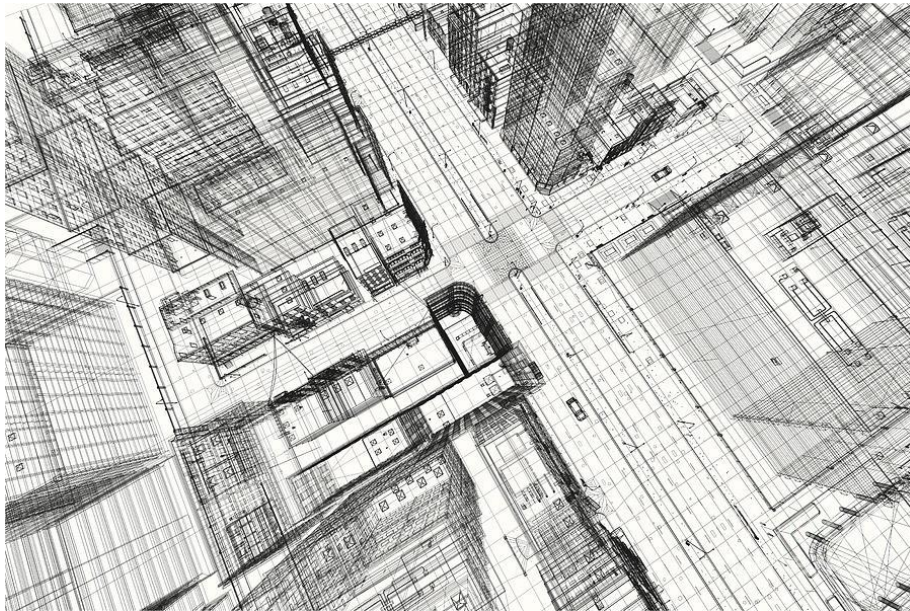


Linking indoor 3-dimensional visualizations with physical architectural floor plans



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Abstract

Architects are dependent on visualizations as their main source of communication with their clients. These visualizations range from scale models to state-of-the-art virtual reality applications. Technological advances provide new opportunities for visualising, but often these new techniques create more confusion than clarity for the less tech-savvy individuals. These problems especially occur when it comes to the interaction with, and understanding a proposed building's interiors. Often clients are shown scale models and floor plans which can be difficult to comprehend for the untrained eye. To counter this, 3-dimensional renditions are used. The problem with these is that often the overview is lost, and for most people the interaction can be difficult. The aim of this project was to create a new visualization, which provides intuitive interaction to the user in such way that they would be able to better understand the proposed build plans. This, while still incorporating state-of-the-art technology such as virtual reality. The resulting prototype uses physical floorplans as its input, where the user is able to navigate through by means of a tangible interface. The virtual realization of any point on the floorplan can be seen by the user on either a display or in virtual reality. The user is also able to place different objects into the environment to get a better idea of scale and distance. These objects are real physical objects that can be placed on the floorplan comparable with a board game. Testing showed that users found the tangible interaction intuitive and fun. Testing with the client showed that the system was beneficial to narrate one through a proposed interior of a building. Although having the final prototype satisfactorily tested, it still needs to be tested within an actual meeting between architect and client.

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Chapter 1: Introduction

1.1 Problem introduction

In the field of architecture, visualizations are an essential tool for communication. Using good visualizations has proven to be efficient in informing both client and public about proposed build plans. In the past architects were limited to presenting sketches and scale models of the proposed building, but these methods were revolutionized with the introduction of computers. The introduction of computers provided architectural designers with new tools for both designing and visualizing buildings. This could be done by using computer-aided architectural design (CAAD in short). These new tools and techniques enabled architects to evolve from merely using sketches to the usage of state-of-the-art 3d renditions. By doing this, the designers were now able to show an accurate virtual representation of a future building. This gave the designers a whole new way of visually communicating with their clients.

There are however, many different techniques to present these 3-dimensional renditions of a building. These techniques range from using a traditional computer display to the usage of state-of-the-art virtual/augmented reality glasses. Navigating through these 3d environments can also be done in several different ways; it could either be a static viewpoint or the user could freely roam around with some form of interaction.

When designing a building's interiors, the clients are often involved during an iterative design process, where the needs of the clients are being adapted in the building's interior design. For example, during the interior design of a hospital, the design choices were being discussed with clients with knowledge of the needs of the medical staff and patients.

Involving the client to some degree in the design process minimizes the risk of substantial failures in the completion. A problem that often arises though, is that miscommunication occurs between clients and designers. Essentially the designers show the architectural floor plans and discuss these with the clients, where the clients are often not proficient in reading two-dimensional floor plans; as two-dimensional floor plans are known to distort scale and sizes to the untrained eye. To overcome this problem, they show their clients a 3d rendition of the indoor environment in virtual or augmented reality. Although this provides the user with a high level of immersion, it also gives rise to a new problem. As soon as people put on these reality glasses, they are absorbed in their own 3d world space. This makes it really hard to discuss the technical details with a group of clients properly. The alternative is to perform a 3-dimensional walkthrough of the building on a regular display, but here the interaction is only done by the architect, as most people have no experience in navigating through virtual worlds.

1.2 Client task

For this project the challenge is to overcome the problems stated in section 1.1. This should be done by providing a new way in interacting and visualizing the proposed building's interiors. To get a better idea of what makes a visualization efficient and usable for our client we will conduct a background research on visualizations in chapter 2.

1.3 Research questions

The following research questions have been formulated for this project:

The main research question is:

- *How can the indoor environment of a proposed building efficiently be visualized to their clients/stakeholders?*

The sub questions that need to be answered are:

- *Which factors are key in efficiently perceiving indoor virtual environments?*
- *What techniques are currently being used to visualize proposed buildings?*
- *What kind of haptic or tangible instrument is best suited for indoor navigation?*

Chapter 2: State-of-the-Art on “Visualizations and interaction in indoor spaces”

2.1 Background research

In order to create an efficient visualization, we need to first explore what is of importance for the viewer in a virtual world. In this chapter the first sub questions will be answered to create a better understanding of the challenges in designing a new type of visualization.

To get a good understanding of what is meant by an architectural visualization we will explore this topic first. Visualizing is defined as following: “If you visualize something, you imagine what it is by forming a mental picture of it”. Linking this to the field of architecture, the conclusion can be made that architectural visualization has something to do with forming a mental picture of an architectural building or structure.

2.1.1 Effectiveness of 3d visualizations

The term effectiveness is a broad one, thus for the sake of length of this section we will narrow down this term to the degree of effectiveness in communicating spatial data. This degree of effectiveness is also known to be used in the measuring the effectiveness of landscape visualizations (Hayek, 2011). Taking into account the architectural focus in this report, we will add to this spatial dimension: the *immersion* and *interaction* in these virtual worlds.

As is stated by Sheppard (2005), for a visualization to be effective they have to meet societal and professional needs to be of real added value. However, this applies more to visualizations as a whole and is not exclusively aimed at 3d visualizations. He also states that a visualization should be truthful in an ethical sense, in order to avoid potentially misleading the viewer (Sheppard, 2001). Schroth et al (2006) focuses more on the viewer’s information processing. The visualization should motivate and focus the attention of the viewer to help him or her extract the relevant information, contextualizing the information and providing links between reality and the viewer’s concept of an issue. Since visualizations are often used as form of communication between designer and stakeholder, interactivity and immersion are very important in participatory planning within the use of 3d visualizations (Salter, Campbell, Journeay, & Sheppard, 2009). Considering these views, we can conclude that a visualization should be preferably interactive and add value to understand what the creator is trying to communicate to the viewer in a fair and truthful way.

Research on immersion in architectural visualizations mainly focuses on the immersion in a virtual reality situation, which we will explore later, but what do we actually mean with immersion? Sheridan (2000) describes immersion as presence, namely the actual feeling of being present in a virtual environment. Presence can be better explained by the definition of Witmer & Singer (1998); “as the subjective experience of being in one place or environment, even when one is physically situated in another”. Heydarian et al. (2015) focuses more on the explanation of immersion as the level of realism experienced in a virtual world. Their study is focused on visualizations in architecture, construction and design which can explain this difference in conception considering the broader context of immersion. In a study done by Christou (2014), immersion is seen as the level of presence again. Therefore, in this report we will define immersion as a combination between presence and realism.

2.1.2 Methods of 3d visualization

When architects were first able to use computer-aided-design (CAD) in the 1990s, they were only able to do this in a conventional way; with a mouse, keyboard and screen (Shih, 1996). Although this still is the main method of showing and creating a 3d environment, new technologies have come up which give designers more options in communicating their proposals. Especially the way of showing these 3d environments has changed over time as mixed reality displays are starting to take over.

Mixed reality can be distinguished in three different levels: reality, augmented reality and virtual reality (fig.1) (Guo, Du, Luo, Zhang, & Xu, 2008).

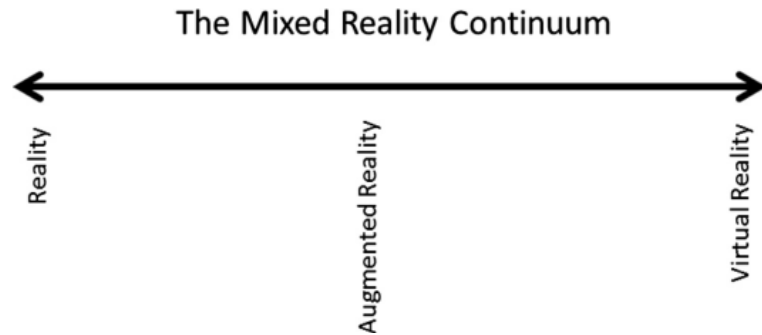


Figure 2.1 The mixed reality continuum (Guo et al., 2008)

First let us explore where it all started, conventional 3d visualizations on a regular display. One could argue that this way of visualizing is also a form of virtual reality as a virtual 'reality' is shown on a display. To make this distinction clear we need to define virtual reality first. It has been proven difficult to find a clear definition for virtual reality in literature, different sources are often contradicting each other. Coates (1992) points out that virtual reality involves electronic simulations of environments experienced through head mounted eye goggles and wired clothing enabling the end user to interact in realistic three-dimensional situations. Curious enough, literature before 2000 all agree to a certain degree about fore mentioned description (Greenbaum, 1992; Krueger, 1991). Two decades later though, this term has become somewhat more open to interpretation. The general definition of virtual reality is that it resembles a computer generated environment that, to the person experiencing it, closely resembles reality. Paes et al (2017) are the first to make a distinction in the definition of immersion; a virtual reality system with non-immersive model is a traditional way of showing virtual reality. In summary a virtual reality system with an immersive model is the one most people today now associate virtual reality with; virtual reality glasses and an optional spatial input; which is the definition we will assign to virtual reality.

Virtual reality, like augmented reality, has not yet fully been incorporated in architectural practice, but the benefits of these technologies in the design process to understand and communicate ideas are clearly there (de Freitas & Ruschel, 2011). Usage of virtual reality in architecture brings multiple benefits, for example in perceiving distance (Interrante, Ries, & Anderson, 2006). Likewise, users feel more immersed in the environment when their whole field of view is filled by the 3d environment and the images are stereoscopic to perceive depth. More immersion leads to higher spatial understanding (Bowman & McMahan, 2007), which is of importance in the field of architecture.

Augmented reality essentially is a toned down version of virtual reality, it integrates virtual objects in the real world around us (Azuma, 1997). This technique has the possibility, for example, to show a past or future on-site architectural visualization (Chung, Zhiying, Karlekar, Schneider, & Lu, 2009). Although augmented reality is somewhat more limited than virtual reality in terms of actual being in a different place, there are certain advantages that augmented reality offers in the field of architecture. Augmented reality is useful to visualize how a building, modification to a building or extension to an existing building will look relative to its surroundings (Thomas, Piekarski, & Gunther, 2001). This can also be used indoor to visualize interior in buildings when actually being at the location (Phan & Choo, 2010). It seems that all these three techniques have their advantages and weaknesses, choosing one will depend mostly on the level of detail, immersion and realism the designer needs to communicate.

2.1.3 Interaction with 3d visualizations

With enough methods to choose from to visualize a virtual world, the next step is to think about the interaction with this environment. This is not as trivial as it might sound, as there are multiple actions one could take in such environment. Hanson & Wernert (1997) emphasize on this with stating that often there is a poor match between the goal of a navigation activity, the control device and the skills of the average user. The interaction, historically done with mouse and keyboard, can be of two categories. Mine (1995) distinguishes these two categories of interaction with a virtual world, namely *selection* and *movement*. Selection involves the manipulation of objects in the 3d world, while movement concerns with moving the user's viewpoint; the camera.

With lack of studies focusing on the navigational aspect in architectural visualizations, we have to look elsewhere for research done in navigating virtual worlds. For this we can involve the game world, as these worlds often closely resemble an architectural environment where the user feels a need to navigate through. Besides both making use of a virtual world, games use input devices; which are also used to navigate through architectural 3d environments. Brown & Cairns (2004) point out that immersion is closely related to the way the interaction is done in the virtual world. Their model of immersion can be divided into three levels: engagement, engrossment and total immersion. Engrossment happens when emotional attachment occurs with a virtual world, and total immersion occurs when actual virtual presence is experienced (just like we have seen in earlier sections). Engagement is what happens when the input and virtual world itself is logical to the user, and confirms the importance of intuitive interaction in architectural visualizations if we want to achieve a high level of immersion.

