Bachelor Degree Project

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3D VIRTUAL SPACE FOR COLLABORATIVE DESIGN REVIEWS

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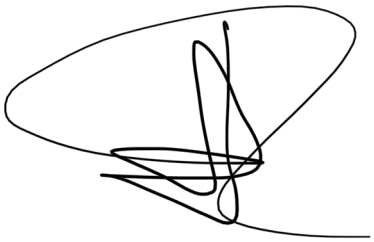
Assurance of own work

This project report has on 16th of May 2023 been submitted by Paula Reyes Aguilera and María Teresa Trujillo Rufino to the University of Skövde as a part of obtaining credits on basic level G2E within Product Design Engineering.

We hereby confirm that for all the material included in this report which is not our own, we have reported a source and that we have not – for obtaining credits – included any material that we have earlier obtained credits within our academic studies.



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Abstract

The PLENUM group, formed by researchers and developers of XR methods, aims to develop functions and spaces in virtual reality to improve the design environment. In the field of design reviews, although design reviews are now increasingly being conducted digitally, teams are still reliant on video conferencing software, as currently no dedicated tools are available. Due to the unique nature of design reviews, current solutions are inadequate. Therefore, this project aims to create a virtual design review space for collaborative design reviews. It will also be defined in this project a guideline for realising virtual design review spaces.

Initially, a literature study was carried out to understand the concepts of design review, virtual reality and virtual spaces, among others. User and empirical studies were conducted to gather information on user feedback and further define the requirements. Based on the gathered information, concepts were generated and subsequently transferred to Blender. The implementation and testing was carried out in Unreal engine through the screen, keyboard and mouse, as well as through the virtual reality glasses Metaquest 2 from Oculus.

Preface

Dear project supervisors and beloved family,

We find ourselves at a pivotal point in our academic journey, where the culmination of years of hard work and dedication is reflected in this thesis. In this special moment, we would like to express our heartfelt gratitude to all the people who have supported and accompanied us on this exciting path.

First and foremost, we want to thank our project supervisors, Nathanael and Paco, who have been invaluable guides in our final year project. Your expertise, knowledge, and dedication have been essential to our professional growth and the achievement of this milestone. We are deeply grateful for your commitment and for sharing your wisdom and experience with us.

We would also like to extend our sincere gratitude to our beloved family. You have been a fundamental pillar on our journey towards obtaining this degree. Your words of encouragement during challenging moments and your celebration during times of triumph have given us the strength to persevere.

Additionally, we want to acknowledge all the professors and academic staff who have supported and guided us throughout our university studies. Your dedication to education and your commitment to our success have been instrumental in our development as engineers and professionals.

We also want to thank our friends and classmates. You have been a constant source of inspiration, motivation, and collaboration. The enriching discussions and exchange of ideas we have had with you have significantly contributed to our academic and personal growth.

Last but not least, we would like to express our gratitude to all those who have influenced our educational journey in some way, including mentors, institutions, and organizations that have provided us with opportunities for growth and learning.

This thesis is the result of the collective effort of all these individuals, and it would not be the same without your support. We feel truly blessed and grateful to have had the opportunity to have your backing every step of the way.

With humility and sincere gratitude, we dedicate this preface of gratitude to our project supervisors and our beloved family. We hope that this work serves as a testament to our appreciation and a reflection of the dedication and commitment that all of you have invested in us.

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ASSAR: Assar Industrial Innovation Arena

CAD: Computer-Aided Design

HMD: Head-Mounted Display

HTML: HyperText Markup Language

QFD: Quality Function Deployment

LED: Light Emitting Diode

PhD: Philosophie Doctor

PLENUM: PLENary multi-User development arena for industrial workspaces

UCPD: User Centered Product Design

UI: User Interface

UX: User Experience

VE: Virtual Environment

VR: Virtual Reality

VRML: Virtual Reality Modeling Language

WWW: World Wide Web

XR: Augmented Reality

1 INTRODUCTION

The concept of Virtual Reality (VR) has been around since the 1950s, when it was defined as the user's sensation of being in a different environment than the one they are actually in, when placed in front of a computer screen (Schroeder, 1996). Currently, virtual reality can be defined as a computer-generated, three-dimensional (3D) environment which users can interact with using sensory input devices such as goggles, gloves, and body suits (Lehtinen et al., 1999).

VR has recently become a viable technology for consumers and it can revolutionize how we experience the world, from entertainment to education to healthcare. It offers users a more immersive and realistic experience than traditional entertainment media by allowing them to fully immerse themselves in a virtual world and can also facilitate problem-solving skills, which is useful in many professions (Seidel & Chatelier, s. f.).

Nowadays, virtual reality can help to improve experiences in different areas of companies. With this final degree project, what is expected to be achieved is an improvement in the design environment, to make this field more efficient in less time and, simultaneously, more beneficial. Improvements would include enhanced collaboration and communication between designers, allowing them to review quickly and easily, criticize and provide feedback on each other's work, resulting in a better design and thus a better product (Seidel & Chatelier, s. f.).

1.1 Background

Design reviews are an important part of the design process because they allow stakeholders to ensure that the design meets their standards and that it is within the scope of the project. Design reviews help prevent costly changes down the road and ensure that the design is well thought out and meets the end user's needs.

The physical challenges companies face today (they cannot always meet physically) and the current state of digital meetings have made it difficult to effectively conduct a design review. Whether in person, where meetings end up lasting long hours and no agreement is reached, or virtually, where searching for the call link, dealing with technical issues with external applications such as Zoom or Teams and trying to review a design properly through a shared screen display, make communication, visualisation and therefore design review difficult (Keating, 2020).

Some of these problems are:

- **Time and space limitations**: Traditional design reviews often require the physical presence of all stakeholders in a specific location. This can be inconvenient and limit the participation of people located in different geographic areas. A 3D virtual space would allow design teams to collaborate and review projects regardless of their physical location, saving time and resources.

- **Costs associated with physical prototypes**: Creating physical prototypes can be expensive and time-consuming. Additionally, changes and adjustments in the design require the creation of new prototypes. A 3D virtual space would provide a platform for digitally reviewing and refining designs, reducing costs and material waste.

- **Design communication and understanding**: Clients and design teams often struggle to communicate and fully understand a design based solely on sketches or descriptions. A 3D virtual environment would enable a more realistic representation of the design, facilitating communication and understanding among all involved parties.

- **Efficient iterations and modifications**: In a 3D virtual space, designers can make changes and iterate in real-time, speeding up the design process and allowing for greater experimentation without having to recreate the entire design from scratch. This enables greater agility and flexibility in the design process.

- **Evaluation of ergonomics and usability**: Evaluating the ergonomics and usability of a product is crucial in industrial design. A 3D virtual space would provide tools for simulating and evaluating product usage, allowing for the identification of potential issues before physical production.

- **Remote collaboration and feedback**: In a 3D virtual environment, design teams can collaborate and provide feedback remotely and in real-time. This improves the efficiency of the review process and avoids delays associated with scheduling in-person meetings.

- **Access to data and documentation**: A 3D virtual space can integrate and centralize all relevant information about the design, including blueprints, specifications, materials, and more. This facilitates access and management of data, resulting in better organization and informed decision-making. The design phase is likely to be the phase with the most input as each member shares their key expertise (Haksever, s. f.).

The emergence of XR (virtual and augmented reality) presents an exciting opportunity for design reviews. With XR it is now possible to create interactive 3D models of a design, allowing stakeholders to tackle the project in a virtual environment. This could be beneficial for the understanding of the design and help to ensure that the design meets the needs of the stakeholders. XR could also reduce the need for physical meetings, reducing the cost and time associated with travel and environmental load. The design review process is often expensive because of the need for face-to-face meetings between the designers, reviewers, and customers to articulate requirements, problems, and solutions (East, 1998).

By creating and using a 3D virtual room for meetings and design reviews it is possible to provide methodological support to the participants during the design

review by providing a platform for collaboration and communication. In addition, by creating a 3D virtual space for design reviews would contribute to sustainable development. By considering environmental, social, and economic factors, it is aimed to contribute to a more sustainable and responsible approach to design review processes:

Environmental Sustainability:

- **Virtualization and Reduced Travel**: By conducting design reviews in a virtual space, travel-related carbon emissions can be significantly reduced. Studies have shown that virtual collaboration tools can effectively substitute physical meetings, leading to substantial carbon footprint reductions (Robinson et al., 2018) . Virtualization also reduces the need for physical prototypes, minimizing material consumption and waste generation (Luttropp & Lagerstedt, 2006).

- **Energy Efficiency**: Modern rendering engines, such as Unreal Engine 5, offer advanced rendering techniques and optimization features that enable energy-efficient real-time visualization. Compared to other rendering engines (Godot), the capabilities offered by Unreal Engine 5 make it possible for the project to minimize energy consumption during design reviews, promoting sustainable resource utilization (Misra et al., n. d.).

Social Sustainability:

- **Inclusive Collaboration**: Virtual design reviews enable stakeholders from diverse geographic locations to participate, fostering inclusivity and equal participation. This promotes social sustainability by reducing barriers to collaboration, empowering remote team members, and incorporating diverse perspectives into the design process (Sekiguchi et al., 2016).

Economic Sustainability:

- **Cost Reduction**: Traditional design reviews often incur significant costs associated with travel, accommodation, and physical prototyping. By transitioning to a virtual space, these costs can be minimized, benefiting project budgets and promoting economic sustainability (Manzini & Vezzoli, 2003).

- **Time Efficiency**: Virtual design reviews can significantly reduce the time required for coordination and logistics associated with physical meetings. By streamlining the review process, project timelines can be shortened, contributing to economic efficiency and reduced resource consumption.

In conclusion, incorporating these sustainability aspects can contribute to a more responsible and efficient design review process.

1.2 Organizational setting

The organizational setting is User-Centered Product Design, a research group that aims to generate solutions that contribute to a positive user experience, good ergonomics, and high-quality products for user groups. This final degree project focuses on the PLENary multi-User development arena for industrial workspaces (PLENUM) project. The PLENUM project has as one of its multiple objectives to create an ergonomic, cost-effective and interactive 3D environment by using XR to develop functions, upskilling/reskilling multiuser environments on a digital industrial platform for analysis and design of workplaces and factories (*PLENUM*, s. f.).

Primarily the start of this project is for automotive companies such as Volvo but aims to expand to any type of company. Also, other stakeholders such as: design engineers, product developers, programmers, university researchers and potential customers are interested in this area.

1.3 Formulation of problem

Although design reviews are increasingly performed digitally nowadays, teams rely on video conferencing software such as Teams or Zoom, as there are currently no bespoke tools available. Due to the unique characteristics of design reviews, current solutions are insufficient.

Overall, the development of a 3D virtual space for design reviews aims to address these problems and improve efficiency, collaboration, and communication in the industrial design process.

1.4 Aim

The aim of this project is to create a virtual design review space for collaborative design reviews in a VE that solves the problems of physical reviews explained, as well as the current digital tools available. For this purpose, the space will be designed in a CAD programme and will be transferred to an interactive video game platform, and the tools to support design review will be explained conceptually. It will also be defined in this project a guideline for realising virtual design review spaces.

1.5 Objectives

This degree project objective is to design and implement a virtual design review meeting space that will be implemented in a software solution, a space adapting to the needs of clients for any company. For this, how design reviews are carried out in the industry today and the current knowledge about 3D meeting rooms will be explored. The result is a conceptual idea of the design of the room with design review support tools and the design method support, since the next step of including it in the program requires much more time.

