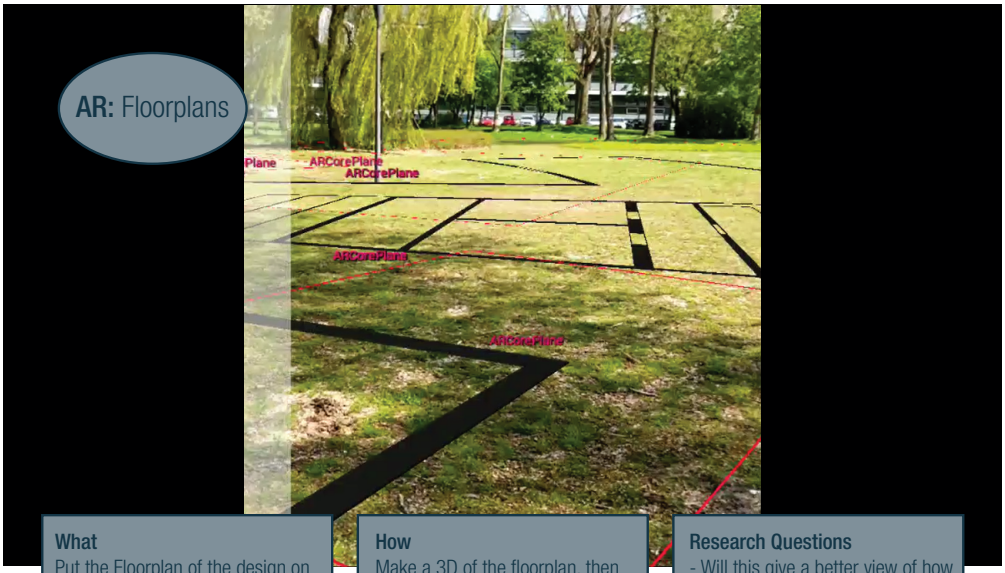
How
Make a basic model, probably in Sketchup or Rhino, then use Sketchfab on the iPad to put it on the site.

Research Questions
- Will this give a faster and/or more realistic impression, relative to seeing the model on a screen?

AR: Form & Space
The purpose of this experiment was to evaluate the Spatial qualities of the design 1:1 on site.

+ Good indication of the size of the building

– Without materialisation the design feels very massive.
– Objects that should be in front of the AR model are not.
– Hard to get the model on the right spot.



What
Put the Floorplan of the design on the site on a 1:1 scale.
Adaptation of: Viewing the floorplan on paper.

How
Make a 3D of the floorplan, then use Sketchfab on the iPad to put it on the site.

Research Questions
- Will this give a better view of how the building will be situated on the site, relative to inspecting the floorplan on paper?

AR: Floorplan

This experiment was to see what kind of information it would give if the floorplan was put on the site at 1:1 scale.

+ Interesting to walk between the lines of the floorplan.

– Basic principles are harder to read.

What
Put the Floorplan of the design on the site on a 1:1 scale.
Adaptation of: Viewing the section on paper.

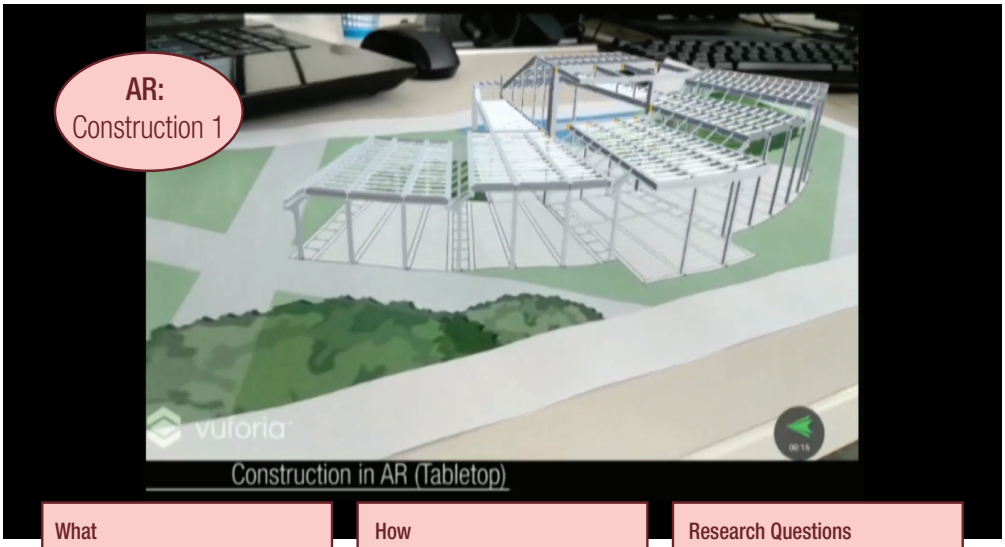
How
Make a 3D of the section, then use Sketchfab on the iPad to put it on the site.