Oddly enough there are no cases to be found of examples where the manipulation of virtual objects in an architectural visualization is implemented. Usually the user is presented with, independent of the method used for visualizing, a finished rendition of the building where there is no intention to manipulate virtual objects on-the-fly. There could be opportunities here to involve the manipulation of virtual objects in order to create better understanding of scale and distance, as these objects contribute to the individuals perception of spatial dimensions (Lin, Woldegiorgis, Caesaron, & Cheng, 2015).

2.1.4 Background research conclusion

Visualizations are a very powerful communication tool and widely used in the field of architecture, but choosing an appropriate visualization technique can be a challenging task for designers. If high level of immersion is important, virtual reality seems to be the best choice. When the architect wishes to show how a building will end up looking like in respect to its environment, augmented reality is the most suitable way of visualizing. When immersion is not of major importance, such as is the case in the early design process, a conventional way of showing 3d visualizations could suffice, which often leads to the highest degree of realism as the user is not limited by the technical shortcomings of virtual or augmented glasses.

The effectiveness of architectural 3d visualizations seems to be build upon the level of immersion, realism, spatial perception and interaction. All these factors seem to contribute to effectively communicating the designer's plans to their clients. The research question is answered to an extend where it is known what the most likely variables are to create an effective 3d visualization, but the most effective implementation relies on the ultimate communicative goal of the visualization. In order to create a new visualization, multiple ideas will be proposed in the next chapter.

2.1.5 Problem Analysis

Following from the background research, there are certain problems to be overcome in an effective visualization. Something that was not immediately included in the background research was the technological proficiency of the client. This technological proficiency is comparable with the skill gap that still exists between the so-called 'tech-savy' people and the less technological experienced people. This technological skill gap is well described in the book "Diffusion of Innovations" (Rogers, 2007). Our client, the architectural bureau, clearly stated that this is something that they are still struggling with in their visualizations. In cases where they have used new technologies to visualize their proposals, such as virtual and augmented reality rather than older convenient methods, they have experienced a sort of retreat amongst their clients. To overcome this, an extra requirement needs to be added to the conclusion of the background research; which is that the visualization should be accessible to the less 'tech-savy' people.

2.2 State-of-the-art review of related works

2.2.1 Virtual and augmented reality visualization methods

Augment LSI



Augment LSI is an augmented reality application that can be used to visualize proposed real estate of buildings, with the use of a floorplan and a smart device (“Key benefits of Augmented Reality for Architecture Projects,” 2015). This technique combines the real world with an augmented reality overlay so that the user can freely look around the proposed building. The user is also able to look inside the building as the device can freely move through the visualization.

Enscape Virtual Reality



Enscape virtual reality is a real-time rendering plugin for most CAD-programs used by architects, which enables the user to engage in a 3D walkthrough of the building (“Virtual

Reality Headset - Enscape,” 2017). This is an easy way for architects so that their projects can be easily converted to a virtual reality environment compatible with modern VR-headsets such as the Oculus Rift and the HTC Vive. Also, interaction with the environment is possible. For example, a case where the user can set a certain time of day with the virtual reality controls. This enables for very immersive virtual environments.

Argos



Argos uses augmented reality to render a proposed building on-site (“Argos - view the giant before it’s built,” 2016). Smartphone GPS sensors and gyroscopes enabled for on-site augmented reality visualizations, which is what the designers of Argos used to visualize proposed buildings. This enables the user to get a very good understanding of how the final building will look in it’s environment.

Trimble HoloLens Mixed Reality



Trimble Connect for HoloLens utilizes mixed-reality technology to take 3D content off the screen and into the real-world, providing project stakeholders with enhanced 3D design review, coordination, collaboration, and project management processes (Dezeen, 2016). Somewhat comparable with Augment LSI, this technique can also be used to augmentedly view a proposed building. The advantage of this technique is the better mixed reality experience and to design or alter certain elements in a proposed structure with gesture controls.

RoundMe app

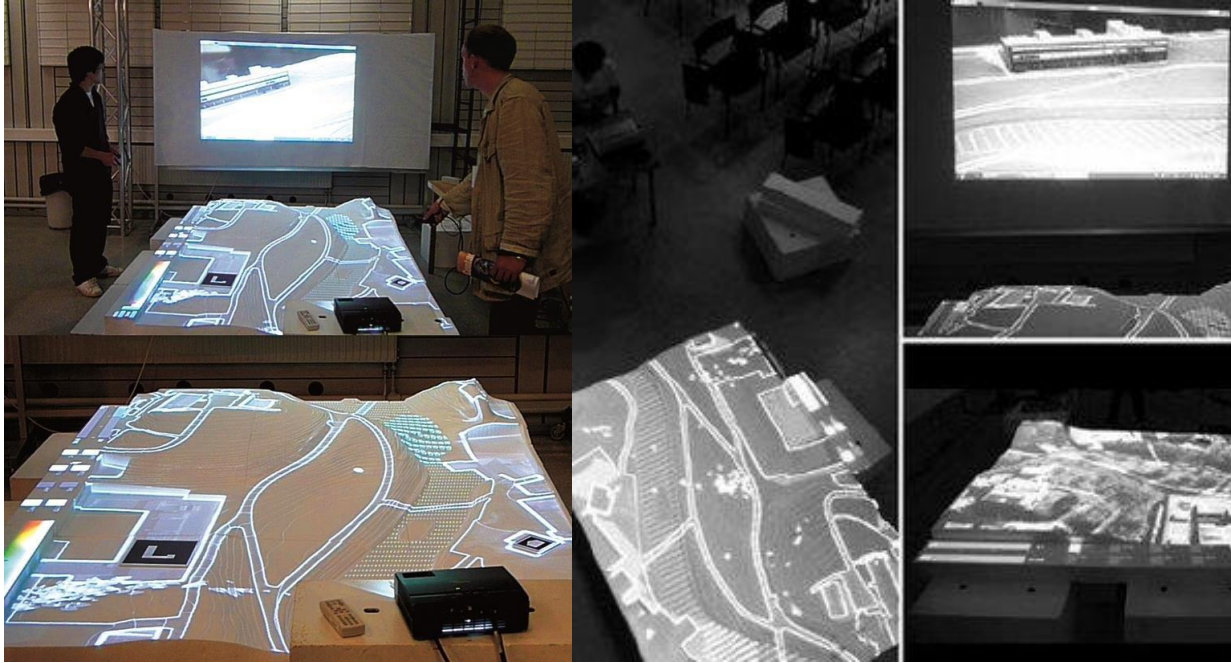


Roundme can be used to explore buildings in photorealistic way (“Virtual Tours Made Simple,” 2017). This technique is virtual reality compatible and is mostly used for visiting an already built

building. Although it might not add to the presentation of a proposed building, certain elements from already built structures could be shown with this technique.

2.2.2 Static architectural visualization methods

AHO Digital Experimental Architecture Studio



AHO Digital Experimental Architecture Studio used a physical terrain model with projected interactive datasets and integrated augmented reality visualization (Hensel, Sørensen, & Killi, 2016). This creates a projection on a table of how the terrain or building is going to look like, which can be altered on the spot.

Chicago Architecture Center Hologram



Visualizing a city's architecture by using a hologram ("Chicago City Model Experience," 2009). Holograms are comparable with augmented reality, although the major difference is that a hologram is physically there (as far as there is a 'physically' to a hologram). Holograms have the advantage that there is no medium needed for the user to look through such as a smartphone or glasses, but the disadvantage is that holograms are often static and non-interactive.

2.2.3 Noteworthy techniques

Microsoft Surface Table



Although it dates back to 2008 (“Retro review,” 2017), the concept of an interactive table is something that is of interest concerning this project, as it provides another way of displaying and interacting. The Microsoft Surface table was intended to be a multimedia device, but building upon this idea it could be used for interactive 3d visualizations as well.

2.2.4 State-of-the-art conclusion

Different existing techniques of visualizing and ways of interacting have been explored in the state-of-the-art review. For this project the interaction is going to be important, as the target group are often not the most ‘tech-savy’ people. The medium and method visualizing will probably be inspired by one or more of these techniques covered in the state-of-the-art. For means as input more ideas need to be generated, and the state-of-the-art can function as inspiration.

Chapter 3: Methods and Techniques

This chapter will focus on various methods and techniques used in the Creative Technology design process.

3.1 Understanding the user and context

When meeting a client whom is having a problem which could possibly be solved with the usage of creative technology, the first step is to perform a context analysis. This phase centers on understanding the domain, the user and their daily practice. According to Jonathan Lazar, Feng, & Hochheiser (2017), this can be done with the following techniques:

- Interviews
- Surveys
- Observation
- Reading literature and documentation
- Investigating similar products

For this particular graduation project, the idea generation heavily relied on the usage of techniques such as observation, investigating similar products and interviews to gain a good understanding of the user and their requirements.

3.2 Design Process for Creative Technology

When a solid understanding is achieved of the contextual situation and the user, we can proceed to use the Design Process for Creative Technology written in the homonymous paper by Mader & Eggink (2014). This design process is based on the iterative design approach, where the iterations start divergent and will converge along the process, which is very applicable in a creative design process as often something fundamentally new is created for the user/target group. The design process framework as described in Mader & Eggink (2014) consists of four distinctive phases which can co-interact with each other during any stage of the design process. These four phases in relation to this graduation project (see *figure 3.1*) will be explained in the next subchapters.

3.2.1 Ideation Phase

The ideation phase focusses on idea generation with the aid of multiple techniques such as using state of the art, brainstorming, interviewing experts and stakeholder analysis. The stakeholder analysis will be done by using the iPACT method. iPACT is short for ‘Intention’, ‘People’, ‘Activities’, ‘Context’ and ‘Technology’. The method used in the ideation phase during the graduation project was to first generate a number of ideas by brainstorming and using the “state of the art” research. The next step was to apply a stakeholder analysis in preparation of the final iPACT analysis to make a final selection of product proposals.

3.2.2 Specification Phase

When the rough idea is formed, we can proceed to the specification phase. In the specification phase the idea is further explored and first prototypes concepts are evaluated by the user. This to be able to refine the product idea to a list of specifications needed for the final realisation, while encompassing the feedback loop to the users. In order to properly compose specifications and requirements, two analyses will be conducted. The FICS analysis; which stands for 'Functions', 'Interaction', 'Content' and 'Services' (Benyon & Macaulay, 2002), will be used together with the MoSCoW analysis; which stands for 'Must haves', 'Should haves', 'Could haves', 'Won't haves' (Vliet, 2008). Furthermore, the requirements resulting from the MoSCoW analysis will be divided into functional and non-functional requirements.

3.2.3 Realisation Phase

This phase is introduced when the specifications and requirements are sufficiently clear. In this case the prototype will be developed according to the iterative design principles of making – confronting – reflecting. This achieves the continuous evolution of the product, a user centered design and making sure the product adds value.

3.2.4 Evaluation Phase

To evaluate the product, a functional test of the category usability test will be conducted together with semi-structured interviews. This will provide a greater understanding in how the product adds value and what could be improved.

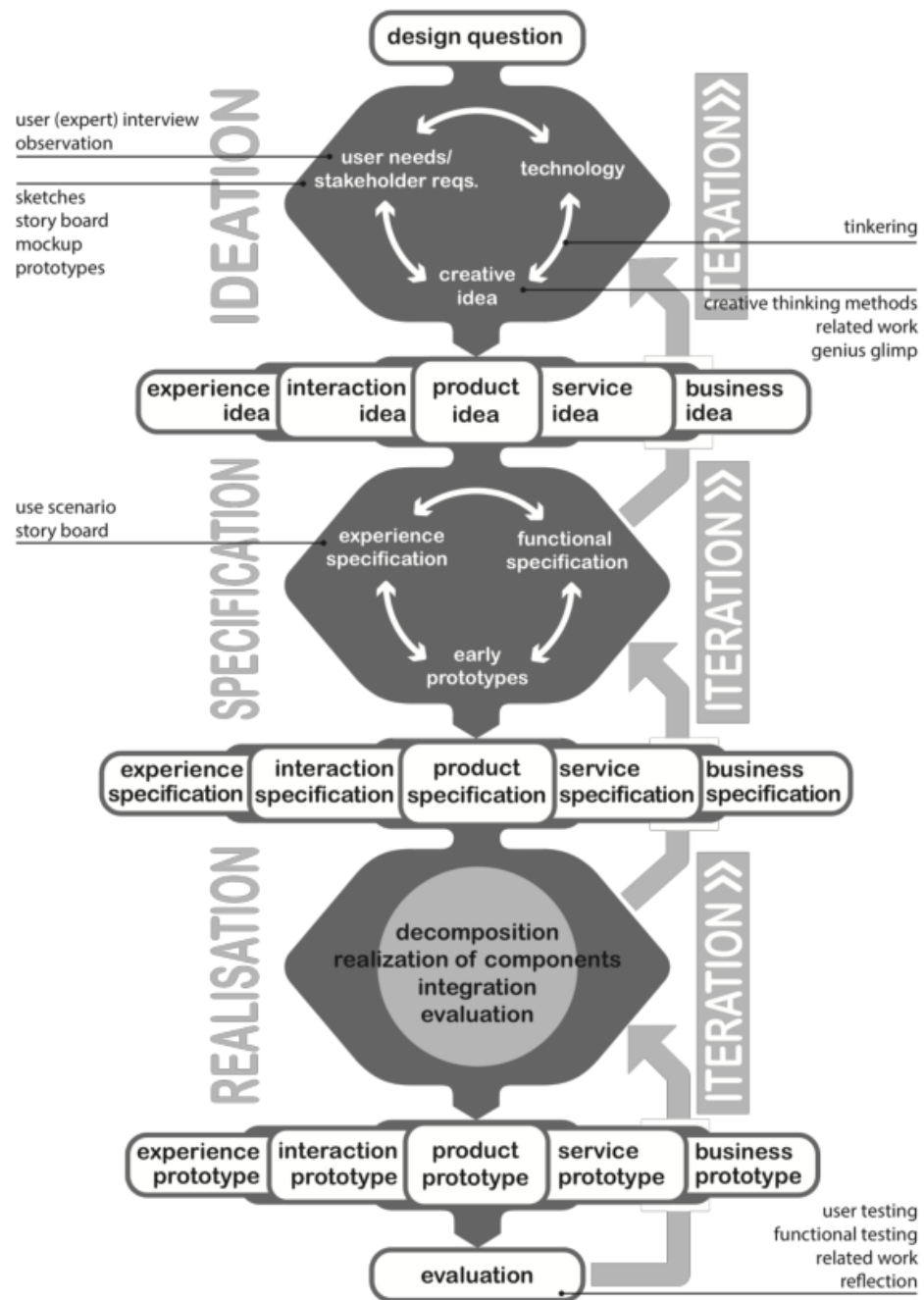


Figure 3.1 Framework for A Creative Technology Design Process (Mader & Eggink, 2014)

Chapter 4: Ideation

As stated in chapter 3, the ideation phase will focus on identifying the requirements and wishes of the user through observation, interviews and background research. The background research conducted in chapter 2 together with the user observations and interviews will be the foundation to create creative ideas.