1.6 Strategy for execution

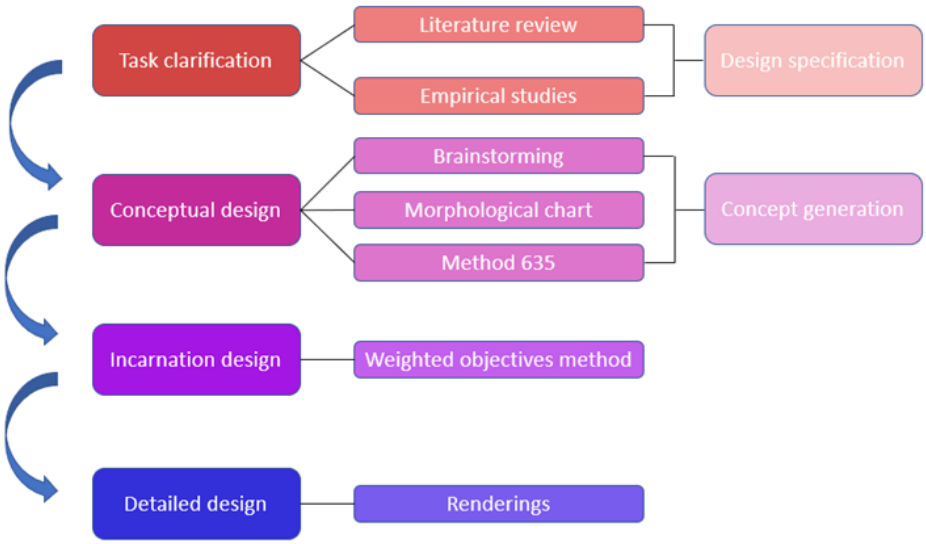

Figure 1: Design process

In this design process (showed in the figure above), the methodology of Pahl and Beitz will be applied during the weeks of the final degree project (Beitz & Pahl, 2007). This methodology is 19 weeks into 4 phases, each of which has a specific focus in our project:

1. **Task clarification:** carried out during the first 4 weeks, tries to gather information about the requirements to be embodied in the solution and about the constraints.

2. **Conceptual design:** carried out during the next 6 weeks, consists of establishing functional structures and searching for suitable solution principles.

3. **Incarnation design:** takes place over the next 3 weeks, consists of determining the layout and forms and developing a product or technical system.

4. **Detailed design:** takes place in the last 3 weeks of the final degree work in which the layout, shape, dimensions, and surface properties of the individual parts are established, materials are specified, and all drawings and other production documents are produced.

It is important to note that the phases do not necessarily follow one another in a rigid sequence. They are often carried out iteratively, going back over the previous ones, thus achieving step-by-step optimization (Cross, 2000).

Incorporating the Pahl and Beitz design process provides a valuable insight for several reasons.

First, the Systematic Design Approach: the Pahl and Beitz design process is a well-established systematic approach widely used in engineering design. It offers a structured framework to guide the design process from problem definition to concept generation, evaluation, and embodiment design. By following this process, you can ensure a systematic and rigorous approach to the 3D space design, addressing the key aspects and considerations necessary for its successful implementation.

Secondly, User-Centered Design: the Pahl and Beitz approach emphasizes the importance of considering user needs and requirements throughout the design process. In the context of a virtual 3D space for collaborative design reviews, understanding the users' preferences, tasks, and expectations is crucial. By incorporating the Pahl and Beitz design process, you can systematically gather user requirements, conduct user studies, and integrate user feedback to ensure that the virtual space effectively supports collaborative design reviews and meets the needs of the intended users.

Thirdly, Iterative Design and Evaluation: this process encourages an iterative design and evaluation cycle, which aligns well with the nature of designing a virtual 3D space. The iterative approach allows you to create design concepts, gather feedback, and refine the design based on evaluation results. It enables you to incrementally improve the virtual space's features, functionality, and usability, ensuring its effectiveness in facilitating collaborative design reviews.

These aspects will contribute to the overall effectiveness and success of the project.

2 PRESTUDY

2.1 Literature review / theory background

In order to design a Virtual Environment for design reviews, it is important to understand what a design review is, so it is the first concept explained in this report. Secondly, an investigation into Obeya rooms is covered, a concept very similar to a design review. Definitions of Virtual Reality, Virtual Environment, the first design review in a Virtual Environment as well as some aesthethic aspects of VE, the definition of XR, Metaverse, UX and UI design are explained in this section. Finally, in the section 2.1.8 an overview of 3D Game Engines is included as a tool to develop the VE.

2.1.1 Design reviews

In the field of engineering, design review is a must. When a project is carried out, conceptual design review helps to move forward in the right direction by correcting errors and implementing improvements. Each design stage helps to share and communicate project information to provide feedback and check for mistakes, or other types of conflicts (East, 1998).

A design review consists of subjecting the design to a series of evaluations to check its correct functioning and performance and to detect any possible failures. This review is carried out by a group from different fields: an electrical engineer, a design engineer, etc. Each member of the review team represents a different concern (East, 1998).

The process of a design review consists of three steps (East, 1998):

- The prototype, model or prototype drawings are analyzed.
- Based on rules and standards, the reviewer notes potential errors and omissions.
- Proposed changes are discussed and integrated. This step also can include giving feedback on how the design review went and proposing improvements for the next time.

The final design emerges from numerous iterations of the proposed designs, which are represented in the early stages by diagrams and schematics, and as the project progresses, physical models or digital 3D models (CAD) are made. In this way, the designers can convey the aesthetics and function of the product.

2.1.2 Obeya Rooms

Obeya means "big room" in Japanese and was introduced in the early 1990s (Terenghi et al., 2014). It consists of a space where members of a company gather to provide input and solutions to project problems (Dalton, 2019).

Its first use was by a Toyota executive to improve workers' initiative in engineering by using different methods to obtain the point of view of each worker (Nascimento et al., 2018). The Obeya Rooms is a method that helps improve and manage a project's organization and make decisions more quickly and efficiently (Javadi et al., 2013). Obeya's rooms have traditionally been physical, but virtual versions have also been developed and used, enabling remote teamwork from different locations, as the network connection allows workers to access, manipulate, and share information in real-time. (Abramovici et al., 2016).

The purpose of such a room is to enhance communication and coordination between all parties involved, using all the information through different visual tools placed on the wall (Abramovici et al., 2016) to get the context that will help to make better decisions. The Deming cycle (PDCA) is the main source of inspiration for the creation of the Obeya rooms (Aas & Alaassar, 2018). The deming circle can be seen in figure 2.

Figure 2: Deming circle (Alencar, 2020)

It is a four-stage cycle to improve problem-solving and avoid repeating mistakes when setting project standards. The four stages are (Moen & Norman, 2009):

- **Planning:** description of the problem, causes, and possible solutions.
- **Do:** manufacture and work on the designed product.
- **Check:** test and evaluation of results.
- **Action:** implementation of the solution discussed in the first stage.

In the case of Obeya digital rooms, the number of people participating is related to the size of the room, usually no more than 7 or 8 people, and several rooms can be connected via software, so that information from one room is displayed in the same way in the room where the meeting leader is located. (Abramovici et al., 2016)

2.1.3 Virtual Reality/VR

The term Virtual Reality was first coined in 1987 by Jaron Laenier. However, as early as 1950, the first contributions in this field were being made, such as the creation of a stylus for drawing vector lines on a computer screen by Ivan Sutherland. He defined the core abilities of VR for artificial worlds: interactive graphics, force feedback, sound, smell, and taste (Sutherland, s. f.). Another definition of VR is *"multi-dimensional human experience which is totally or partially computer generated and can be accepted by those experiencing the environment as consistent*" (Seidel & Chatelier, s. f.).

Years later, Sutherland described the concept of a head-mounted display (HMD) and an immersive 3D computing environment in his article "The Ultimate Display" (Sutherland, s. f.). A head-mounted display consists in a pair of goggles or a full helmet that implements a monitor in front of each eye, in which images are shown as three-dimensional. Currently, HMDs include a head tracking technology so that the system can respond to head movements. In addition, most HMDs include hand tracking (Lehtinen et al., 1999).

In the 1980s, computer graphics and technologies such as motion tracking and audio-visual systems led to more immersive experiences. In 1989, the first virtual

reality headset, the View-Master, became commercially available (Sutherland, s. f.).

In 1991, commercial virtual reality goggles were produced by Virtuality Group. In the 2000s was the development of motion tracking technology and the launch of the modern form of virtual reality goggles, the Oculus Rift, which became commercially available in 2012. The Oculus Rift being the first consumer headset to use VR technology, developed by Oculus VR. This led to several companies launching their versions of VR headsets on the market and ushering in the modern era of VR (Nagta et al., 2022).

2.1.4 Virtual Environments/VE

To arrive at the definition of the virtual environment, it is necessary to first define what virtual reality is, which is *"a computer-generated screen that allows or forces the user (or users) to have the sensation of being present in an environment different from the one they are actually in and to interact with that environment"* (Schroeder, 1996).

From the above definition, it can be seen that an important focus of virtual reality is the sensory experience, without which everything could be called virtual reality and the term would become meaningless.

However, virtual environments are not the same as virtual reality, the difference between the two terms is that virtual environments are worlds where people meet and interact with each other (Schroeder, 2008).

Three important characteristics are immersion, interaction, and presence (Burdea & Coiffet, 2003):

- **Immersion:** the ability to feel deeply enveloped by an environment that provides different experiences and stimulation (Witmer & Singer, 1998).

- **Interaction:** two types of interactions are supported in VE; explicit interactions are those in which the keyboard or mouse is used, and implicit interactions are those in which there is the possibility of a more natural human-computer interaction (Bowman & Hodges, 1997).

- **Presence:** the sensation of users being in one place physically, but at the same time being in a different place simulated by a computer (Slater et al., 1998).

2.1.4.1 Virtual Environment in design reviews

The design industry is interested in using virtual reality to improve clients' design choices and to enhance understanding of their needs. Design can be used to fully involve all users of a design review in the design phase decisions through a participatory design approach (Whyte, 2002).

There are currently versions of design reviews in virtual environments. The first was conducted in April 1998 according to (East, 1998), where a design review was virtualized to evaluate a building design for the first time.

The review space consisted of three building models and two databases that allowed all team members access to the review comments. They could choose avatars and used software browsers to connect to a central information server with the VRML model of the building to be reviewed and to talk via multi-party conference in real time.

The space was based on the client-server architecture of the WWW or World Wide Web, and allowed real time connection (East, 1998). The possibility to make comments, store them as HTML documents, and make them accessible to every team member also existed.

2.1.4.2 Aesthethic properties of Virtual Environments

Spaciousness

In a virtual reality environment, it is important to consider the space available to the user. It is recommended to design large spaces to allow for comfortable and unrestricted interaction (Hale & Stanney, 2015).

Comfort

Usercomfort is essential to ensure a pleasant immersive experience. This entails taking into account factors such as the ergonomics of the virtual reality devices used, such as headsets and controllers, to minimize fatigue and discomfort during review sessions, and the layout of the furniture and the arrangement of the interactive elements within the virtual environment (Hale & Stanney, 2015).

Visualization

Visual quality is essential in a virtual reality environment. High-resolution displays and accurate head tracking systems should be utilized to deliver an immersive and realistic visual experience. Additionally, it is important to consider the representation and graphics quality used in the design of the virtual room (Hale & Stanney, 2015).