Research Questions
- Will this give a better view of how the building will be situated on the site, relative to inspecting the section on paper?

AR: Section

This experiment was to see what kind of information it would give if the section was put on the site at 1:1 scale.

+ Interesting to walk underneath the lines of the section.
+ Easy to inspect the height of the levels.
– Basic principles are harder to read.



What
Viewing the construction created in the VR as a scale model in AR.
Adaptation of: making a physical scale model of the construction.

How
Using Vuforia to view the construction on top of an image tracker.

Research Questions
- Will this result in extra insights into the possible solutions, problems and opportunities with the construction, relative to evaluating solely on paper?

AR: Construction - tabletop
The purpose of this experiment was to use an AR model to communicate the construction of the building.

+ Very easy to navigate through the construction as you move the camera around.
+ Construction immidiately becomes clear.
+ Constructional issues become very noticable

What
Viewing the construction created in the VR on site through AR.
Adaptation of: making a physical scale model of the construction.

How
Loading the model of the VR into Sketchfab and then view it through the iPad.

Research Questions
- Will this result in extra insights into the possible solutions, problems and opportunities with the construction, relative to evaluating solely on paper?

AR: Construction - site
The purpose of this experiment was to evaluate the construction of the building on site in 1:1 scale.

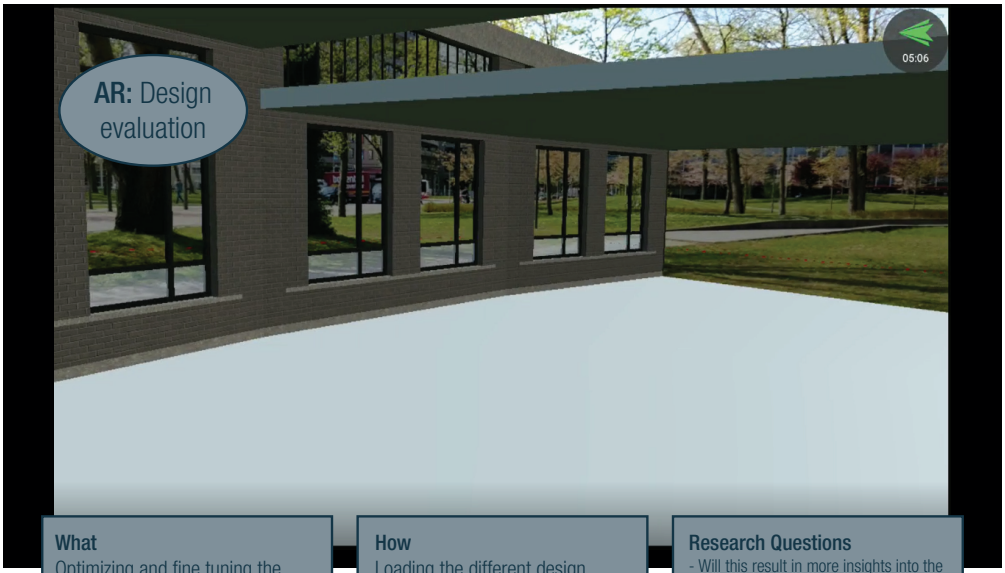
+ Very easy to navigate through the construction as you move the camera around.
+ Constructional issues become very noticable

– Objects that should be in front of the AR model are not.

AR: Materialisation

The purpose of this experiment was to evaluate the materialisation of the building on site in 1:1 scale.

+ Inspecting the design becomes as intuitive as walking through a real building.
+ Using realistic materialisation brings the model to life.
– Objects that should be in front of the AR model are not.
– Requires UV mapping of the model, which slows down the workflow.



AR: Design evaluation

This experiment was a recurring one, as I inspected different design stages on the site in AR.

+ Evaluating the design becomes as intuitive as walking through a real building.
+ No detail goes unnoticed, because all of the building is exposed.

– Every detail becomes important, even when they are not required during that stage.

The Augmented Design Process

Research into the integration of VR and AR into the architectural design process

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Abstract

Virtual Reality and Augmented Reality have the potential to enhance the capabilities of the architect. This thesis explores the implications of the integration of these technologies into the architectural design process. It provides a theoretical framework by discussing what VR & AR would mean to the architect's workflow, and to his workspace. In doing so, VR & AR are not regarded solely as tools or media, but also as a potential design environment. This is reflected in the main research question: "What are the implications of using VR & AR as the workspace in the architectural design process?" As a conclusion of the theoretical framework a personal view of a possible virtual design environment is argued.
The thesis also provides a practical framework in the form of a comparison between the 'traditional' design process and the 'augmented' design process, which is based on a set of VR & AR experiments done during the design process of the 'University Forum for the TU Delft'.
The underlying function of this thesis is to kickstart the discussion on VR & AR in the architectural design process.

Keywords: Virtual Reality, Augmented Reality, Architectural design, Design environment