Having a broad idea of the context by identifying the experienced problem and gaining understanding of visualizations used in architecture, the next step is to identify the stakeholders and final users.

4.1 Stakeholder Analysis

Users

The final end users of this project will be a relatively small target group. Initially these users are going to be clients of an architectural bureau. These group of users could eventually be expanded to a much larger one, options should be kept open to use the project for other fields than indoor architecture such as real estate, urban planning, landscape architecture and interior architecture.

The users are mostly people who are by no means experts in the technology/visualization field, which is one of the reasons for the need of this project. Under this assumption we can imply that the users need an intuitive solution for understanding the interior spaces of proposed buildings.

Developers

The developers, or rather developer, will solely be the author of this thesis.

Legislators

As the project is not connected to any laws, there are no real legislators active in the process.

Decision Makers

Abels and Partners (former IAA-Architecten) will be the main client for this project. The prototype will be tested with their clients and they will provide floor plans and 3d-models of their buildings in order to test with. Most communication will be done with Harry Abels, head of Abels and Partners. He will make decisions based on his experience in visualizations and provide guidance to the project to make sure the end product will be of added value. Job Zwiers supervizes the project and will have influence on design choices as well as providing valuable input. Lastly, Randy Klaassen, the critical observer, will also have the ability to guide the design process and provide additional input.

4.2 Brainstorm Sessions

The initial brainstorm sessions were done by Harry Abels and me, when he explained the problem he was experiencing with visualizing indoor spaces. This session led to the initial generation of ideas. The type of brainstorm used would be most similar to the ‘free form’ technique, as the goal was just to generate as much ideas as possible without constraints. Several ideas that came up during these sessions:

- ❖ An interactive augmented reality floorplan
- ❖ An interactive table in the style of a Microsoft Surface coffeetable
- ❖ Holographic or augmented projection on indoor scale models
- ❖ Moving objects around in real life and see feedback on the screen/table

These ideas were generated without technical constraints, so in order to get to a preliminary concept; some ideas had to be adjusted or combined.

4.3 Preliminary Concept

The overall resulting concept from the brainstorm sessions, background research, stakeholder analysis and ‘state of the art’ research was to intuitively combine the virtual world with the physical one. This would be done by providing some kind of input from the user, which was not yet clear and needed testing first, and an interface for the user to work with. This interface would be physical in nature to form this connection with the virtual world, and this is where the idea of using a floorplan came from.

This idea of using a physical floorplan as the user’s interface roughly became the conceptual idea that was taken to the next phase; the specification phase (chapter 5).

4.4 iPACT Analysis

To get a better idea of how to envision the product, an iPACT analysis will be conducted in the next part.

Intention

The intention of the system is to give the end users a deeper and better understanding in how a proposed building looks from the inside, and to let them interact and navigate in it without any specific technological skill required for the user.

People

Anne (42) is an expert on hospital facilitations, in the field of radiography. In the process of designing a new hospital, she has to provide her expertise to the architects for them to know which dimensions certain radiography rooms should have. This resulted in the architects coming up with a floorplan and 3d-model. They sit around the table and discuss the new plans, while the architects show her the floor plans and 3d-model. The 3d-model gives her an idea of how it is going to look, but by being limited by just looking at the floor plan; she fears that some rooms are either too large or too small.

Activities

The system will make a direct connection between a distinct location on the floor plan and the 3d-model. Also, for a better understanding of scale a vr-headset can be used to get a stereoscopic view of the environment. Furthermore, virtual objects c.q. furniture can be moved around on the floor plan to gain an even better understanding of scale.

Context

The context in where the system will be used, will be that of a meeting with mostly multiple stakeholders around a table. The location where it could be used should be anywhere at a table large enough for a floor plan, which would imply any room suitable for meetings. Portability is an important factor here, as this could be limiting.

Technology

The technology used should be able to track the user input on the floor plan, as well as showing the 3d representation to the users.

Chapter 5: Specification

As stated in section 4.3, the ideation phase led to a rough idea which is still open to implementation. To get a better idea if the client and developer are having the same overall idea in mind, a first prototype is designed after the FICS analysis is done.

5.1 FICS Analysis

To gain deeper understanding in what the system should achieve and how the interaction and feedback to the user should be, we are going to conduct a FICS analysis; which stands for ‘Functions’, ‘Interaction’, ‘Content’ and ‘Services’ (Benyon & Macaulay, 2002). To conduct this, we are going to methodically split up the system in multiple components.

Functions

The main functions the system has to provide are:

- ❖ Being able to track the user navigating through this 3d environment
- ❖ Being able to track physical objects placed by the user
- ❖ Real time rendering of the environment
- ❖ Manipulation of the 3d environment in real time
- ❖ Showing the 3d representation through a screen or vr-glasses

Interaction

The user interaction will consist of the following options:

- ❖ Changing the viewpoint/location of the camera
- ❖ Adding virtual objects to the 3d environment
- ❖ Moving virtual objects around in the 3d environment
- ❖ Removing virtual objects from the 3d environment

Content

The content will include:

- ❖ A paper floorplan
- ❖ Camera to track the user input
- ❖ Ability to view the indoor 3d space

Services

The system will provide a new way of visualizing indoor environments by giving the user a new way of interaction rather than a traditional one.

5.2 First Iteration

In order to end up with a proper requirement analysis, the decision is made to create a first prototype to gain a better understanding of these requirements. According to the research done, the client needs a way to combine the physical world with the virtual one through a visualization. Augmented reality came to mind here, as augmented reality provides an overlay of the virtual world onto the physical one. A quick prototype by using Unity Vuforia was developed, where a floorplan of a house was linked to a 3d model of that same house.

The augmented reality itself could be seen on a smartphone, which could be moved freely around the augmented reality floorplan. The client was enthousiast about this idea, but the problem of people being 'in their own world' still persists with using this technique, as not all stakeholders are able to see the same visualization. Also, the interaction itself was not easy, in the sense that hovering around with the camera (smartphone) was not optimal for longer durations of time. An added problem was that a viewpoint representing a person inside the 3d environment could not be achieved.

5.3 Requirement Analysis

This first prototype was of great importance to conduct a proper requirement analysis. The given feedback was included in creating the MoSCoW analysis. The MoSCoW analysis is constructed by functional and non-functional requirements.

*Must have*s

- ❖ A realtime rendered representation of the 3d visualization (functional requirement)
- ❖ Combine physical floorplan with the virtual world (functional requirement)
- ❖ Viewpoint should be that of a person in the environment (non-functional requirement)
- ❖ Multiple users need to all be able to see the same visualization (non-functional requirement)
- ❖ Easy and intuitive interaction (non-functional requirement)

*Should have*s

- ❖ Provide a clear impression of scale and distance (functional requirement)
- ❖ Add, remove and move virtual objects around physically (functional requirement)
- ❖ Virtual reality support for extra immersion (functional requirement)
- ❖ Aesthetically pleasing visualization (non-functional requirement)
- ❖ Clear and easy to read floorplan (non-functional requirement)
- ❖ A large display to view the visualization on (non-functional requirement)

*Could have*s

- ❖ Portable system (functional requirement)
- ❖ Ease of setup (functional requirement)
- ❖ Virtual reality or augmented reality support (functional requirement)

*Won't have*s

- ❖ Augmented reality support
- ❖ Detection of floorplan to load corresponding 3d environment

5.4 Second Iteration

Resulting from the requirement analysis and feedback on the first prototype, the concept for the second prototype is formed. The smartphone showing the augmented reality overlay is changed to a rather static setup. The floorplan itself remains, but instead of navigating with the camera; the new method is going to have a static but movable viewpoint (comparable to moving a person through the building as can be seen in figure 5.2).

This change also led to the need of an alternative medium to show the 3d representation. Essentially for this prototype, this is going to be a display. As is stated in the 'Could haves', a virtual reality addition could still be added later on. For clearance, a 3d rendition of this concept can be seen in figure 5.1. The camera serves for tracking, this design choice will be explained in chapter 6, but for now it can be ignored.



Figure 5.1 The setup

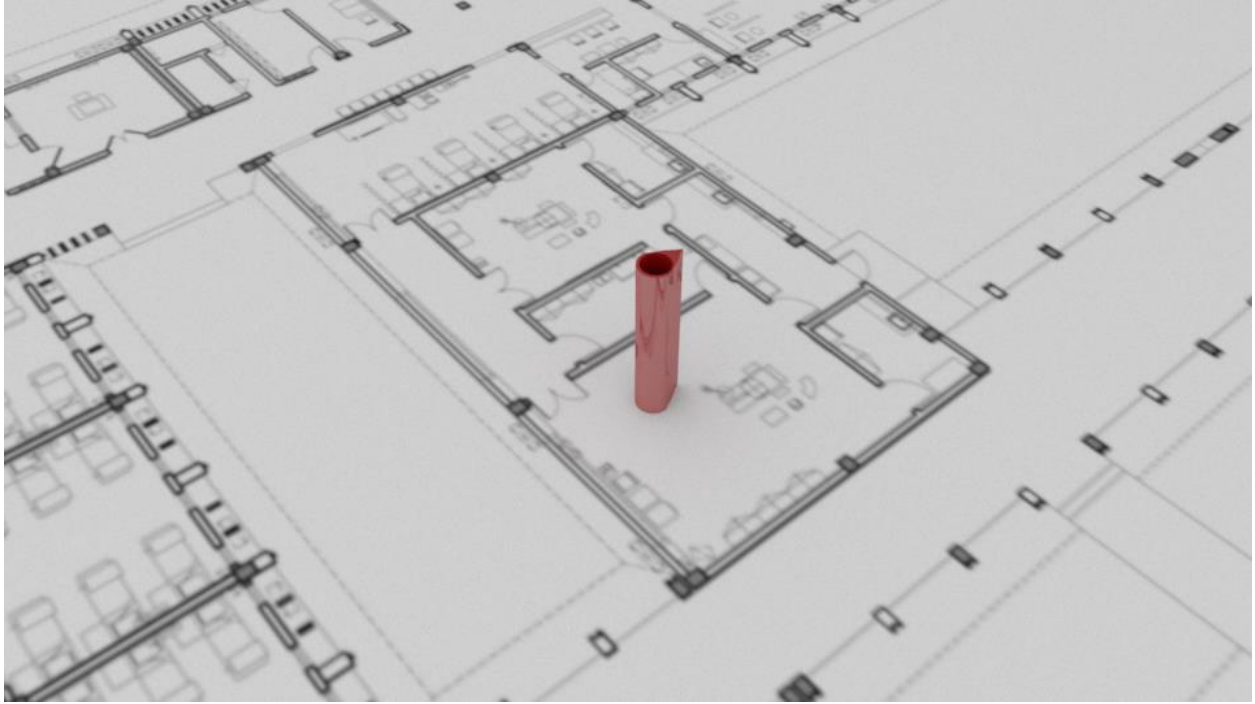


Figure 5.2 The movable 'person', also known as viewpoint object

5.5 Third Iteration

The third iteration idea for the prototype has extra functionality added from the MoSCoW analysis. In this prototype the possibility is added to place, remove and move objects with colored objects on the floorplan. On top of this the user can switch between two methods of displaying the 3d visualization; either in VR or with a static view. In chapter 6 these extra components are described.