Accesibility

The design of the 3D room should consider accessibility for users with different abilities and needs. This may involve providing alternative navigation and control options, size and height adjustments for interactive elements, and the ability to customize settings based on user preferences (Hale & Stanney, 2015).

Lights

Lighting in the virtual room can impact user perception and visual quality. Suitable light sources should be considered to illuminate the virtual environment and avoid excessive contrast or glare that may distract or negatively affect the user

experience. It is important to consider ambient lighting and directional lighting to highlight important objects and create an appropriate atmosphere (Hale & Stanney, 2015).

Colours

Colour selection can significantly impact the atmosphere and legibility of a virtual reality environment. Visually appealing colours should be chosen, allow easy differentiation of elements, and align with the theme or purpose of the virtual room (Hale & Stanney, 2015).

Optimisation

A level of priority exists when it comes to optimising models in VR. There must be a balance between the desire for accurate and realistic detailed geometric information and the need for real-time interaction. As real-time visualisation is more important because as much realism as possible is sought, the geometry can be simplified, using primitive solids (e.g. cubes) (Whyte, 2002).

In any system, there is a choice between the number of polygons, lighting, rendering, navigation speed and interaction (Whyte, 2002).

Prototypes

In industry today, virtual reality is used especially for design review in its final stages. By using virtual reality for design, the models created can be commercialised or used for marketing at a later stage, gaining additional benefits (Whyte, 2002).

In the development of complex products such as automobiles, virtual reality has been used as a prototype in design reviews. BMW used the interaction tool EASY2C, which allows you to rotate a physical prototype in your hands, using it as an intuitive interface with the virtual data displayed on a screen. Today, thanks to improvements in the field of virtual reality, it is possible to recreate the prototype on a real scale (Whyte, 2002).

Minimalism

Minimalism in the design of virtual reality environments implies a clean and distraction-free interface. It is recommended to eliminate necessary elements and simplify the presentation of information to focus the user's attention on the main aspects and facilitate intuitive interaction (Hale & Stanney, 2015).

Futurism

Futuristic design in virtual reality environments can explore innovative ways of presenting information and creating immersive experiences. This can include cutting-edge design elements, advanced technologies and aesthetics that evoke the future (Hale & Stanney, 2015).

2.1.5 XR

Extended Reality or Cross Reality (XR) includes Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR). In all these realities, human interaction is possible in a digital or semi-digital environments created by technology (Mystakidis, 2022). However, they present a few differences:

- **VR:** as we have already defined in the previous section, is a separate, digitally created artificial environment. It is highly immersive, where users interact as if they were in the physical world with the help of HMD equipment (Mystakidis, 2022).

- **AR:** is the spatial fusion of the physical and virtual worlds. It consists of a thin spatially projected screen of devices such as tablets, glasses, smartphones or other transparent surfaces (Mystakidis, 2022).

- **MR:** is a combination of both, any combination of VR and AR, sometimes being considered an iteration of AR. It also requires special glasses (Mystakidis, 2022).

2.1.6 Metaverse

Metaverse is a word composed of two elements: meta (greek prefix meaning after or beyond) and universe. In other words, it is an interconnected network of immersive environments and persistent multi-user platforms. VR and AR converge in the metaverse, enabling real-time communication and digital interactions with technologies that involve multi-sensory interactions with virtual environments, digital objects, and people (Mystakidis, 2022).

Users in Metaverse are represented by digital bodies called avatars. The first iteration of the metaverse was defined as a network in which avatars could travel from one virtual world to another (Mystakidis, 2022).

The second MR iteration of the Metaverse is currently being created, in which social virtual reality platforms will be compatible with multiplayer online video games and augmented reality spaces. Thanks to this, users will have the opportunity to meet and interact without restrictions as avatars or 3D holograms in both physical or virtual environments (Mystakidis, 2022).

2.1.7 UX/UI

UI stands for User Interface. It is based on the choice of elements based on the task to be performed by the user and organizes them for ease of understanding and use (Garrett, 2011). On the other hand, User Interface (UI) refers to the visual elements and interactive components through which users interact with a digital product or system (Dix, 2004).

UI design involves designing the graphical user interface, including icons, buttons, typography, color schemes, and layout. It aims to create an intuitive and visually

appealing interface that guides users through their interactions, ensuring that the product is visually cohesive, accessible, and user-friendly (Dix, 2004).

UX stands for User Experience and refers to offering products that are a pleasure to own and use. It is about meeting the customer's needs exactly (Norman, s. f.). User Experience (UX) refers to users' overall experience and satisfaction when interacting with a product, system, or service. It encompasses various aspects, including ease of use, efficiency, effectiveness, and overall user satisfaction (Dix, 2004).

UX design focuses on understanding user needs, behaviors, and motivations to create meaningful and enjoyable experiences. It involves conducting user research, creating user personas, wireframing, prototyping, and conducting usability testing (Dix, 2004).

2.1.8 3D Game Engine

Since a 3D Game Engine will be used to realise this project, it is considered necessary to include it in the literature review.

Computer games consist of computer programs composed of lines of code or instructions that are controlled by a user in possession of a controller, i.e., a mouse, keyboard or joystick. The engines within these games are responsible for making the games work, reproducing picture elements in 2D, 3D or both. These elements are displayed by the controllers on a screen or monitor in real time, producing human-computer interaction or HCI. This type of video game is called interactive.

Interactive and immersive games are mostly those that use 3D game engines and therefore include a 3D environment. Some of the advantages of 3D games are: real-time rendering, real-time scrolling, interactivity, multiplayer, lighting and collision detection, according to (Finney, 2004).

"What a game engine does is that it provides you with tools and programs to help you customize and build a game; it gives you a head-start in making your own game" (Misra et al., s. f.). Currently, Unreal Engine is one of the best options out there as it is completely free, is widely customisable, has cross-platform capability and the ability to create high quality games.

2.2 Empirical studies

In this section, different methods of empirical studies used are explained, such as interviews, and questionnaires to gather information for making the engineering specifications. Visual references concerning the aesthetic theme of the 3D space for collaborative design reviews are presented in section 2.2.3 of this chapter. Finally, a quality matrix study has been carried out to evaluate the characteristics of the room.

2.2.1 User studies

Interviews were conducted with a group of users related to this project. An interview is a research method where a conversation takes place between an

interviewer and an interviewee to gather firsthand information on a specific topic or to explore an individual's experiences, perspectives, or expertise. It is commonly employed as a qualitative research technique to generate rich, contextualized data and gain insights into complex phenomena (Bryman, 2016). Interviews offer researchers the opportunity to engage in a dialogue with participants, allowing for in-depth exploration of topics, clarification of responses, and the emergence of unexpected insights (Rubin & Rubin, 2005).

However, the first interview made was very incomplete. First, the project was explained to the users. Then they were given a first idea of the layout and content of the rooms. Finally, they were asked a series of questions to find out what they thought of these first ideas. The mistake was that an interview has to be open and not explain an earlier idea, since the users' opinion is gathered precisely in order to work out the specifications and, from there, to design the idea.

In addition, a new interview has been made. This new interview would be conducted with people who have ever participated in a design review, as this is the only way to get reliable and useful feedback on the design of a virtual room, the purpose of which is to improve the current design reviews.

Thus, a new, more complete interview model is proposed and would have been implemented instead of the first one (the first interview with answers is shown in Appendix A).

Interview

- What kind of design reviews are carried out regularly in your company and what is their importance in the product development process?

- Do you have previous experience with virtual reality and have you ever used this technology to review designs or prototypes?

- What do you think are the most important aspects to consider in a design review room using virtual reality?

- What kind of furniture and equipment would you like to find in this room to facilitate design reviews?

- Do you consider it important that the room provides an immersive and comfortable experience? Why?

- In your opinion, what features or elements should a design review room using virtual reality include to facilitate collaboration and decision-making?

- What level of visual realism and interaction do you expect from a virtual reality experience in a design review room?

- What would you like the design review process to be like in the virtual reality room? What specific features or functionalities would you like to have during the reviews?

- What aspects of the current physical design review room do you think are relevant or important and will be transferred or adapted to the virtual reality room?

- In your opinion, what would be the ideal size of the design review room using virtual reality? Should it be a single space or should it be separated into different rooms?

After the interview, users were asked to respond to a questionnaire designed to measure their needs in more concrete terms. The original questionnaire was also incomplete, so it was decided to change it too, adding more specific questions and focusing more on people who had participated in design reviews (the first questionnaire with answers is shown in Appendix A).

Questionnaire

- What is your role in the design and product review process? How often do you participate in design reviews?

- What are the main challenges you face during current design reviews in terms of communication, visualisation and collaboration?

- What benefits do you expect to gain from using virtual reality for design reviews compared to traditional methods?

- Do you consider it important to have an accurate and realistic representation of the products and materials in the VR room? What level of visual detail do you expect?

- Would you like to be able to interact directly with virtual models and prototypes during reviews? What kind of interactions do you consider important?

- Do you expect it to look and feel like a physical room?

- What colour palette would you like the virtual reality room to have?

2.2.2 The Objectives Tree Method

The method selected in order to clarify the objectives was The Objectives Tree Method. Clarifying design aims, subobjectives, and their connections is the goal of the objectives tree method (Cross, 2000).

The method is as follows:

- **Step 1:** with the information from the interviews and questionnaires, a new list of design objectives was made.

- **Step 2:** after being ordered from most to least important, another list of objectives and sub-objectives was made and further grouped into hierarchy levels.

- **Step 3:** finally, a tree diagram was drawn. The arrows symbolize the relationships and thus aspirations to achieve the objectives (Cross, 2000).

The Objectives Tree can be seen in Appendix B.

2.2.3 Visual references

In this chapter inspirational visual references such as moodboard and room color themes are developed.

2.2.3.1 Mood board

A fundamental tool in the design industry, the mood board, has been used in this design phase. This tool is used generically to refer to different types of boards, with specific objectives (Cassidy, 2011).

This tool consists of transmitting the mood or feeling and translating the meaning of the idea of what is wanted to be expressed, but it is difficult to do it verbally or in writing. It is about bringing together different images of environments, materials, products, and colours, to arrive at an idea through many different images but with something in common between them (Öberg, 2016).

The aim of the mood board is to be able to translate the meaning of what is wanted to express in a visual form in order to facilitate clarification for the people referred (Öberg, 2016).

Two images have been created to be used as inspiration when creating future concepts, focusing on a concrete approach. Figure 4 represents the futuristic and modern approach that would be use as inspiration for the rooms. It is based on a mix of light and dark colours with bluish and off-white LED lighting to mimic a futuristic aesthetic.

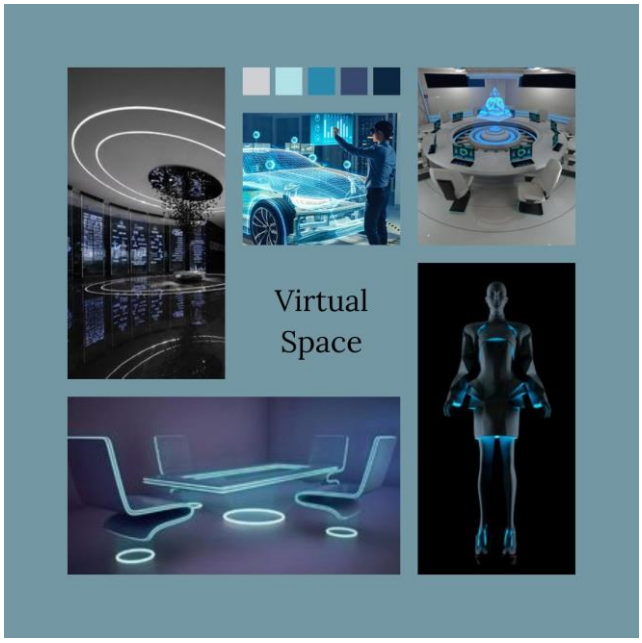

Figure 3: Moodboard

Figure 5 represents the colour palette. Discreet colours have been chosen, as in the interview carried out previously, the majority opinion on the colour tones in terms of the structure of the rooms was that they should not be striking colours so as not to distract the designers and engineers when carrying out the work. Unlike the lights, which could be of more striking tones to maintain the illumination of the rooms or to highlitght objects, as seen in literature review in section 2.1.4.2.