5.5 Activity Diagram

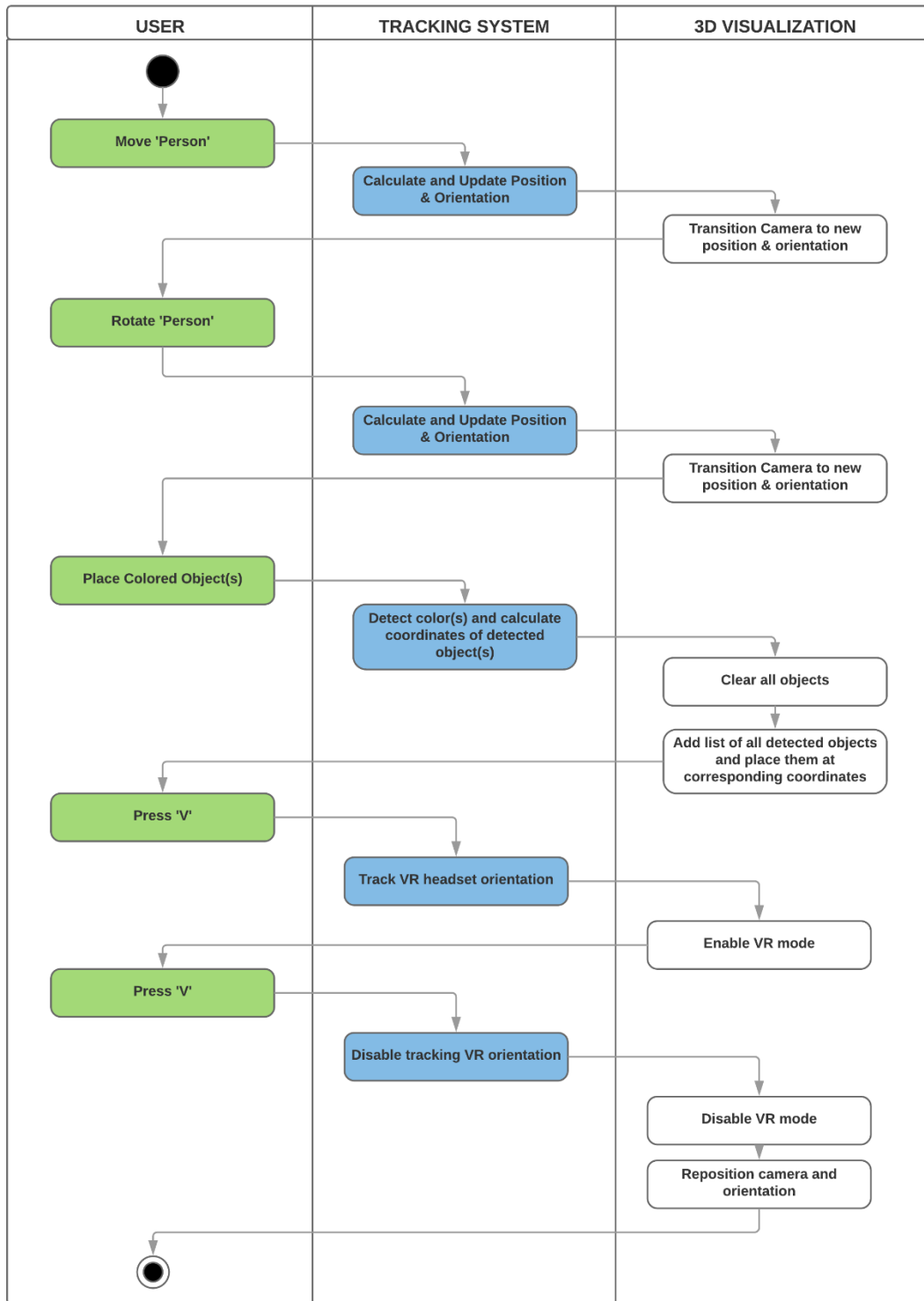


Figure 5.3 Possible actions activity diagram

5.6 Data Flow Diagrams

5.6.1 Level 1:

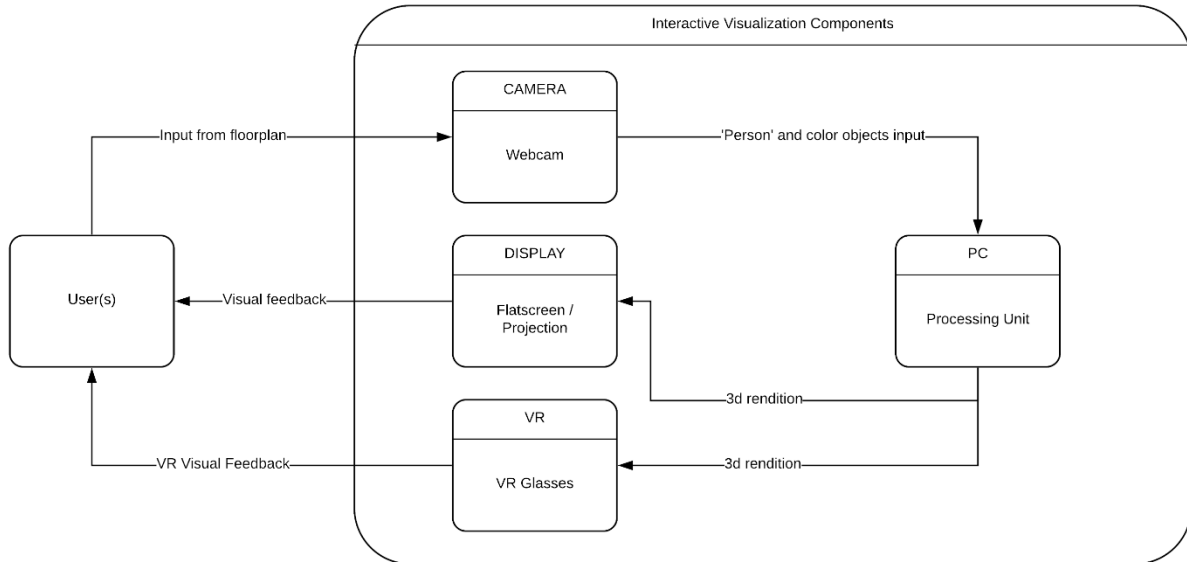


Figure 5.4 The overall data flow diagram

5.6.2 Level 2:

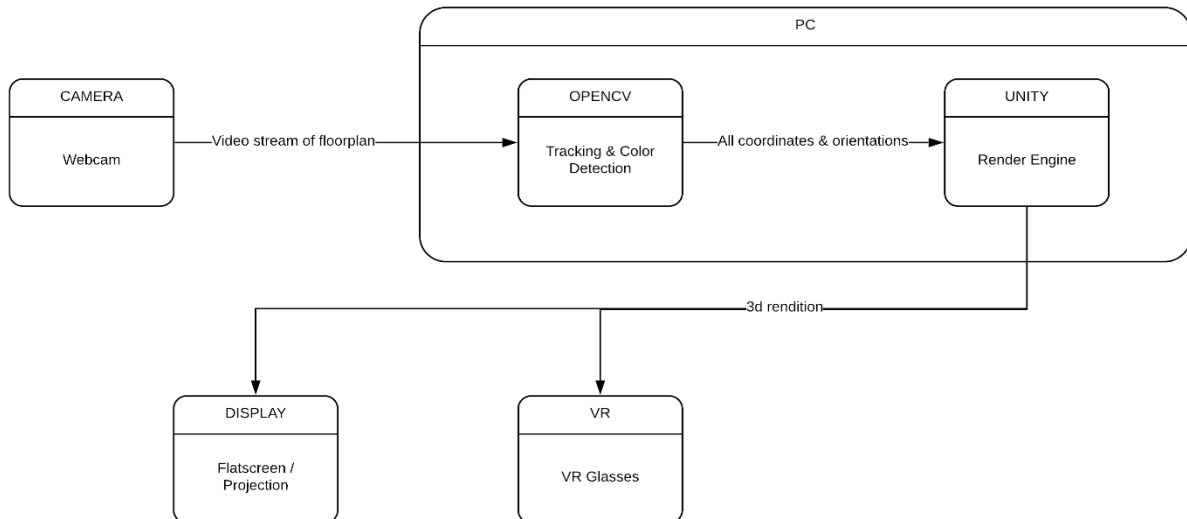


Figure 5.5 The system data flow diagram

Chapter 6: Realization

The completion of the product specification the next step is to advance to the realization phase. In this phase we will focus on the technical implementation of the prototype.

6.1 Main components

The visualization will consist of a few main components; the floorplan, the viewpoint object, the tracking device, the display and the 3d interior model of the building.

The floorplan

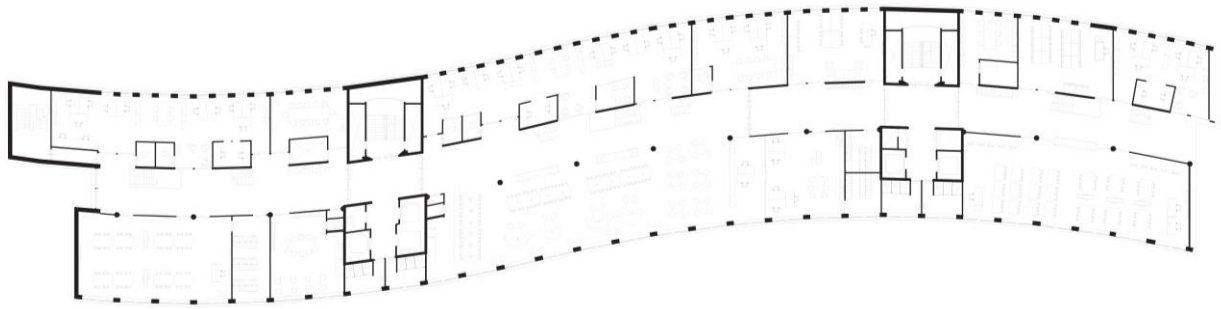


Figure 6.1 The 'HHS 6th floor' floorplan

For this project Abels en Partners provided me with a detailed floorplan of a building they are currently working on, namely the 6th floor of de Haagse Hogeschool (figure 6.1). This is the plan where this prototype will mostly focus on visualizing. The floorplan is printed on the universal A0 size.

The viewpoint object

The user should be able to move around the virtual world using an object that is placed on the floorplan. This object needs to be easy and inviting to move around and in order to accomplish that, the design needs to have sufficient affordance (Norman & Berkrot, 2011). Furthermore the (rotational) orientation of the viewpoint should be clear to the user.

The tracking device

To track the 'person' on the floorplan a tracking device is needed. There are multiple techniques available to track an object in the physical 3-dimensional space, but for this prototype the choice has been made to use a camera for tracking. This will be further explained in section 6.2.1.

The camera needs a videostream that can be easily captured through a digital I/O interface and have a sufficient video capturing resolution. For this prototype the camera of choice is the Logitech C930e webcam (see figure 6.2), which can be easily connected to a computer and can provide realtime streaming in a resolution of 2304x1296 pixels.



Figure 6.2 The Logitech c930e

The display

The display does not need any specific requirements, as long as it can be connected to a digital I/O interface. The screen should ideally be not be on the small side, ideally a beamer and a projection screen should be used to achieve the largest viewing experience.

The 3d model

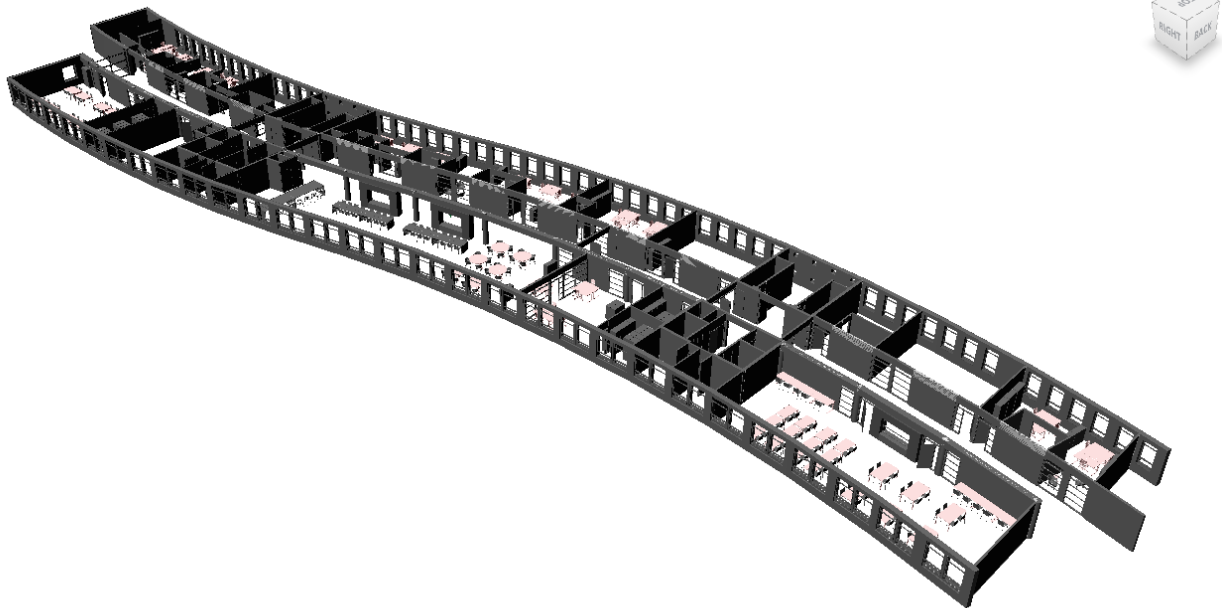


Figure 6.3 The converted 3d model

Abels en Partners have provided an AutoCAD 3d model of the 6th floor of de Haagse Hogeschool, which will be used in for the indoor 3d representation. The model itself has been converted and optimized with Maya to prepare it for real time rendering. The model will be shown on the display, with the virtual camera placed at the corresponding position and orientation of the physical viewpoint object on the floorplan.

6.2 Technical components

The technical components are mostly invisible to the user, but they are essential to make the system work. In this section we will focus on those technical components of the prototype. This will be split up in the two main PC components of the system as they are shown in *figure 5.5*: the tracking program and the render engine.

6.2.1 Tracking Methods

As stated in 6.1 (*Main components*), we need a viewpoint object that the user(s) can move around the floorplan in order to navigate. Furthermore, we need a method of tracking this viewpoint object, its position relative to the floorplan and this position translated to coordinates relative in the 3d model.

Tracking technique

With the ‘could haves’ in mind from the MoSCoW analysis, the choice is made to use a camera for tracking the viewpoint object. Other tracking techniques that have been considered are: lasertracking (as it is used in the roomscale tracking of the HTC Vive VR headset), infrared tracking (as is implemented in Microsoft’s Kinect) and inside out tracking (as used in Samsung’s Odyssey mixed reality headset). To achieve the highest portability and ease of setup, the choice was made to perform the tracking with an external camera pointed at the floorplan.

In order to positional track an object in 3d space with a camera, we need to take the perspective effect into account. If we position a camera directly above the table this effect is not that much of an issue, although the scaling is; unless it is a static installation. Considering the aforementioned requirements this is not something we want. This is how the idea started to borrow a technique from augmented reality to determine the camera position.

Traditional augmented reality makes use of markers in order to determine the position of the camera, which allows to estimate a pose of the marker. This is done by the detection of a marker, the black bordered marker with the ‘A’ in *figure 6.4* for example, and subsequently the screen coordinates of the marker can be determined. By knowing the size of the marker, the algorithm can determine the camera coordinates relative to the marker. In this way every marker has their own coordinate system, as well as the camera itself (see *figure 6.4*).

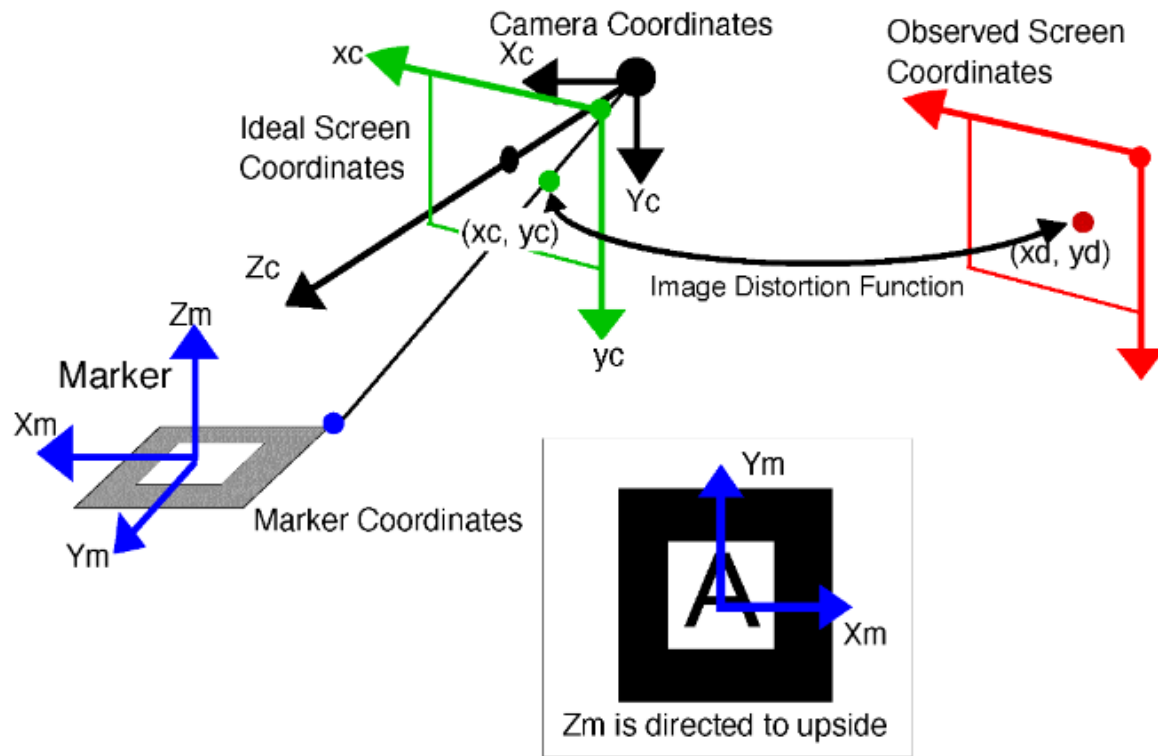


Figure 6.4 Marker and camera coordinate spaces conversion (Kato, 2015)

Almost every camera has some kind of lens distortion, which makes this technique prone to errors. Fortunately, this lens distortion can be determined for the camera using calibration maps. When the lens distortion is known, the image can be transformed to undistort the image. This process is illustrated in *figure 6.5*, and in *figure 6.4* it can be seen that the same 'Image Distortion Function' is used to get the 'Ideal Screen Coordinates' of the marker.



Figure 6.5 Left: The distorted raw image. Right: The undistorted picture. (Van den Boomgaard, 2017)

The difficulty to overcome was to be able to position and rotate the camera around the table with automatically recalculating the pose of the floorplan. The aforementioned augmented reality marker detecting technique provides a solution for this problem. The only thing is, it would be inconvenient to have one large marker as the floorplan, so the idea was to have 4 different augmented reality markers on each corner of the paper. These markers together function as one large marker with its own image points. By using the same mathematics as used in the marker pose estimation, the orientation and position of the floorplan can be calculated. In *figure 6.6* this process can be seen, the four markers are detected and four imagepoints are created from their centers, just like we have seen with the single marker technique. If we know the precise dimensions between the four markers, we can calculate the camera position and orientation. By doing this we can translate the coordination system of the board to that of the camera.



Figure 6.6 Four different perspectives

Tracking the viewpoint object

Using the same augmented reality tracking technique as described before, we will be able to track the viewpoint object as well. In theory we could use something else than an augmented reality marker as well for tracking the viewpoint object, but the augmented reality markers enable us to easily calculate the rotation in respect to the board. This is needed in order to set the correct orientation of the virtual camera in the 3d world.

To prevent blocking the marker from being tracked when moved, and to prevent the marker from blocking the floorplan to the user, the idea is to have the marker elevated above the drawing. The marker will be placed on a glass cylindrical object in order to be able to see where the center of the marker is placed. The diameter is roughly of thumb size.

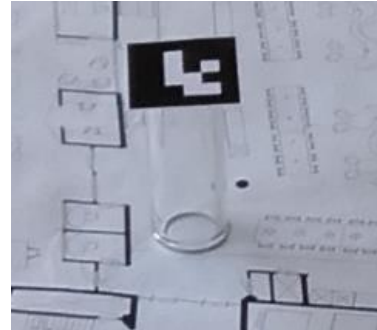


Figure 6.7 The viewpoint object

Tracking the colored objects

We are able to calculate any relative position on the board by using the techniques described in the previous sections. In theory, as long as we can distinguish unique shapes and/or colors, we can calculate their position and rotation in the 3d environment. In figure 6.8 this idea of colored objects being placed in the boundaries of the board can be seen. For this project the goal is just to place objects in order to get a better idea of the scale of the environment, so we will (for the prototype at least) omit the possibility to rotate them. In the next subchapter the colordetection technique will be further explained.

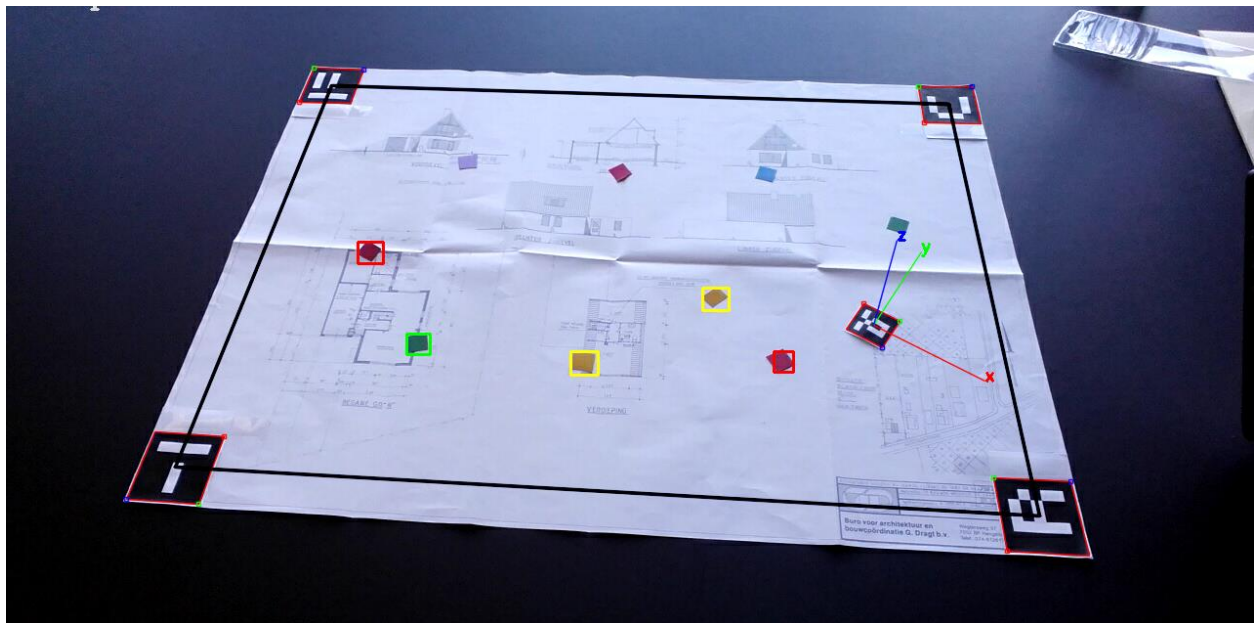


Figure 6.8 Colored objects being detected

6.2.2 Computervision Library

In order to implement the tracking methods described in 6.2.1, software needs to be developed. A computer vision library is needed to perform these tasks as quickly as possible, and for this OpenCV has been chosen. OpenCV is an open source library for image and video analysis, originally introduced more than decade ago by Intel (Culjak, Abram, Pribanic, Dzapo, & Cifrek, 2012). OpenCV has a large variety of different libraries, such as the library Aruco; which we will use for the marker detection. Aruco is an efficient library for detection of planar markers and camera pose estimation (“ArUco | Aplicaciones de la Visión Artificial,” 2015), which is exactly what is needed to determine the relative coordinates of the board. The choice for Aruco is made as it is using of the fastest and most efficient augmented reality marker detection methods (Garrido-Jurado, Muñoz-Salinas, Madrid-Cuevas, & Marín-Jiménez, 2014).

OpenCV and Aruco both can be used with both C++ and Python programming languages. We will use C++, for the implementation because this allows for easier modification of the libraries themselves. Visual Studio 2015 is used as IDE (integrated development environment).

Implementing board and viewpoint tracking

As soon as the four markers are detected by using the Aruco library, we request the center points of the four markers and we push these points to a `vector<cv::Point2f>` datastructure. The corresponding objectpoints, the predetermined markers on every corner, are pushed to a `vector<cv::Point3f>` datastructure (figure 6.9 & 6.10). We can get the rvec and tvec of the board by using the OpenCV function `solvePnP`, which translates the objectpoints and imagepoints to the translation and rotation vector. The `solvePnP` function also takes the cameramatrix and distortion as parameters to account for the image distortion as seen in figure 6.4.

```
std::vector<cv::Point2f> imagePoints;
std::vector<cv::Point3f> objectPoints;

imagePoints.push_back(board[0]);
imagePoints.push_back(board[1]);
imagePoints.push_back(board[2]);
imagePoints.push_back(board[3]);

objectPoints.push_back(cv::Point3f(0., 0., 0.));
objectPoints.push_back(cv::Point3f(0., 731., 0.));
objectPoints.push_back(cv::Point3f(1079., 731., 0.));
objectPoints.push_back(cv::Point3f(1079., 0., 0.));
```

Figure 6.9 Image and object points are pushed onto the vectors in millimeters accuracy.

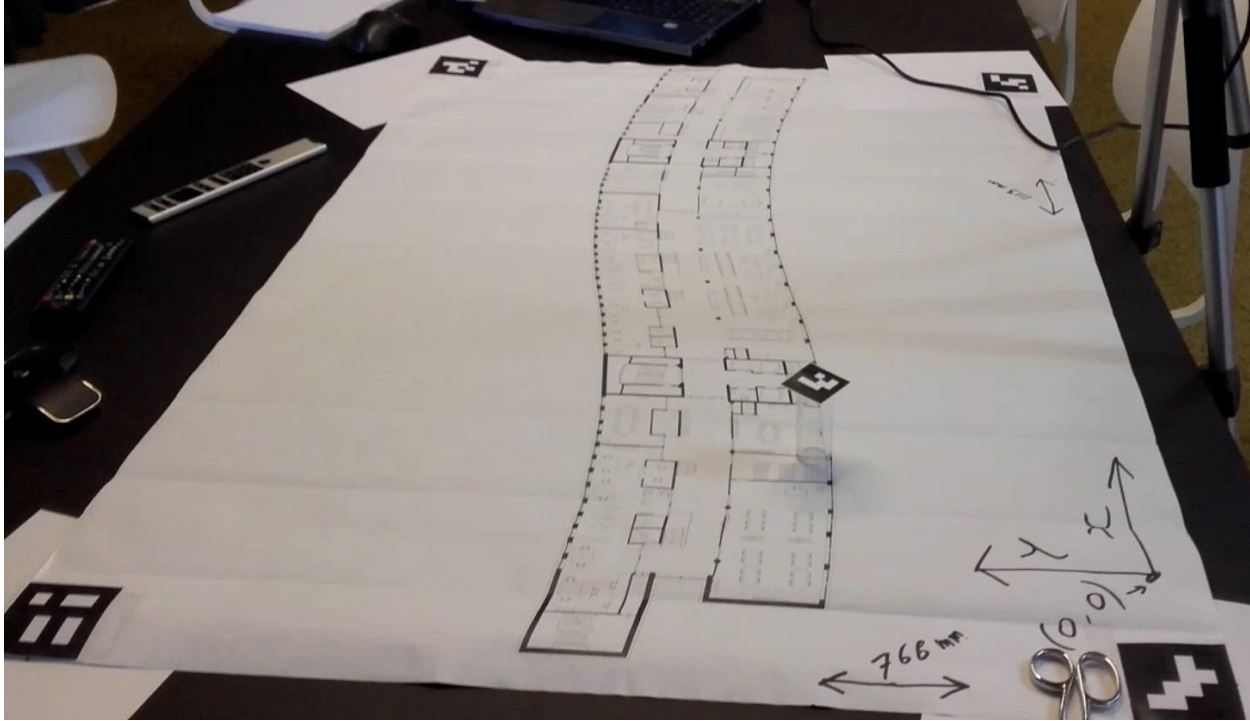


Figure 6.10 Coordinate system of the board.