Figure 4: Colour palette

2.2.4 Quality Function Deployment Method

A Quality Function Deployment (QFD) Matrix was made to determine the characteristics of the rooms (the QFD matrix can be seen in Appendix C). The QFD Matrix is a useful tool to ensure that all the needs and requirements of a project are adequately met. This is especially important for a project such as a virtual design review room, where users have a variety of particular needs and requirements. This method emerged in Japan in 1970, and was applied with great success in Japanese, European and American companies, as it helped them to develop better products.

Akao, the QFD founder describes QFD as *"a method for developing a design quality aimed at satisfying the customer and then translating the customer's demand into design targets and major quality assurance points to be used throughout the production phase*" (Chan & Wu, 2002).

The first step is to identify the requirements and attributes of the virtual space, which was done in the Objectives Tree Method. The next step was to select the importance of the attributes, ranking them from one to ten. This was useful to determine which characteristic was more important, and to identify which requirements were critical to the success of the project.

Customer needs were translated into engineering terms, i.e. technical characteristics in the third step. Designers are responsible for ensuring that these characteristics become measurable and real characteristics so that they can work with them with some control (Cross, 2000).

Once the technical characteristics were written, they were related to the attributes chosen above. This relationship can take on different values depending on the intensity of the influence they have on each other, ranging from stronger to weaker. Symbols were used to represent them.

In the fifth step, to prevent technical features from influencing each other, the matrix ceiling was added. The functionality of the ceiling is to measure the interactions between engineering features in positive or negative terms. Also, it gives an appearance like the shape of a house, the result being known as "the house of quality".

Finally, targets were set for the engineering characteristics. The team decides what goals can be set for the quantifiable technical characteristic parameters to satisfy the customer's needs or enhance the product relative to its rivals (Cross, 2000). The engineering characteristics of the room were determined thanks to this analysis, as the important needs were separated from the unimportant ones and their usefulness was evaluated. For instance, the need for separate rooms and the need for them to be spacious was the one that stood out the most.

Thanks to the matrix, the client's needs were better understood, as before the matrix, the special functions were more prominent. Some of the benefits of this method are a better understanding of the clients and better communication and faster decision making (Chan & Wu, 2002). It also has benefits such as focusing on

the customer, decreasing implementation time, promoting teamwork and providing documentation (Bossert, 2021).

2.3 Design specifications

The requirements were made by following The Performance Specification Method. The Performance Specification Method provides a clear and understandable way to determine the general limitations for the generation of solutions and intends to help in defining the design problem (Cross, 2000). Information was gathered from literature survey and from the objectives tree.

The objective of The Performance Specification Method is making an accurate specification for the design solution (Cross, 2000). This table will be a guideline for the realisation of concepts in the idea generation phase and the subsequent choice of concepts. The specifications can be seen in table 1.

In order to have a better understanding and division of the requirements, they were divided into functional, cognitive and emotional. It is necessary to identify the types of actions, processes and reactions that users must perform in order to use the system effectively (Gause & Weinberg, 1989).

Functional requirements refer to the expected behavior of a system, usually expressed as inputs, outputs, processes, and data storage (Gause & Weinberg, 1989). Cognitive requirements relate to the user's understanding of the system, how they interact with it, and mental activities such as memory, decision making, and problem solving (Gause & Weinberg, 1989). Emotional requirements refer to emotions, attitudes, and feelings between users and a system, and how it affects their overall experience (Gause & Weinberg, 1989). Engineering specifications are shown in table 1, 2 and 3.

Table 1: Engineering specifications

Nº	Demands (D) and Wishes (W)	Matter of concern	Definition	Weight (1-5)	Fulfilment
1	D	Spacious	Rooms that give a feeling of spaciousness	4	• Rooms with large dimensions

2	W	Minimalist	Rooms that give a feeling of spaciousness	3	• Few furniture
3	D	Comfortable	• Intuitive • Differentiate stages	4	• Well distribution of the furniture • Separated rooms
4	D	Visualization	• Visualization of people comments • See visual information • Detailed view of the room • Easy visualization of the prototype	5	• Placing devices • Possibility zoom in • Visualization from any point
5	D	Accessibility	Possibility of going from one room to another	5	• Walking • Flying • Rotating • Virtual Reality
6	W	A moderator	Guide the meeting	4	Special functions

7	D	Annotation	Take notes	5	Real-time note-taking
8	W	Aesthetic	Innovative and realistic	3	Themed room
9	D	Good communication	Interaction of information between rooms	5	Placing interactive devices in each room

Table 2: Definitions

Annotation	Function that allows users to take real time annotations whenever they want
Aesthetic	Realistic and inspirational theme but at the same time has an impressive factor so that the room gives a sense of realism
Good communication	Need to send information from one room to another, e.g. a floor plan from room 2 to room 3
A moderator	Need for a moderator to guide the meeting
Special functions	Special functions are covered by the moderator who can run the meeting, to spawn in case she/he wants to gather everyone in one place and who starts with the framework method

Table 3: Technical specifications

Importance	Requirement	Unit	Demand	Wish
1	Room with large dimensions	m^2	93	100
3	Few furniture	%	40% of the room covered by furniture	30% of the room covered by furniture
2	Separated rooms	nº	3	3
4	Screen sizes	In.	70	75

	Functional
	Cognitive
	Emotional

3 DESIGN

3.1 Concept / solution generation

In this chapter different room proposals have been generated. In each proposal is shown a solution that is intended to fulfil the specifications presented in table 1. The concepts are presented in section 3.1.3, 3.1.4 and 3.1.5.

3.1.1 Idea generation

Different methods of idea generation have been carried out. The conceptual idea is presented in this section.

With the results obtained from the information obtained in the interviews and questionnaires, a first list of objectives was formulated. It was then arranged in a tree of objectives, and the importance of each attribute was established thanks to a QFD matrix. This information was translated into engineering terms, the most important of which were the need for the virtual space to be spacious, minimalist and comfortable.

Spacious, in order to give a greater sense of spaciousness, it must also guarantee a sufficiently large area to allow natural and unrestricted movements, which was translated into a large space. Minimalist, to focus the user's attention on the main aspects and facilitate intuitive interaction, so a clean interface without distractions is needed. Finally, user comfort is fundamental for a pleasant experience. This is translated into a good distribution of furniture and a separation of areas that allows a better focus on each section of the meeting and ensures the concentration of the participants in each task to be performed.

In the case of brainstorming, it was considered essential to have a first arrival room for participants to choose their avatar. On the other hand, as mentioned in section 2.1.1, a design review consists of three steps (East, 1998). It was established that the first two steps could be unified in a second room where participants enter individually to look at the prototype to be reviewed in question, consult the rules and regulations. The function of this room is only to analyse the prototype, as well as to be able to write comments on it, which can then be shared in room 3.

Pointing to the information gathered from the Obeya rooms in section 2.1.2, it was decided to implement a room where communication and coordination between all the participants of the meeting would be possible in real time, using information through different visual tools placed on the wall (Abramovici et al., 2016). In addition, it was decided to create the figure of a moderator to guide this meeting with special functions that will be explained later.

3.1.1.1 Brainstorming

For the first stage of concept generation, brainstorming sessions were conducted. Brainstorming was originally suggested by Osborn, with the aim of getting a group of open-minded people to brainstorm the first thing that comes to mind, bringing new ideas into the minds of others (Beitz & Pahl, 2007). It also encourages the exploration and understanding of different topics through concrete ideas contributed by participants from completely different fields, so that ideas can be more varied as everyone has a different perspective on the same idea (Dr.Taibah, 2022).

Four brainstorming sessions were held. The first was for the composition of the rooms, where the idea was to design 3 different rooms, each focusing on one phase of the design review. This was due to the need to avoid mixing the steps and objectives of a design review and to have separate rooms, which was specifically requested in the design specifications. The second, third and fourth brainstorms were conducted for the design of each room and its corresponding functionalities. The results of the brainstorming can be seen in figures 5, 6 and 8.

For the method to reach its maximum effect, 3 steps were carried out, according to Beitz and Pahl (Beitz & Pahl, 2007).

The first step is the composition of the group in which the authors of the final project were selected as members.

The sessions took place at Assar Industrial Innovation Arena centre. The participants were given between two and a half and five minutes to draw sketches of the different rooms. All solutions provided should be represented in whatever form they are saved (written, sketched, or recorded), and should also be concrete enough to be able to draw a specific solution (Beitz & Pahl, 2007).

When the specific time was up, the sketches were shared and discussed. This process was repeated up to five times.

Sessions lasted between 30 and 45 minutes, as longer sessions are not effective enough and are considered a waste of time. The final result should be reviewed by the group to avoid possible confusion (Beitz & Pahl, 2007).

The benefits that can be derived from brainstorming are the expansion of new data or new procedures by the participants, as well as being a very appropriate activity to stimulate the creativity and imagination of the participant (Beitz & Pahl, 2007).

The sketches in room 1 are the first to appear in figure 6. Different locations for the avatar selector were explored, as well as different shapes for the avatars, such as a table or a screen. The possibility of including the company's presence in the room by means of a screen that would allow the logos of the different companies to be displayed was studied.

In room two, different supports for the prototype were studied, as well as the location of screens to have access to plans and regulations of the prototype.

In room 3 different concepts of meeting tables, location of windows to give more light to the room and different blackboards for feedback on the design review were drawn.

Rooms 2 and 3 can be seen in figures 6 and 7. Figure 8 refers to the different furniture to be included in each concept.