Furthermore, the Rodrigues function is used to get the rotation matrix of the camera. As the viewpoint object marker is 7 centimeters above the 0 Z-axis of the board, we need to compensate this in order to get the relative position of the viewpoint object marker. The full calculation can be seen in figure 6.10.

```
cv::Mat rvec(1, 3, cv::DataType<double>::type);
cv::Mat tvec(1, 3, cv::DataType<double>::type);
cv::Mat rotationMatrix(3, 3, cv::DataType<double>::type);

cv::solvePnP(objectPoints, imagePoints, TheCameraParameters.CameraMatrix, TheCameraParameters.Distorsion, rvec, tvec);
cv::Rodrigues(rvec, rotationMatrix); //camera rotatie

cv::Mat uvPoint = cv::Mat::ones(3, 1, cv::DataType<double>::type); //u,v,1
uvPoint.at<double>(0, 0) = lastPivot.getCenter().x + 0.; //x imagepoint van pion
uvPoint.at<double>(1, 0) = lastPivot.getCenter().y + 0.; //y imagepoint van pion
cv::Mat tempMat, tempMat2;
double s;
Mat CameraMatrix;

TheCameraParameters.CameraMatrix.convertTo(CameraMatrix, CV_64F);
tempMat = rotationMatrix.inv() * CameraMatrix.inv() * uvPoint;
tempMat2 = rotationMatrix.inv() * tvec;
s = 70 + tempMat2.at<double>(2, 0); //Zconst
s /= tempMat.at<double>(2, 0);
pioncoords = (rotationMatrix.inv() * (s * CameraMatrix.inv() * uvPoint - tvec));

pivotx = pioncoords.at<double>(0);
pivoty = pioncoords.at<double>(1);
```

Figure 6.11 Calculation of the 'pioncoords' (viewpoint object coordinates)

The result can be seen in *figure 6.11*, the relative position of the viewpoint object is being calculated in millimeters accuracy (upper left).

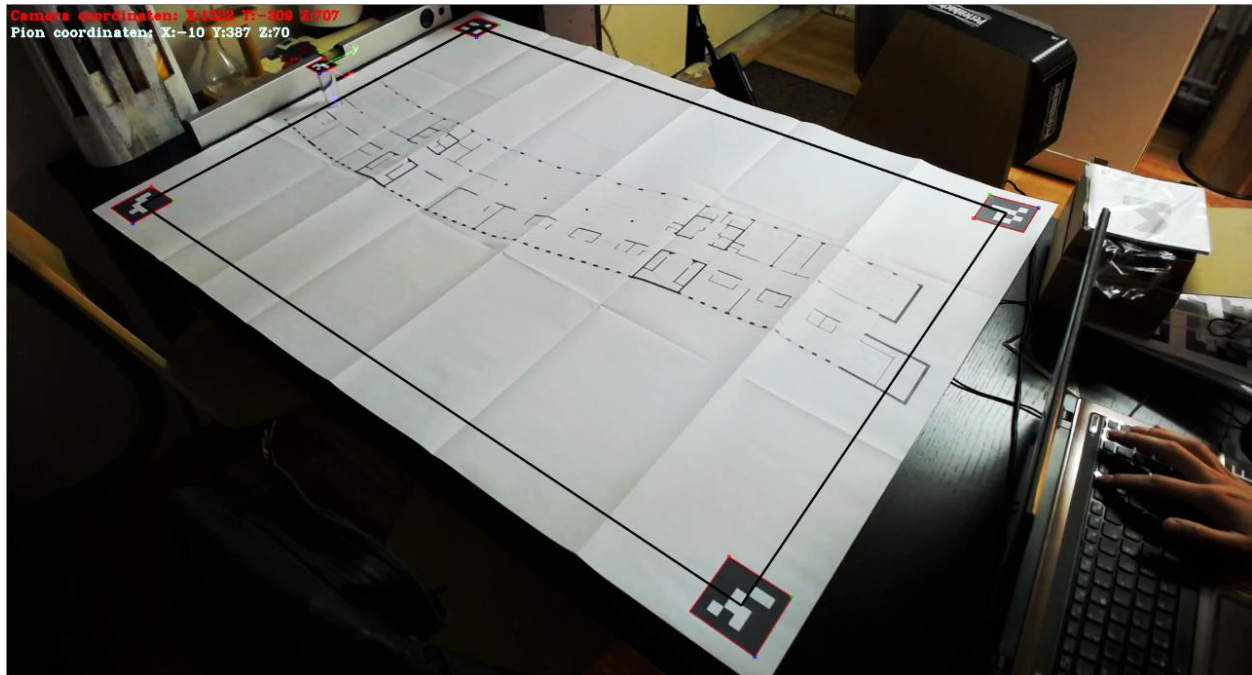


Figure 6.12 The resulting viewpoint and camera coordinates (top left)

Implementing color detection

The color detection is a relatively easy process and makes use of built in OpenCV functions to achieve this. As colordetection is a very processor intensive task, the colordetection is run on a separate thread within C++, to make sure the colordetection does not obstruct the marker detection. OpenCV's `inRange` function is used to detect the color. Two different scalars containing HSV (Hue/Saturation/Value) values are passed to see if where and if a color within that range is contained in the image. After this is done, the centerpoints of the different colored objects are determined as can be seen in *figure 6.12*.



Figure 6.13 Calculation of the center points of the colored objects

By using the same calculation as used to get the relative coordinates of the viewpoint object marker (*figure 6.10*), the relative coordinates are calculated of the centerpoints of the colored objects in respect to the board. The only difference is that instead of the $Z_{const} = 70$, the $Z_{const} = 0$ here; as the colored objects roughly are right on the paper.

When all the different colored objects are determined, their centerpoints are added to a list and are send to the render engine. The name of the object, which is specified in to its associated color, is added as parameter in this list as well. The final step is to send these objects and their respective coordinates to the render engine, which will be further explained in section 6.2.4.

6.2.3 Rendering Engine

To show the 3-dimensional representation of the building to the users, a render engine is needed. For best results realtime rendering is needed together with virtual reality support. Architects often use CAD software with their own render engines, but these do not render in realtime, thus not applicable for this project. That is why the decision is made to use a game engine for the rendering, game engines have the ability to render real time as they use all kinds of optimizations. The game engine of choice is Unity 2018, this engine supports virtual reality and is heavy customizable with C# programming.

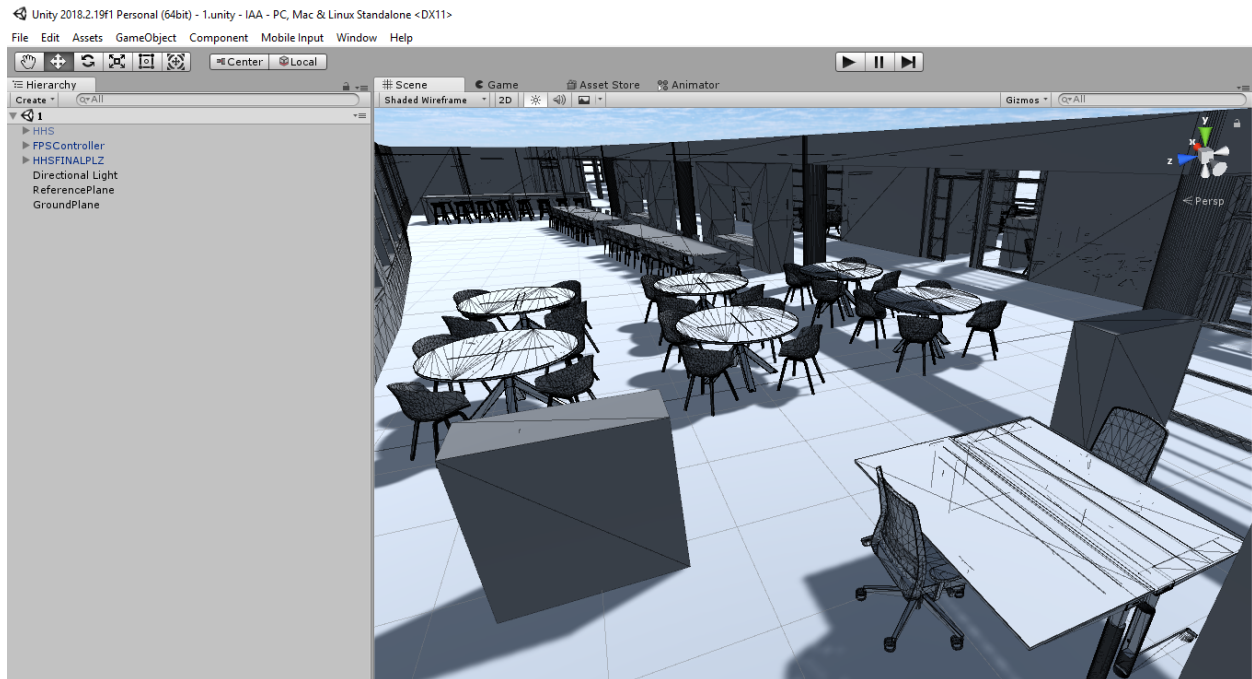


Figure 6.14 The project in Unity

Reference plane and camera

The 3d model is delivered in AutoCAD format by Abels and Partners and is converted and optimized in Autodesk's Maya to be compatible with Unity. A reference plane is created within Unity and is calibrated to the same coordinates as the coordinate system of the floorplan itself, as can be seen below in *figure 6.15*. By having the reference plane, the 3d model can be easily replaced and recalibrated in possible future scenarios.

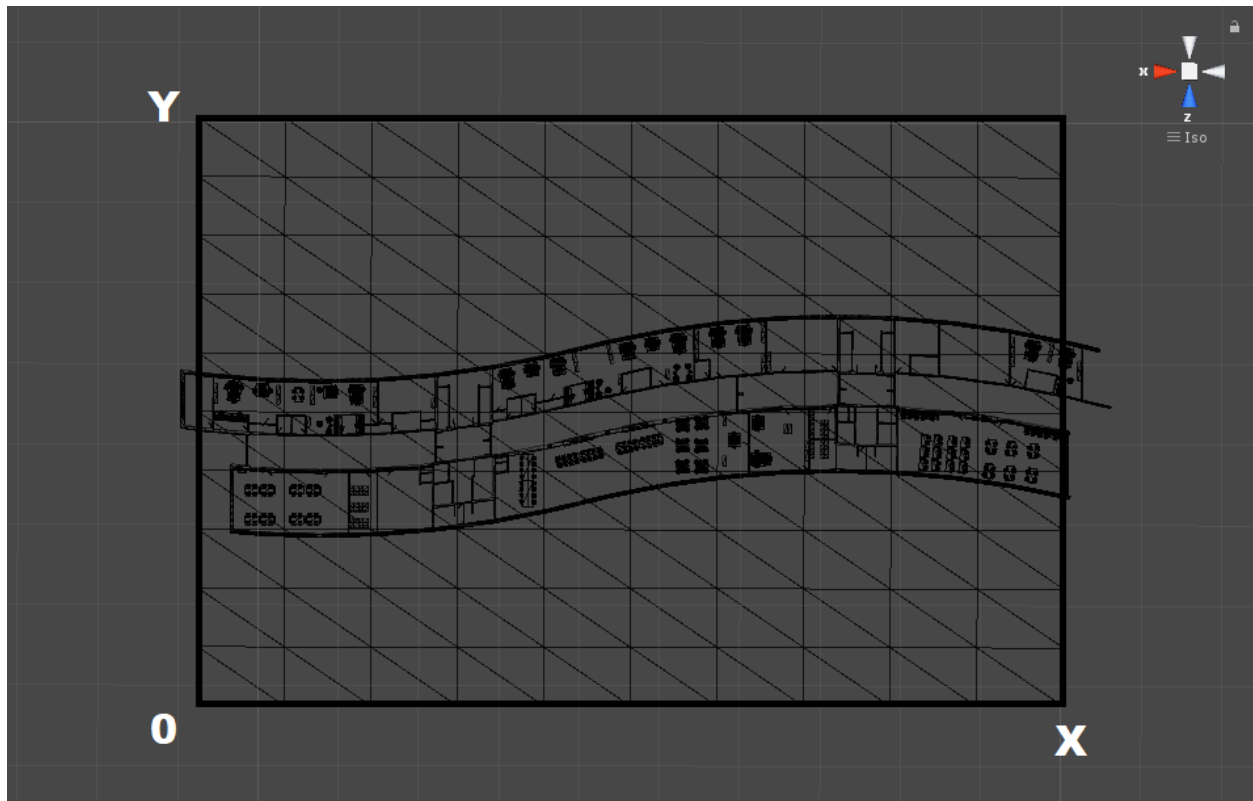


Figure 6.15 The reference plane

A ‘First Person Controller’ and camera are placed at (0,0) with a field of view of 70 degrees. This value is chosen in accordance to what architects generally use in their visualizations. The height of the person is set at 175 centimeters, which is about in between the average height of Dutch males and females (CBS, 2013). The ‘First Person Controller’ script is disabled, as we do not want the player to be controllable with mouse and keyboard. A custom C# script is created to receive the position and orientation of the viewpoint object (more on this in section 6.2.4).

When a new position or orientation is received, the ‘First Person’ is changed by using the ‘Lerp’ function on the Vector3 for the position and the Quaternion for the rotation respectable (figure 6.16). This achieves a smooth transition when moving the viewpoint object, which has been proven to provide a better experience than instant teleporting during the iterative prototype testing.

```
if (move) {
    transform.position = Vector3.Lerp(transform.position, nextpos, Time.deltaTime * speed);
    if (Vector3.Distance(transform.position, nextpos) < 0.02 && move)
        move = false;
}

if (rot) {
    transform.rotation = Quaternion.Lerp(transform.rotation, nextrot, Time.deltaTime * speedrot);
    if (transform.rotation == nextrot && rot)
        rot = false;
}
```

Figure 6.16 Interpolated functions to smoothly move and rotate

Object manipulation

The same C# script accounts for the manipulation of objects in the environment. It is possible for the user to place an arbitrary number of objects in the scene, which is received and processed by the before mentioned script. The list of objects and their respective locations are received, and subsequently instantiated into the scene. For the project two different assets are used; a human character and a round poker table. These assets are linked to their specified colors, so in this case green corresponds to the character and red to the table.

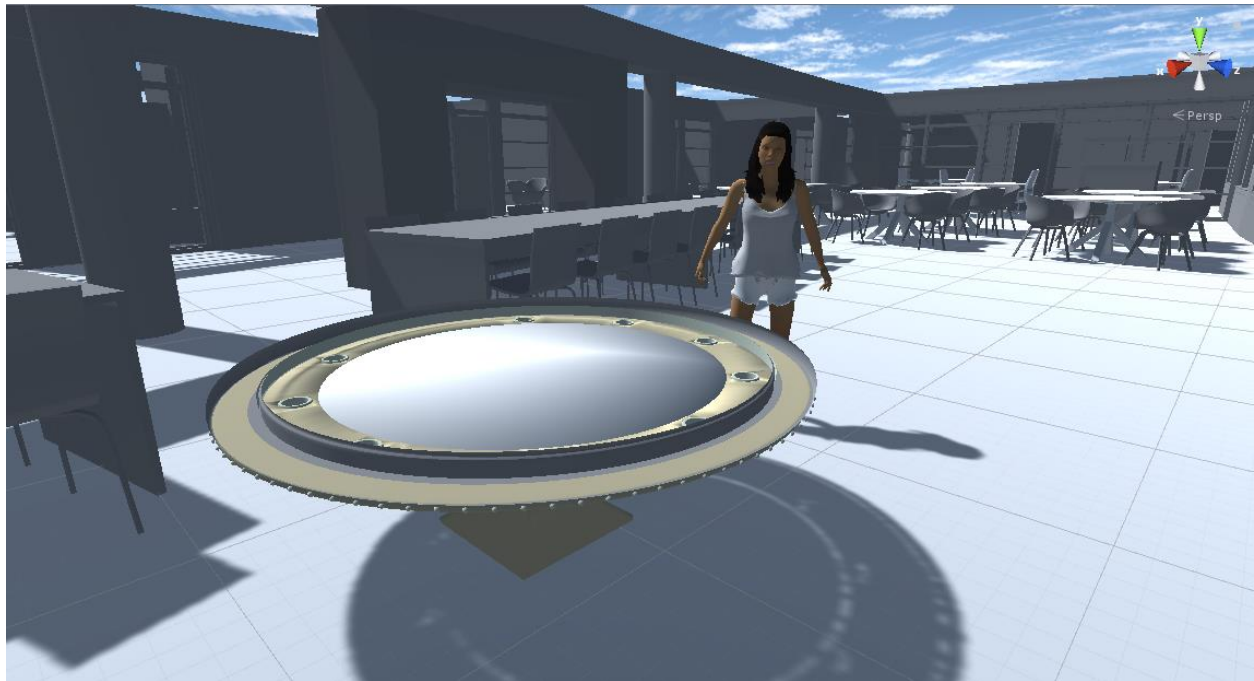


Figure 6.17 The two placable objects, character and table

For every iteration of the color detection the object list is received and updated by deleting all existing objects and re-instantiating all objects on the new list.

Virtual Reality Support

Fortunately, Unity natively supports virtual reality, which means it can be easily implemented. The program is started with the virtual reality setting on, and is thus seen as a virtual reality game by for instance Steam VR. It is however immediately turned off as soon as the environment loads, but can be turned again by pressing 'v'. This implementation makes it very easy to switch between the two modes, and is easy to implement as seen in *figure 6.18*.

```
if (Input.GetKeyDown(KeyCode.V)) {  
    UnityEngine.XR.XRSettings.enabled = UnityEngine.XR.XRSettings.enabled ? false : true;  
}
```

Figure 6.18 The only code needed to switch between VR and native mode

6.2.4 The Communications

Having both the tracking and the render engine ready, communication is needed between these two. This was initially done by using a file that both processes access, but this led to synchronization problems. That is why the choice is made to utilize the UDP network protocol. UDP is perfect in this situation, as we only need to have one sender and one receiver, without the need of setting up a connection. Another reason to not use the connection-based TCP protocol is because the communication is only done locally on one machine.

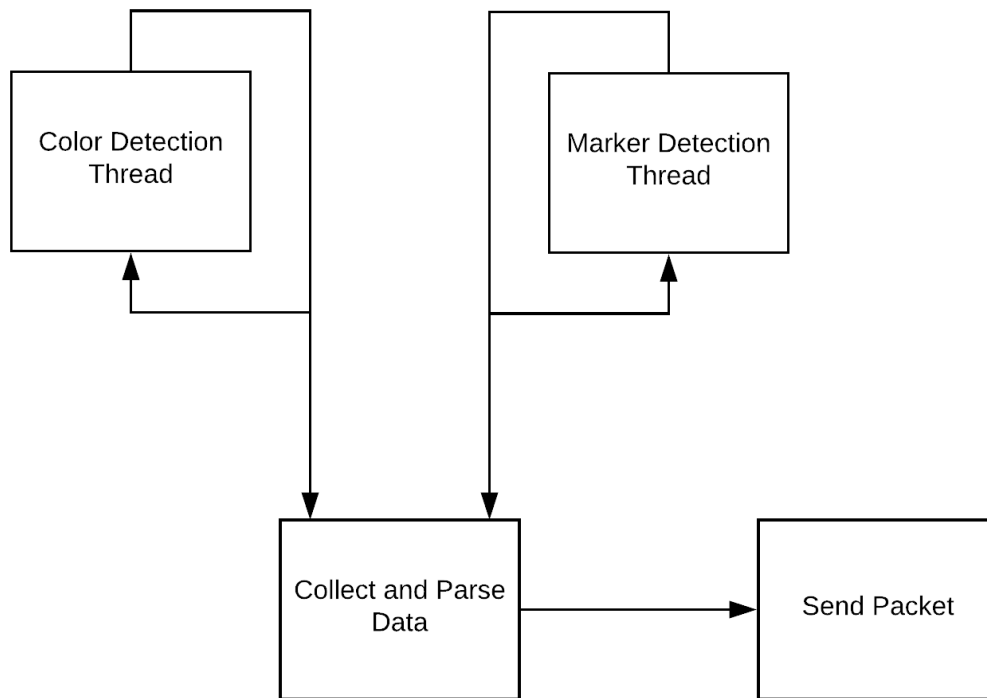


Figure 6.19 *The process running on the client (tracking program)*

In figure 6.19 the process running on the client can be seen. The color and marker detection threads are both executing in an asynchronous fashion, and whenever one of them completes the data is collected and parsed in a simple protocol (more on this later). When this is done the packet is send to the server, which is Unity in this case.

The process running on the server is rather simple, its only task is when a packet is received to parse the commands and execute them. This is illustrated in *figure 6.20*.

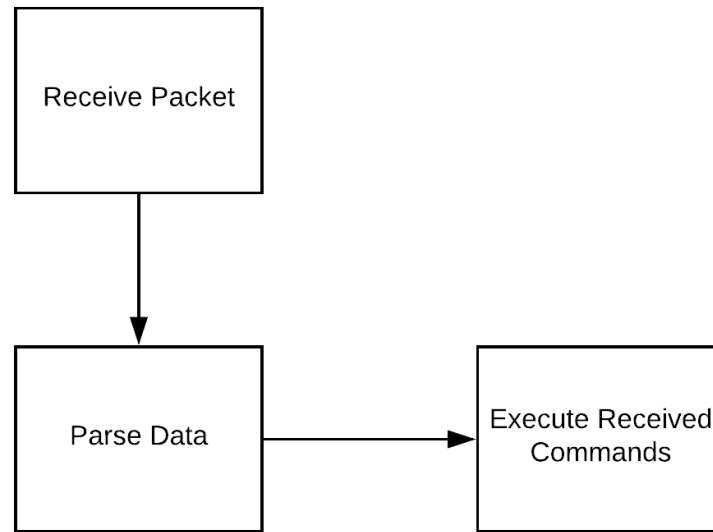


Figure 6.20 *The process running on the server (Unity)*

To parse the data a simple protocol is used. Data is sent using following format:

*Rotation , Xlocation , Ylocation : ObjectName(1) , Xlocation(1) , Ylocation(1) ; ... ; ... ; ... ; ... ;
.... ; ; ; ObjectName(n) , Xlocation(n) , Ylocation(n)*

The first three parameters are the viewpoint object rotation and coordinates divided by a ‘,’ character. Then a ‘:’ character is used to separate the viewpoint object data from the object(s) data. It is then followed by the object name, the x location and the y location all separated by ‘,’ characters. If more objects follow, this is indicated with a ‘;’ character, and the next object follows. This procedure can be repeated until the whole string is parsed.

Chapter 7: Evaluation

7.1 Functional Test

We are conducting a user-centered interaction design test on the final prototype in order to understand how intuitive the visualization is. The test is focussed on the usage of the prototype rather than the setup itself. The test of choice is a usability test. This test will be conducted with both experts in the field (the client) and people without any knowledge about architectural visualizations.

7.1.1 Usability Test Overview

The usability test itself is conducted using the ‘think-aloud’ protocol. The test has been done twice with two different group of users. Unfortunately, within the timespan of this project there was no opportunity to test with the real end user (the clients of Abels and Partners).

- ❖ Group A are users with experience in the architectural workfield, and have experience with architectural visualizations as well.
- ❖ Group B are users without any noteworthy knowledge about architecture or architectural visualizations.

The tests are conducted in two different settings, one for each group.

- ❖ Setting A is a meeting room at the location of Abels en Partners in Amsterdam.
- ❖ Setting B is at any location at any random table large enough for the setup.

We will test with group A in setting A and with group B in setting B. In both settings the users are given minimal guidance on their task, and just some questions are asked in order to get answers to the points in 7.1.2. In both settings the setup is as in *figure 7.2*, without any instructions. In the bottom right corner, the virtual reality headset is located and the provided colored objects can be seen in *figure 7.1*.