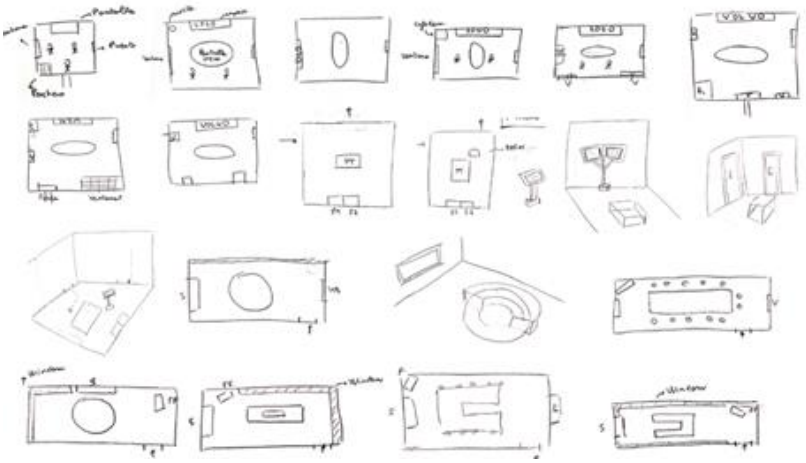

Figure 5: Thumbnails 1

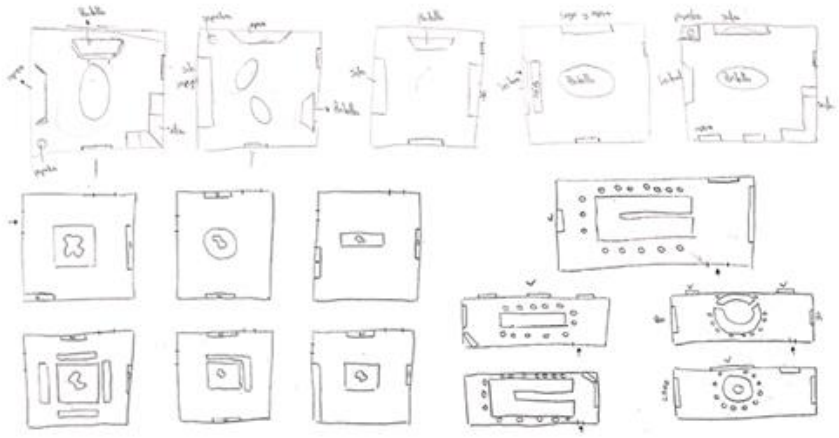

Figure 6: Thumbnails 2

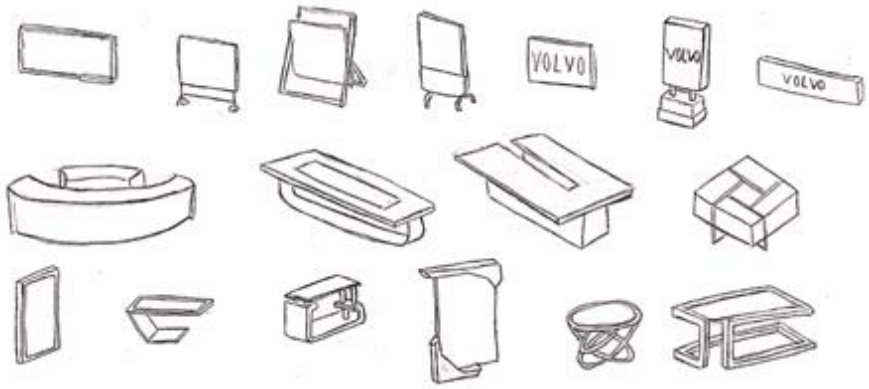

Figure 7: Thumbnails 3

3.1.1.2 Morphological Chart

The Morphological Chart is a method that investigates the design for clusters of interconnected sub-tasks and broaden the range of solutions available (Börekçi, 2018). It was carried out to generate different design proposals with the results obtained in the brainstorming session.

In the first step, a list is made with the essential characteristics to be implemented in the final product (Cross, 2000). These characteristics should be functional and physical in the product and as independent of each other as possible. A key to this method is that the list should be a maximum of 8 characteristics, as more would make it a very complicated situation to realise.

For room one, the characteristics that would be implemented would be:

- Possibility of selecting avatar.
- Possibility of identifying company.

For room two:

- Need for the prototype to be placed in somewhere.
- Need for interaction between rooms.

For room three:

- Need for interaction between rooms.
- Need to give feedback on the design review.
- Need for avatars of meeting participants to be placed in somewhere during the meeting.

Step two is to list, for each characteristic, how these could be achieved, becoming sub-solutions that combine with each other to form the overall design solution.

For room one:

- Screen/digital table for avatar selector.
- Screen to put companies' logo.

For room two:

- Table as prototype support.
- Screen/digital whiteboard.

For room three:

- Screen/digital whiteboard.
- Whiteboard.
- Table.

The next step is to draw up a morphological table from the previous lists, which at first will be an empty table that will be filled in as both lists are entered. When the table is finished, a fairly large total number of combinations is found, each combination being a possible solution (the morphological chart can be seen in Appendix D).

Finally the combinations that are effective as sub-solutions are selected, since having an abundance of combination results, many will be impossible solutions, some existing solutions and a few possible solutions (Cross, 2000).

3.1.2 Concepts

In this section the different concepts resulting from the morphological chart method are presented.

3.1.3 Concepts room 1

The main function of the first room is to be the meeting point where the participants of the meeting arrive once the meeting has started. In this room, the avatar that will represent each participant is chosen.

3.1.3.1 Concept 1.1

In this first concept, the avatar selector is made up of an oval-shaped table located in the centre of the room, so that as soon as you enter the room it is the first thing to be seen, given that the main function of the room and what is most important is the selection of the avatars. After this selector, on the back wall there is the logo screen on which the company that is going to meet inside the room will appear. This would constitute a personalization of the meeting room, which would give a more realistic atmosphere to the room and give visibility to the company in question.

As for the windows, there are two large vertical windows located one on each wall whose function is to bring light into the room and give a feeling of spaciousness. One window would be on the entrance wall itself, and the other would be on the wall to the left in the centre, to provide light strategically and aesthetically.

The seat is a modular corner seat, so that it fulfills the function of comfort, but without taking up too much space in the room, complying with the minimalist aesthetic specified in the design requirements.

As extra elements there is a coat rack and a corner piece of furniture with a coffee pot on it, these are common elements in a meeting room, so they give realism to the room, whose only function would be decorative and to simulate as much as possible a real-life room.

Concept 1.1 is shown in figure 9.

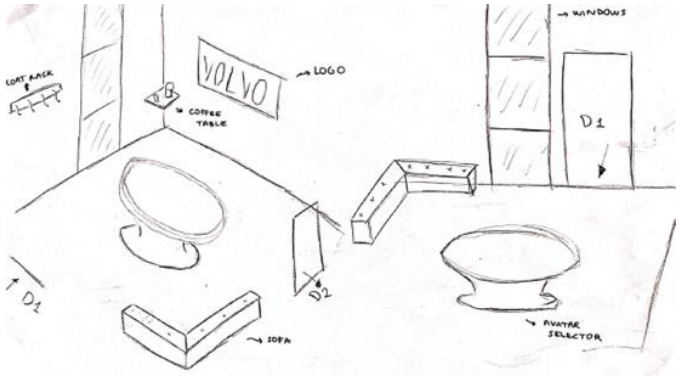

Figure 8: Concept 1.1

Finally, the letters numbered "D1", "D2" and in the following concepts "D3", indicate the entrance to each room, representing the door with D and the numbers 1, 2, and 3 to room 1, room 2, or room 3. This diminutive has been used as clarification as to the perspectives of each concept.

3.1.3.2 Concept 1.2

In the second concept, the layout is similar, but the furniture is completely different.

The avatar's selector is a rectangular table with an inclined base, this being a more modern selector than the previous one, located in the same position.

The seat this time is a circular chair, with a round base and very comfortable, and completely different from the previous concept, as it is a single seat, as well as a somewhat more futuristic theme.

The logo screen remains exactly the same, a rectangular screen on the wall in front of the door indicating the company that will be meeting in the room. To its left, in the corner, there is a minimalist lamp as it is a vertical element with LED lights.

Concept 1.2 is shown in figure 10.

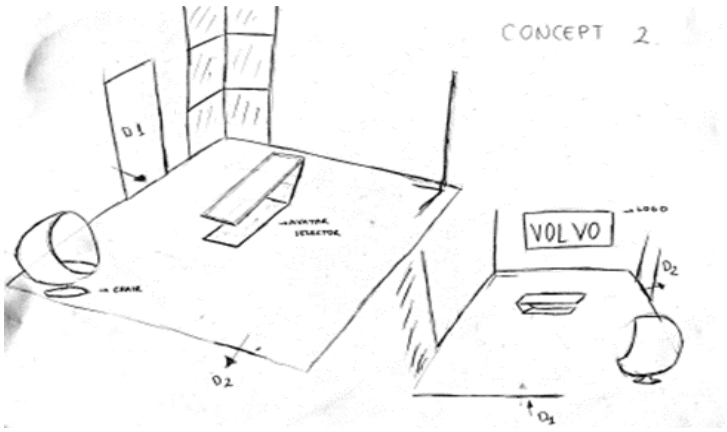

Figure 9: Concept 1.2

Unlike the old concept, the windows are still there, but in this case, they appear cornered, leaving one corner of the room completely transparent.

3.1.3.3 Concept 1.3

The third concept is the most different of the 3, as the avatar selector is a vertical screen placed on the left wall of the room, imitating a mirror, so that the avatar could be seen in real size and thus clarify its choice. As ideas emerged, a more modern and virtual reality approach was taken.

As for the windows, this is also quite a different idea, as they would be located in the ceiling, so that all the daylight would enter directly into the room, obviating the need to apply lights.

On the floor there would be an irregular carpet style as in this case there would be nothing in the centre and for seating there would be two pouffes, which are also quite comfortable and aesthetically pleasing.

The only thing that remains exactly the same in all 3 concepts is the logo display, as the second most important function of room 1 is for companies to have the opportunity to make themselves visible as soon as the participants arrive to the meeting.

Concept 1.3 is shown in figure 11.

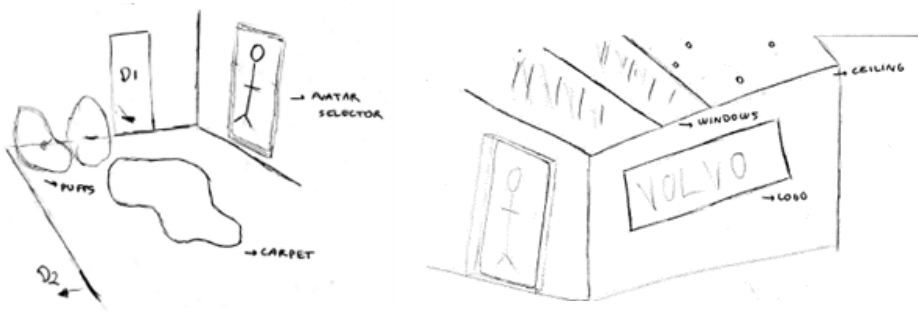

Figure 10: Concept 1.3

3.1.4 Concepts room 2

The function of the second room is to visualise the prototype to be evaluated in the meeting. Therefore, there are 3 very similar concepts and the only thing that changes is the distribution of the furniture. What they have in common are:

- Prototype support
- Tool for seeing visual information
- Tool for real-time note taking

3.1.4.1 Concept 2.1

The first concept has a central rectangular table on which the prototype will be placed so that everyone can see it from all perspectives.

On the back wall there are 2 information screens attached to the wall, on which the plans and regulations of the design can be found, so that it can be observed, and the prototype can be compared with the plans before entering the meeting.

Finally, as soon as you enter on the right, there is a screen with a support, whose function is to write down any comments and then send them to the third room.

There are no windows in this room as any unwanted light can create unnecessary shadows on the prototype.

Concept 2.1 is shown in figure 12.

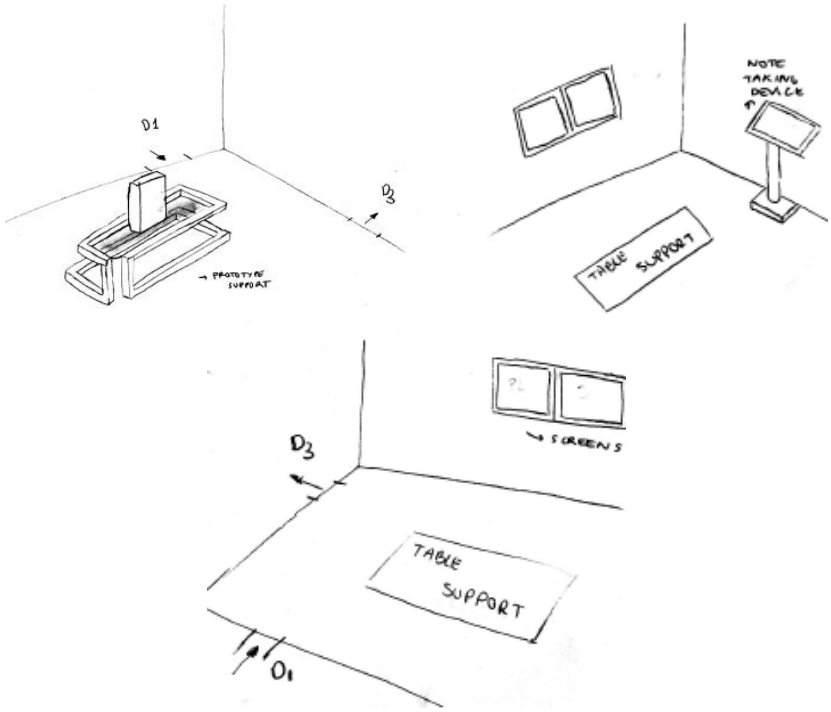

Figure 11: Concept 2.1

3.1.4.2 Concept 2.2

In the second concept, the support table is circular in shape, giving the prototype the same space at every point around it, with greater viewing comfort thanks to the absence of corners on the table.

The information displays are the same as in the previous concept, but in a different location on the left side of the room.

As for the screen with stand, it is placed in front of the door through which you enter the room. This screen has an inclination on the support, it is not completely horizontal, as it is more ergonomic to be able to make notes, as well as being located on a support and not on the wall.

Concept 2.2 is shown in figure 13.

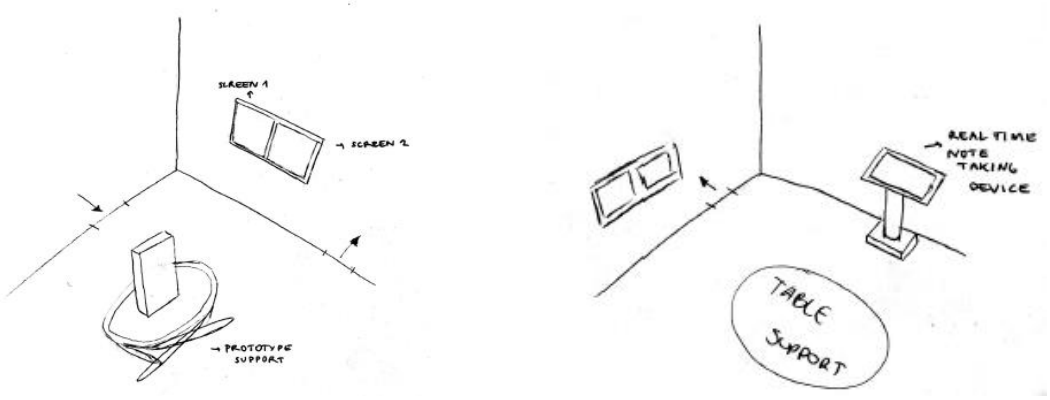

Figure 12: Concept 2.2

3.1.4.3 Concept 2.3

In the last concept shown in figure 14, there is only one informative screen where only the specific and necessary information for a better understanding of the product will be placed.

It is located on the left side of the room, as it is more convenient to capture the client's attention before leaving the prototyping room to find this screen.

The annotation tool in this concept would be a screen with support placed in front of the prototype to be able to have a good observation of it while taking notes.

Finally, the support table has a square shape, as it is a common geometric shape in the rooms (as well as the circle and the rectangle). This table has a lower height than the other two, so that the upper details of the prototype can be better observed.

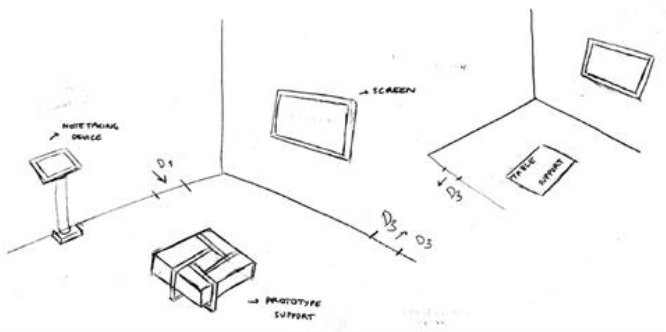

Figure 13: Concept 2.3

3.1.5 Concepts room 3

Finally, the functionality of room 3 is where the design review will take place.

3.1.5.1 Concept 3.1

In this concept the table has an open rectangular shape to facilitate the observation of the person explaining the product in front of the screen, as well as to be the eye-catcher of the room.

In front of the people in the meeting is a screen, whose functionality includes being able to receive and transmit the information processed in room 2. The whiteboard is a tool used for design review feedback, where ideas, questions, criticisms and contributions to the design review can be posted.

Lighting is mainly located at the windows.

Finally, the company logo is again present in the room, as it creates a sense of pride among the employees as well as offering a sign of professionalism.

Concept 3.1 is shown in figure 15.

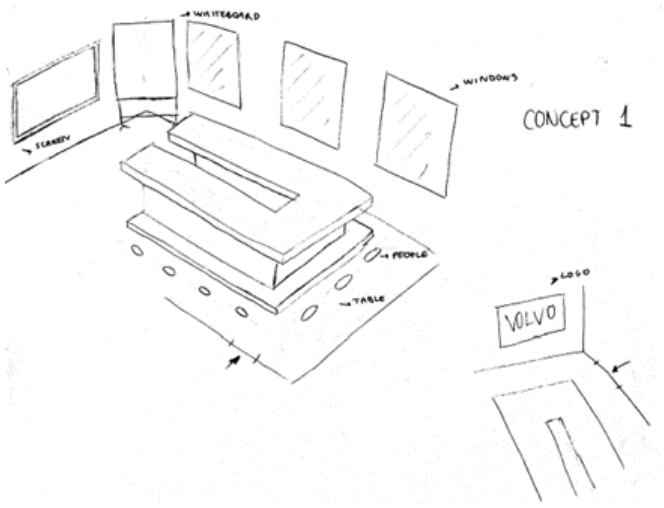

Figure 14: Concept 3.1

3.1.5.2 Concept 3.2

For concept number two, a different type of table was selected to give a greater sense of spaciousness to the room.

The place of the logo has been changed to the front of the table, giving it more prominence in the room, while the screen is placed on the opposite side.

The right wall is completely made of glass, allowing more light into the room as well as a greater sense of spaciousness.

Finally, the blackboard is placed in the front area, next to the company logo, to differentiate the ideas explained on the screen and on the blackboard.

Concept 3.2 is shown in figure 16.

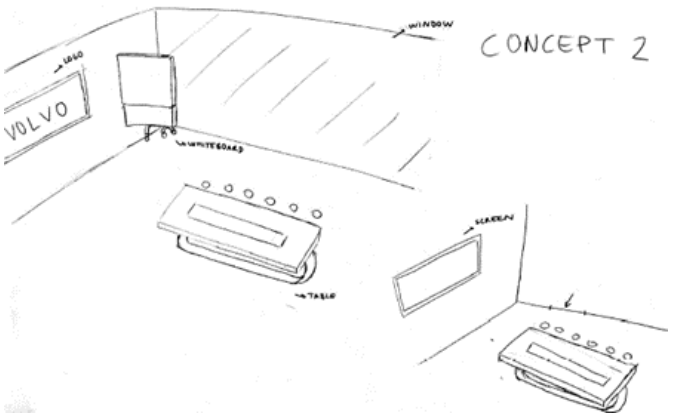

Figure 15: Concept 3.2

3.1.5.3 Concept 3.3

Finally, for concept number 3, a round table was chosen in which the focal point was right in the centre. The only thing that changes is the arrangement of the windows, which become two large windows, bringing light into the room.

In this concept, the logo disappears and instead the blackboard is placed at one end and the screen at the other, in keeping with the minimalist theme.

Concept 3.3 is shown in figure 17

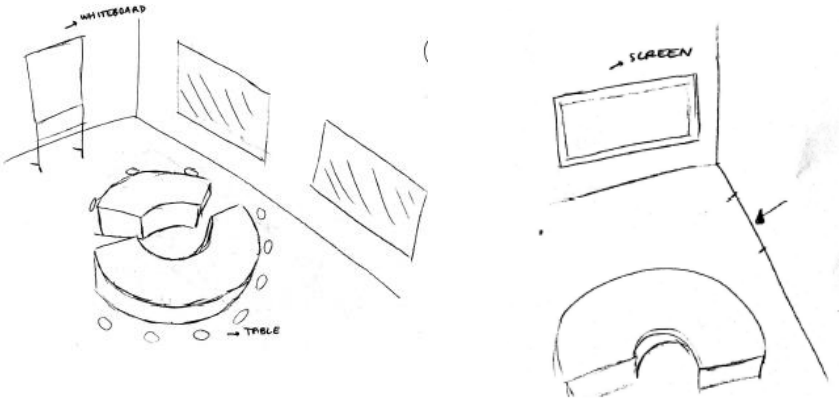

Figure 16: Concept 3.3

3.1.6 Method “635”

After realising the concepts and prior to the concept’s selection, it was decided to go back to the creative phase using the iterativity of the chosen design process, as it was decided to further explore the concept of the virtual environment and to bring a higher degree of virtual reality to it. A new method was used for this, from which another 3 concepts subsequently emerged.

The 635 Method was developed by Bern Rohrbach in 1969 following the assertion that when ideas are picked up by one member of the team and developed by the rest, it is more successful (Schroeer et al., 2010).

It is a brainwriting technique that belongs to the group of progressive methods, generating ideas step by step and iteratively, with constant inspiration from multiple ideas. The 635 Method consists of two steps.

First, six designers develop and write down three ideas in three to five minutes and then pass their ideas to the person next to them. In the case of this final project, this was done between the two designers.

The second step is that each member of the team has to develop ideas from those given through their predecessor, modifying them or developing new inspired ones (Beitz & Pahl, 2007).

This process is repeated until each member is given back their initial sheet of ideas. In this case, to complete the five rounds that would be done in the case of six participants, the process was repeated. Thus, two initial solutions evolved from several different points of view.

The results are presented in the following sections.

3.1.6.1 Concept 4.1

The first room was created by combining the second and the third concept.

For the avatar selector the vertical display of the third concept was chosen, as the best way to choose an avatar that represents you, is to view it vertically with a mirror effect.

As for the windows, the corner ones were the best option, as it gave a feeling of spaciousness to have a practically transparent corner, having the opportunity to be able to see the outside landscape, being inside the room.

To finish with the furniture, on the wall opposite the main entrance door there is a screen with the name of the company on it horizontally, this screen is rectangular in shape to occupy the greatest possible width of the wall. The chair chosen was the circular chair, as its aesthetics are the most suitable for the room, and the one that best combines with the rest of the furniture.

As for the texture and colors of the room, it was decided that all the walls except the one with the company name should have light colors to give a sense of

spaciousness, unlike the last wall, which will have a dark colour, as the screen with the company name is surrounded by white lights, so this screen on a dark wall captures much better the attention of the designers.

The chair is white and red to give a different touch to the room, as all the colors in the room are light or dark.

Concept 4.1 is shown in figure 18.