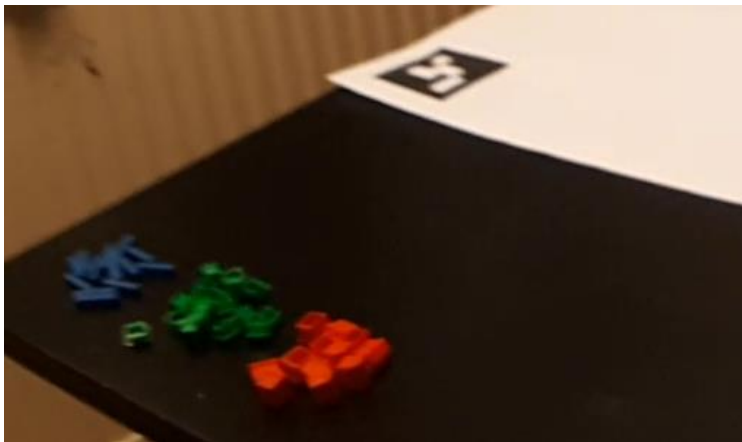


Figure 7.1 The colored objects

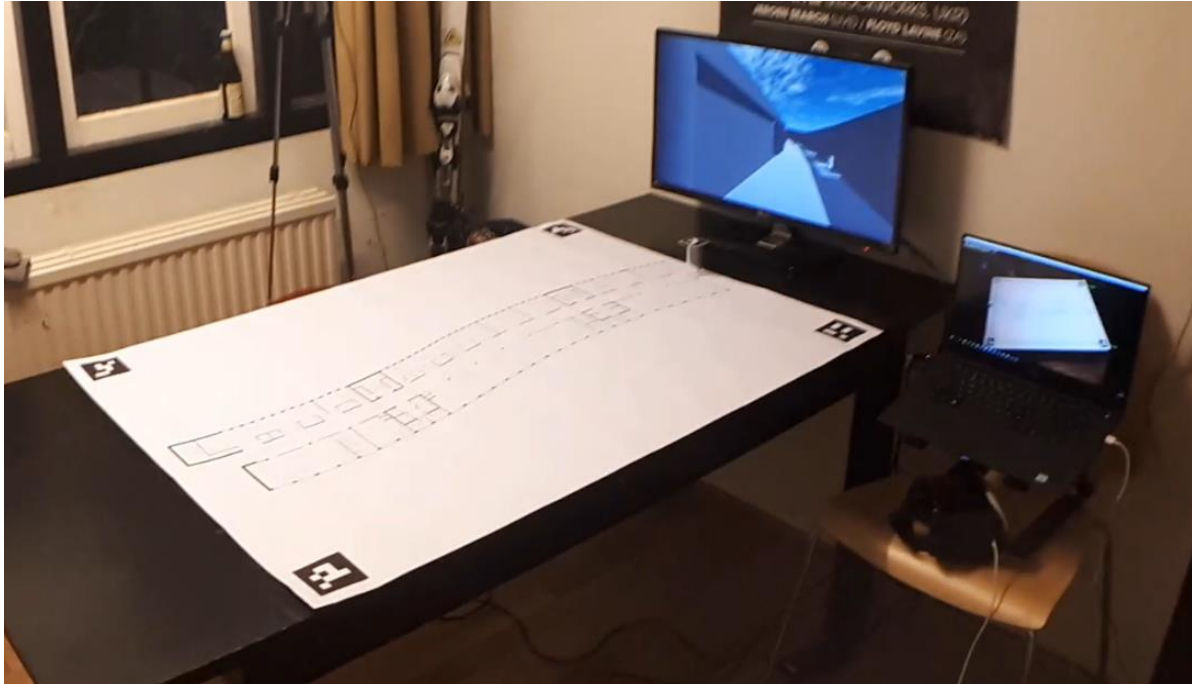


Figure 7.2 The usability test setup

7.1.2 Usability Test Goal

The goal of the usability test is to understand if the experts and non-experts, understand the interaction and feedback of the system without having prior knowledge or experience. There are a few things we want to find an answer to:

- ❖ Does the user understand what the installation shows?
- ❖ Can the user figure out how to move around in the map?
- ❖ Does the user understand how to rotate the viewpoint?
- ❖ Can the user figure out what the colored objects do?
- ❖ Is the user able to switch the virtual reality mode on or off?

7.1.3 Usability Test Results

Almost all participants managed to figure out the purpose of the setup. Group A understood the link between the screen and the floorplan quicker overall than Group B, which is understandable as they have seen floorplan with augmented reality visualizations before. The link between the floorplan and the 3d world on the screen became clearer when the participants started to move the viewpoint object around. Most participants seemed a little hesitant in touching and moving the viewpoint object, which could be the lack of affordance of the object itself or fear of breaking the installation.

As soon as the participants understood the connection between the viewpoint object on the floorplan and the 3d rendering on the screen, no one seemed to have any difficulty to understand how to move around. Even though the scale of the viewpoint object is quite large compared to the rooms on the floorplan, people seemed to be easily able to navigate to different rooms. It seemed to help them for understanding in which room they were, because of the camera transitioning from the last point to the new one.

Although the navigation was easy for most participants, the rotation c.q. orientation was not. The viewpoint object's orientation was only seen by the more observant participants who understood the front orientation of the AR marker. Most participants spent quite some time in turning the viewpoint object before they understood what the viewing direction was.

The colored objects for adding virtual objects on the map were the most troublesome for the participants to figure out. The refresh rate of the color detection is lower than for the marker detection, which made the objects appear on the map slower than the participants were expecting. This led to some difficulty in understanding what these objects were for. As soon as they figured it out, some participants tried to place lots of them around the map, which seemed enjoyable for them. The participants tried to rotate the objects as well, which is unfortunately not yet implemented. Not being able to rotate the objects created some confusion as well.

With some guidance to look on the screen to find the key on how to turn the virtual reality mode on or off, all participants were able to do this. Some of them took some time to figure out that the screen was following the orientation of the VR-glasses now, but still followed the position of the viewpoint object. For the participants new to virtual reality, the wow-effect was clearly present, following the hassle of putting on the glasses. The participants understood how to look around the room in VR, but it was clearly difficult to go to a new position because of their view of the floorplan being obstructed by the glasses.

7.1.3 Usability Test Analysis

The usability test provided great insight in how different people respond to a for them unknown way of interacting with a visualization. The main insights for improvement are listed below:

- ❖ It might be the rather large AR marker on top of the object viewpoint, but people seemed a little hesitant or scared to try and move the viewpoint object around without given the instruction to do so.
- ❖ The viewing direction of the object viewpoint was not immediately clear for all participants.
- ❖ The purpose of the colored objects was sometimes difficult to understand for the participants, which could be due to the slower color detection refresh rate.
- ❖ Having to turn virtual reality on or off should ideally be changed by a more intuitive method.
- ❖ There should be a way to see the floorplan and viewpoint object in virtual reality as well, to still be able to change position while being in virtual reality.



Figure 7.3 Earlier prototype test

7.2 Semi-Structured Interview

7.2.1 Interview Setup

To gain additional feedback we are conducting a semi-structured interview with the client. We have conducted this interview with both the head of Abels en Partners; Harry Abels, and with one of his colleagues who is very experienced in visualizing and 3d designing: Stef Hoeijmakers.

The goal is to gain additional insight in the visualization itself. The interview will try to get an answer to the following questions:

- ❖ Do you think this visualization would make meetings with your clients easier?
- ❖ Is the scale and distance on both the floorplan and the 3d rendition understandable?
- ❖ Is the 3d representation accurate enough?
- ❖ Is there more detail needed in the 3d model?
- ❖ Are the colored objects (adding of virtual objects) beneficial? And if so, should they be able to be rotated as well?
- ❖ Does the virtual reality mode add to the visualization? If so, will it be used?

7.2.2 Interview Results

The interview contributed to helpful insights for future development and potential changes. Through the interview it became clear that Abels en Partners definitely see a merit in using this visualization with their clients. Harry mentioned, that even for him, it would be a way better and easier tool to guide their clients through the proposed building interiors. The easy interaction and the 3-dimensional insight given in 2-dimensional floorplans would make it a good communication tool.

They also thought that the scale and distance are easier to estimate in this visualization than in a regular 3d visualization. This is achieved by the ability to see the distance and scale on the floorplan, which enables for quick comparison and gives an extra dimension to the visualization. There is still the problem that the camera has a static field of view, which can be positively or negatively misleading at times. It was mentioned though; that the virtual reality extension could give a better insight, since it enables for an almost complete field of view and stereoscopic imaging.

The lack of a roof in the 3d representation received some criticism. This is indeed something that was not added due to time constraints and is something that needs to be improved in the future. The detail of the 3d model got positive feedback, as it was as undetailed as possible. They stated that the more details, the more problematic their meetings with their clients become, as people tend to focus on just one little detail and forget about the overall concept. The feedback received here, was that the 3d rendering style could be even more sketchy and with even less detail; to be able to focus more on the indoor spaces.

The adding of objects in the workspace by placing colored objects on the floorplan was something they could really like if it had more possibilities. These possibilities would include rotating, and using objects that are already in the drawing. Using these objects to get a better understanding of scale, such as the human character, was considered a nice addition.

Virtual reality felt more like a gimmick for them, although they thought it could be really useful if there was the possibility to still be able to move the viewpoint object around. However, they did state that the immersion and perception of the building got better in virtual reality, but that they do not need that much detail in the early design process.

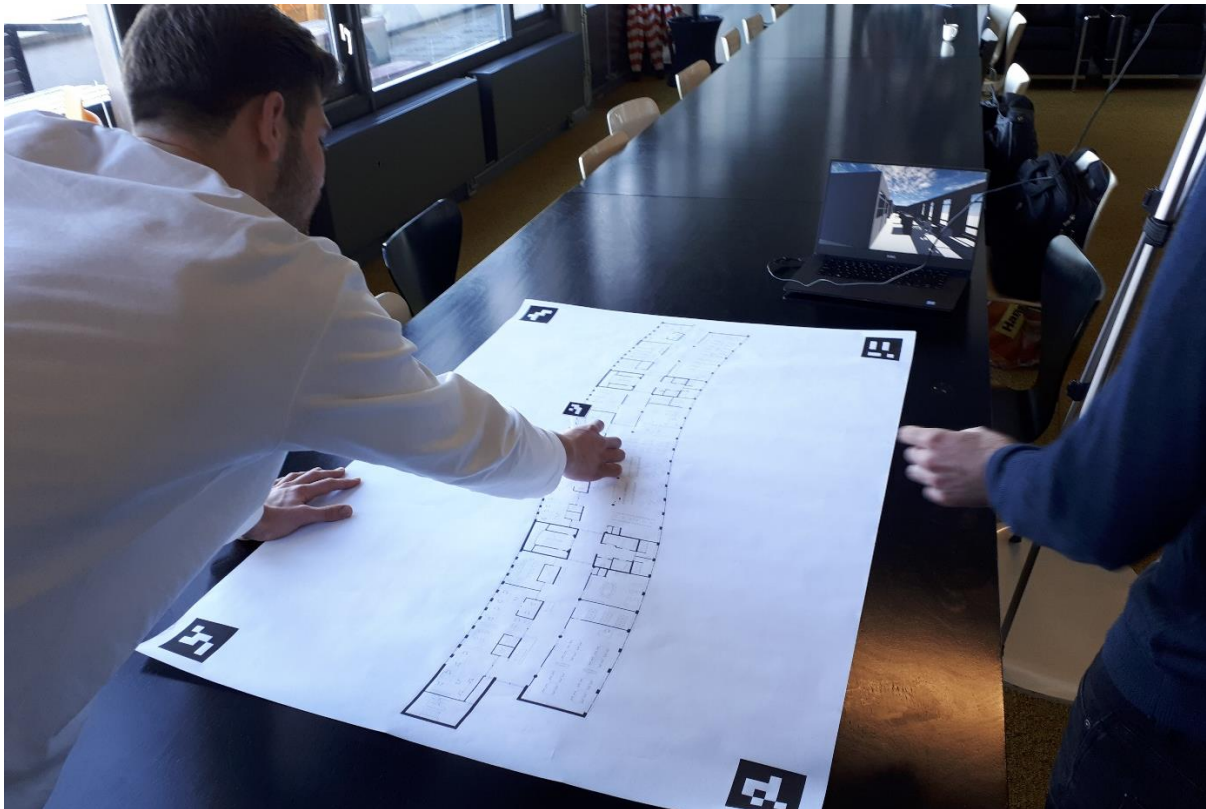


Figure 7.4 Interacting with the system

Chapter 8: Conclusion

8.1 Conclusion

The aim of this project was to create a new, efficient and easy way to visualize a proposed building's interior. This resulted in a complete functional prototype, which was realized by using the iterative design process. Three iterations in the prototype have been made in compliance with the client and the supervisors. Through this process the end result was satisfactory tested with the client. Unfortunately, it was not possible to test the visualization prototype in a real meeting due to time constraints, but this is something that will most likely happen in the future.

This visualization enables the architect to easily narrate their clients through a proposed building, with leaving the option open for their clients to take control by the use of the tangible interface. Besides one user taking control, there is also the possibility for multiple users to gather around a table and interact with the system simultaneously. During the design process it became clear that the interaction should be as easy as possible for the target group, as they are often not experienced in navigating through virtual worlds. Having a physical floorplan with physical means of interaction has proven to be an intuitive and easy way of interacting for most people.

All the user requirements have been implemented to at least some degree in the final prototype. Some of the functionality needs more work and additional tweaking, but the functionality as specified is present.

The research question has been answered to an extent to that we know that there are more accessible and effective methods of visualizing indoor architecture, as has been shown in this project. Even though the research question and project were in essence very concise and focused on solely indoor architecture, during the project interest by the urban planning sector was shown as well; which shows the versatility of this concept.

8.2 Future Recommendations

A few components need improvement, such as the orientation of the viewpoint object; which should be clearer to the user. The placement of the colored objects should be more intuitive, as well as the possibility to move around while being in virtual reality. In order to improve the prototype, another iteration in the design process is needed. Although this being true, the basic functionality; such as navigating and rotating through the building, works almost flawlessly in the current prototype.

Future additions have been mentioned as well by both the client and the supervisors. The ability to have two or more separate floors on one floorplan could be very helpful, as this would mean that there is no need for multiple plans for one building. This also implies that the scale preferably be larger if this were the case, which would also allow for more precise navigation and placement of objects.

In a later stage the virtual reality mode could be expanded to support the ability to position the viewpoint object while being in virtual reality. In the case of multiple users using the virtual reality mode, it would be possible for all users to interact on the same table. This would mean that they would be all able to navigate the viewpoint object in virtual reality, which in turn could really add to the immersion of actually feeling like being inside the building. Extending on this idea, interesting virtual reality interaction could be explored.

Another option would be to project the building on the floorplan in an augmented reality setting. By doing this, the idea of a scale model visualization gets incorporated as well. This could lead to interesting results, as more creative ways of interaction could be explored.

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