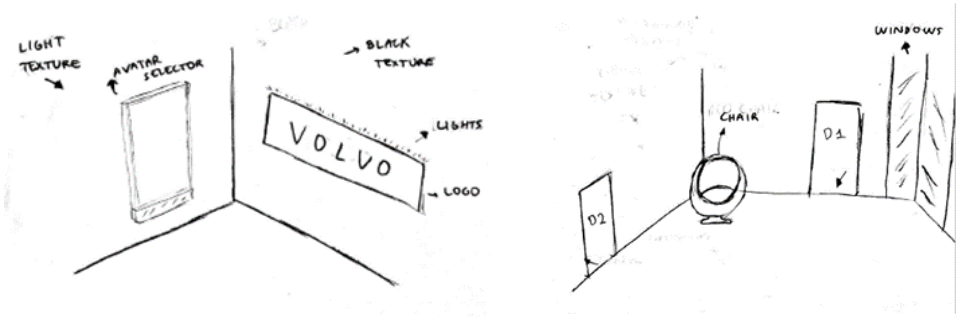

Figure 17: Concept 4.1

3.1.6.2 Concept 4.2

The final concept of the second hall is the most different compared to its former concepts.

All the attention upon entering the room is drawn to the support table, which is circular, with an arc of light illuminating the room but not overly illuminating the prototype, so as to create unnecessary shadows. They simply make the prototype stand out more.

The table has a fairly low base, so the prototype will appear a few centimeters higher than the base of the table, but without colliding with the arc of light. It will appear centred between the base and the arch.

As for the walls, there will also be one wall that is different from the rest. In this room, the different wall will be the one you see as soon as you enter in front of the Gate, it will be a hologram, therefore tactile in its fullness. You can touch any side of the wall and it will display the information you need at the moment.

The rest of the walls will have the same light color as the previous room to maintain a related theme from one room to the next.

Concept 4.2 is shown in figure 19.

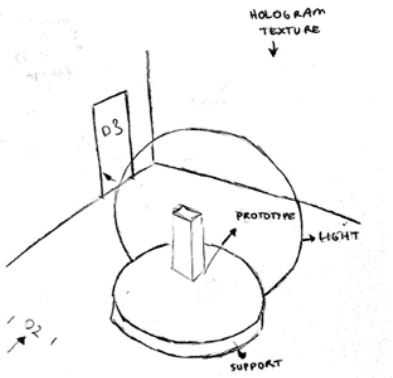

Figure 18: Concept 4.2

3.1.6.3 Concept 4.3

The concept of the third room is similar to concept 2 seen above, as one of the walls is formed by a large window, in this case, it is irregular in shape so that the room feels spacious and free rather than enclosed.

It is also very similar to concept 2 because it has a screen, on which the moderator will explain the review procedure, placed on the wall in the background and directly opposite it another screen with the name of the company, exactly as in the first room.

Finally, the center of the room is dominated by a large, elongated table on which there is a screen at each workstation, which has no support and is completely suspended in the air. And finally, right in the center of the table is a miniature hologram in the shape of the prototype seen in the previous room.

Concept 4.3 is shown in figure 20.

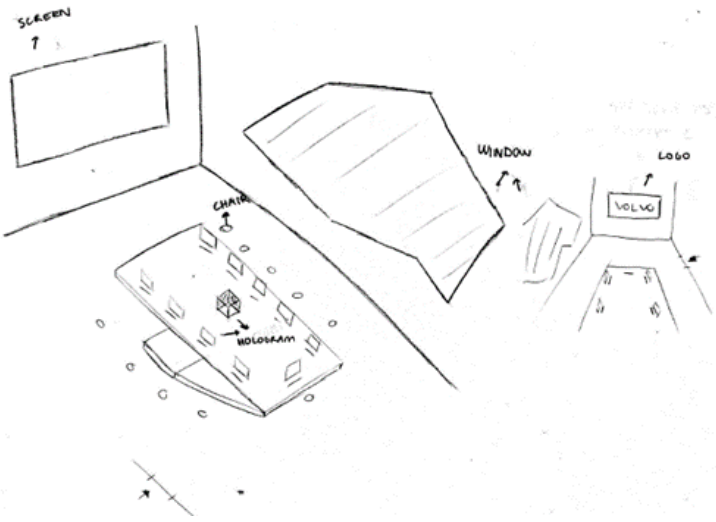

Figure 19: Concept 4.3

3.2 Concept / solution evaluation

In this section the final concepts have been chosen through The Weighted Objectives Method. The concepts have been made in Blender, due to the convenience and the compatible export format to be transferred to Unreal Engine.

3.2.1 The Weighted Objectives Method

The objective of the Weighted Objectives Method is to compare the useful values of the concepts presented, based on the weighting of the objectives in a differentiated form and the result of these (Cross, 2000).

The first step in this method consist in list the design objectives. Since that was covered in the list of requirements, the next procedure is assigning relative numerical weights to the objectives, with the aim of all weights sum 1.0.

The value of one hundred was divided by the factors of the engineering characteristics and different values were assigned depending on the importance considered earlier in the list of requirements. Thus, values such as spaciousness, comfort, visualisation, accessibility and real-time annotation obtained the highest values as they scored highest in the technical specifications.

Rank the various options available depending on how they meet the requirements is the next step. For each concept, it was assessed that from 1 to 10 it fulfilled the requirements. In some cases, as in concept 3, the concepts were very similar, so there are equal values in these concepts.

Finally, each parameter score is multiplied by the performance score of each option.

Comparing and discussing the values is a great design aid rather than choosing the best (Cross, 2000). After comparing the results, the chosen concepts were the ones that obtained the highest scores.

Concept 4.1 won as it scored higher on the factors of spaciousness, minimalism and aesthetics. This is because instead of having a selector cabinet like its competitors, it was attached to the wall, giving a greater sense of space and contributing to the desired minimalist theme.

As for the 4.2 concept, the prototype's support was more attractive and better lit. Also, the elimination of screens, leaving only a wall as a hologram, is a fact that allows a better visualization of the desired information.

Finally, the 4.3 concept was chosen as it had a more futuristic table, an aesthetic more in line with the desired theme and a greater sense of virtual reality, far above the other three concepts.

The results of the concepts selection can be seen in Appendix D.

3.2.2 Blender

Blender was used to model the concepts in CAD format, to give them more detail and shape.

There are several techniques for translating CAD data into virtual reality. Architects technologies such as the Geometric Description Language (GDL) described 3: a library approach, simple translation and database approach (Whyte, 2002).

In this case, it was decided to model the areas in CAD for convenience and export them directly to Unreal, so a simple translation was used. Since Unreal Engine supports this type of export and it is a fast process, creating a library or a database was bordering on being unnecessarily complicated.

The VR medium establishes a detailed representation. However, the representation of an object is not a replica, but its equivalent in terms of structure in a specific medium (Whyte, 2002).

In the following sections 3.2.3, 3.2.4, and 3.2.5, the final concept of each room is shown in CAD format for more visual results. However, the design of the building structure and the rooms had to be extended as there was a dimensional problem at the beginning. This problem was easily solved by redesigning the rooms and increasing their dimensions, so the new redesign of the building structure and rooms can be seen in section 3.2.6.

3.2.3 Room 1

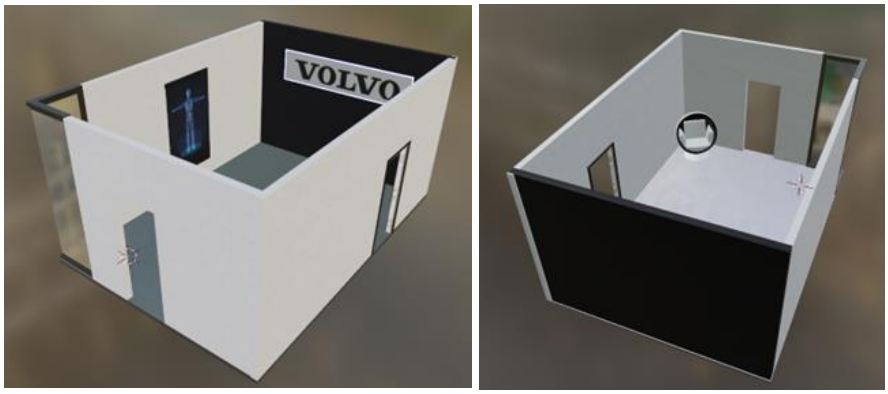

Figure 20: Selected concept room 1

This section provides an explanation of the rendering of the first room of this thesis.

Upon looking around the room shown in figure 21, the black wall with the "Volvo" display immediately draws attention. The wall is painted in this colour to maximize the emphasis on the company name.

The remaining walls are kept light in colour. This contrasts with the black wall, as the colours and shapes of the furniture inside already make a statement, and there is no need to draw attention to the walls' colours.

The furniture has black and white colours that are consistent with the line of neutral colours. The change of colour of the chair is due to the fact that the chair does not perform a job significant enough to draw all attention.

The avatar selector displays a human body in the shape of a cross, implying that this is where users should choose their avatar.

3.2.4 Room 2

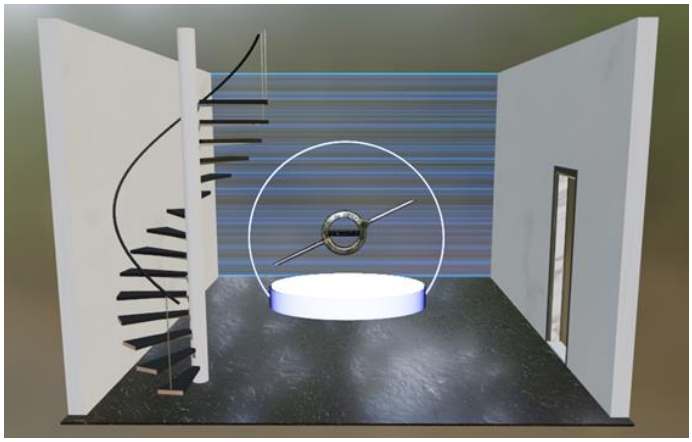

Figure 21: Selected concept room 2

The second room, depicted in figure 22, is exceptionally minimalist as it entirely meets the technical requirements, having solely the prototype stand as furniture. In this instance, the Volvo emblem has been selected as an exemplary prototype.

The walls are white, not requiring any embellishment. However, one of them forms a complete hologram, and by touching any area on it, consumers can discover the requisite information about the prototype, regardless of its location.

The floor has been modified to black to emphasise the white base of the prototype, as this is the primary purpose of the second room.

In contrast to all previous design ideas, which had rooms connected via a door, it was ultimately decided to have room 2 access room 3 through a staircase, placing room 3 on the floor above.

The decision was made based on the space that three rooms would take up on the ground floor and the space they currently occupy on the first floor. The building's structure is more efficient now, as the upstairs room is large and comfortable enough for all review participants to gather.

3.2.5 Room 3

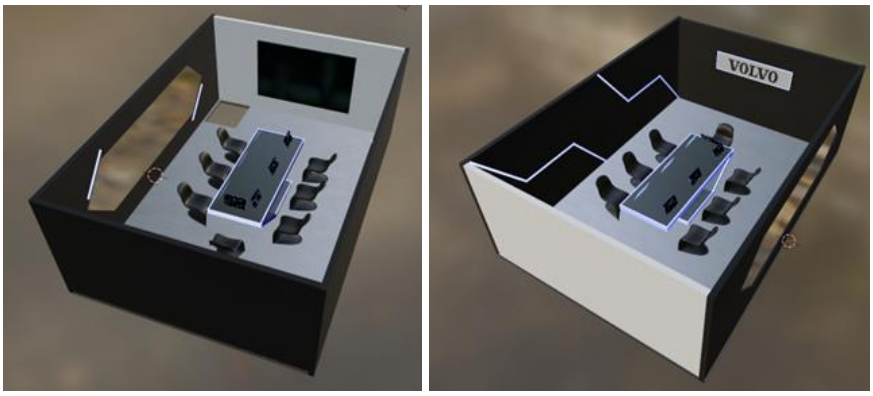

Figure 22: Selected concept room 3

Upon entering room 3, a working atmosphere is immediately apparent. The black and white colour scheme of the room conveys a sense of seriousness and professionalism, which is also reflected in the company logo. Figure 23 displays room 3.

The table is of utmost importance in the room as its primary function is to perform a design review. The spawning points surrounding it indicate the placement of avatars. Moreover, a screen has been placed in front of it to project the information required for the design review.

The lighting in the rooms comprises of several LED lights placed on the window, table, spawning points and logo that create both a futuristic and realistic ambiance, conforming to the technical specifications regarding the room aesthetics. Furthermore, the natural light entering through the window provides a sense of spaciousness to the room, which is also a requirement as per the engineering specifications.

3.2.6 New design

Figure 23: New concepts

The latest building structure still consists of two floors and three separate rooms, and these rooms have the same functions as in the previous design. The main distinction between the two designs is the restructuring of the rooms and an increase in their dimensions.

Room 1 has doubled in width. This was made possible by relocating room 2 and providing it with room 1's prior position. Although an additional window was installed at the opposite end and the door is centered to improve symmetry and balance, aesthetics remained intact.

The second room has undergone most of the changes. Nonetheless, its functions, as well as the aesthetic concepts, remain the same as before. The width of this room matches that of the other rooms, but its length has been extended by more than fifty percent of the length of rooms 1 and 3. The height of this room is equal to the combined height of the other two rooms to provide a feeling of spaciousness and openness.

The old prototype, featuring the Volvo symbol, has been positioned on the top part of the wall for the customer's clear vision upon entering room 3. This has been carried out to project professionalism and seriousness, similarly to rooms 1 and 3. The present prototype is a company-branded car. It has been installed on a novel, customised platform distinctive for every prototype. This room is larger than the previous design and can accommodate a larger prototype.

Access to room 3 remains unchanged from the previous design, with a simple staircase, while the hologram has been relocated due to lighting issues. Locating the hologram behind the prototype would have resulted in unnecessary shadows and confusion, therefore, it was decided to place it beside the prototype instead.

Lastly, room 3 has undergone the least change, maintaining the same dimensions, aesthetics, and functions. The only distinction is that the entry to this room is through a staircase linking room 2 to room 3, placed to the left of the latter, on the opposite side of the previously used corridor.

3.3 Further development / detailed design

This chapter explains aspects related to the implementation of the concepts in the Unreal Engine. First, the different ways to move in the virtual space are covered in section 3.3.1. Then, the menu of functions that each participant is provided with will be explained in detail. The special functions of the moderator are the last concept explained in this chapter.

3.3.1 Commands for movement

This section explains how to move around the rooms. The different options available in Unreal Engine are flying, walking, rotating, and virtual reality, as shown in figure 25.

Figure 24: Commands for movement

3.3.1.1 Flying

In this mode with the paper airplane icon, you walk with the arrow keys at the bottom right of the keyboard, which allows you to move forward, backward, and sideways, and with the help of the mouse buttons you can rotate the perspective you want at any time. The remarkable thing about this mode is that if you choose a perspective towards the upper area, you can go to that area by "flying" and going through the walls.

3.3.1.2 Walking

The second command that appears is for walking. With this command, you move in the same way as in the previous mode, using the keys and the mouse, but the difference is that in this mode you are automatically at a natural height, that is, you walk on the ground, without being separated from it at any time and without the possibility of going through walls, imitating reality as if you were in the real world. In addition, the appearance looks like the shadow of the person's avatar.

3.3.1.3 Rotating

The Rotating command lets you move through virtual space using only the computer mouse. The right and middle buttons are used to change and rotate the perspective, and the mouse wheel is used to move forwards and backwards. The operation is similar to that of any CAD programme.

3.3.1.4 Virtual Reality

This controller requires virtual reality goggles and controllers. It is fully immersive, with the feeling of being inside the room and being able to walk around it as if it were real. In this mode you do not use the keyboard, as it only allows you to move forwards and backwards, but you cannot rotate your environment or perspective in any way to walk around the rooms, making the mouse completely useless.

3.3.2 Participants functions

At the beginning of this project, it was decided to create tools that would improve virtual design reviews, such as the ability to take notes in real time, or the implementation of a moderator who would have special functions and lead the design review. Using the Unreal Engine program, there is a menu that covers several of these functions, so the only thing that needed to be implemented as a new functionality was the moderator functions, which are explained in the following section. This section explains the participant functions contained in the viewer menu.

The Viewer menu is the menu that every participant in the meeting would be able to use in Unreal Engine 5. It contains useful tools for design review, such as the ability to take notes in real time or to export 3D models as prototypes. It is available to each user as soon as they enter the virtual space and is activated by pressing the space bar in semi-immersive mode with screen and keyboard, and by pressing the viewer menu button in virtual reality mode. The menu can be seen in figure 26.

Figure 25: Viewer menu

3.3.2.1 Transform

This command has three options. The first option is to be able to move the objects in any direction, the second option is to reset any unwanted movements and the last option is to reset all movements as if this option had never been pressed.

3.3.2.2 Annotation

Drawing on the screen, recording audio or writing and deleting text are functions implemented in this command. Depending on what the customer is most comfortable with, they can use any form of simple note taking.

3.3.2.3 Snapshot

This function allows you to take screenshots of any scene. When you press the option, a grid appears to help you frame the image and centre it. Simply press anywhere on the screen to take a screenshot. One thing to remember is that the screenshots are always saved under the same name, so if you want to take different screenshots, you must change their names at the same time, otherwise these images will disappear.

3.3.2.4 Xray

The function of this mode is that, for each object or wall selected once inside the room, you can remove the material and texture they have at that moment, leaving a texture of grey and black squares, which has already been implemented in the Unreal Engine.

3.3.2.5 Measurement

This mode allows you to measure the selected objects to know their real size within the program, and there is also the option to change the measurements from centimeters to meters, as you wish.

3.3.2.6 Scale

This mode allows you to maximise and minimise the size of any selected object. It is a quick and easy way to change the dimensions of any object without having to modify the entire object.

3.3.2.7 Bookmark

This command allows you to save any scene with a name and to save several scenes. When you press this option, a folder will be opened in which all the saved scenes will be displayed, so that you can access any of them at any time.

3.3.2.8 3D cut volume

Unlike scaling mode, which changes the dimensions of an object without modifying it, this method allows you to modify any 3D model by cutting it and dividing it into two parts, or by adding a new part to an object. This tool is used to modify 3D models as well as to add or cut them.

3.3.2.9 Data smith

Datasmith is used to import any CAD object into an Unreal Engine. There are more ways to import into this program, but all of them are without starting it, once the program is started, the only way to import an object is with Datasmith.

3.3.3 Moderator functions

The special functions are covered by the moderator, who has access to different functions throughout the meeting that other people do not have access to, because it would be chaotic if everyone had access to all the functions at the same time.

The decision to have only one moderator depends on the number of people in the meeting. In the case of 12 or 15 people, the option of having 2 moderators instead of 1 would be feasible, as it would be easier to divide their tasks and coordinate to run the meeting.

For a design review meeting with a maximum of 7 or 8 people, it is more efficient to have a single moderator who can run the meeting alone.

One of the main functions of the moderator is to start and run the whole meeting. One person must oversee the steering of the meeting towards effective and productive outcomes, following and marking all guidelines along the way.

Another important feature is the spawning point, which allows the moderator to start the meeting at the most appropriate time. At the touch of a button, everyone

in the building will be teleported to their chosen location, saving time waiting for each other.

Finally, at the end of the meeting, a feedback framework is used to evaluate the meeting, comment on what went well during the meeting, criticise the meeting, ask questions that arose after the meeting, and suggest new solutions. All these steps are guided by the moderator, who organises and controls the time of each activity so that it is dynamic and does not become monotonous.

3.4 Final evaluation

3.4.1 User test

To perform the user tests, the Think Aloud technique (Monsalve et al., 2023) was applied, which makes participants verbally express their thoughts and reactions while performing a task. The aim is to analyze a person's cognitive processes and identify their behavior.

In order to carry out this method, it was initially intended that each participant would be fitted with Metaquest 2 glasses so that they could virtually place themselves in each room and react as they walked through them. However, due to technical problems in connecting the glasses to the programme, it was not possible to carry out the method in this way. Therefore, another efficient option was for each participant to use a computer as a means of accessing each of the rooms and giving their opinion on them.

Once each participant's user test was completed, they were asked a series of questions related to the design specifications, which they had to answer with a yes or no answer.

The general results from the first room are quite similar for each participant, as almost all participants agree that the requirements of the design specifications are met and that it is easy to find the selector and enter the room.. Results of the user test can be seen in table 5, 6 and 7.

Table 4: User test room 1

Requirements	User 1	User 2	User 3	User 4	User 5
Enter the room	Yes	Yes	Yes	No	Yes
Find selector	Yes	Yes	Yes	Yes	Yes
Spacious	Yes	Yes	No	No	Yes

Minimalist	No	Yes	Yes	Yes	No
Comfortable	Yes	Yes	Yes	No	Yes
Accesibility	Yes	Yes	Yes	Yes	Yes

In the case of the results obtained in the second room, the opinions of the participants were also mostly the same, except for one: when it came to climbing the stairs, some had more difficulty because it was more complicated than walking on a flat floor. They considered it to be totally minimalist and accessible, two of the requirements mentioned in the design specifications.

Table 5: User test room 2

Requirements	**User 1**	**User 2**	**User 3**	**User 4**	**User 5**
Enter the room	Yes	Yes	Yes	Yes	Yes
Find prototype	Yes	Yes	Yes	Yes	Yes
Up the stairs	No	No	Yes	No	Yes
Spacious	Yes	No	Yes	Yes	Yes
Minimalist	Yes	Yes	Yes	Yes	Yes
Comfortable	Yes	Yes	Yes	No	No
Accesibility	Yes	Yes	Yes	Yes	Yes

Finally, the results obtained in the third room are more varied, since 2 out of 5 participants had problems entering the room because they found it difficult to get in via the stairs. Two participants found it more difficult to move around the room because the meeting table was in the middle of the room, an element not present in the other rooms, and therefore these same participants felt that it was not spacious. This is the user test with the greatest variation of the 3 tests carried out.

Table 6: User test room 3

Requirements	User 1	User 2	User 3	User 4	User 5
Enter the room	No	No	Yes	Yes	Yes
Go to the spawn point	Yes	Yes	Yes	No	Yes
Find screen	Yes	Yes	Yes	Yes	Yes
Move in space	Yes	No	No	Yes	Yes
Spacious	Yes	No	No	Yes	Yes
Minimalist	No	Yes	Yes	No	Yes
Comfortable	Yes	Yes	Yes	Yes	No
Accesibility	No	No	Yes	Yes	Yes

3.4.2 Final result

This section describes the concepts integrated in Unreal Engine, as well as the conceptual functions of each room. Renderings and explanations of the rooms are included in this chapter.

A new approach to virtual space design has been made with a wider range of literature on virtual space design. This literature can be found in section 2.1.4.2.

The most noticeable change is an increase in the dimensions of rooms 1 and 2, with room 3 now being of a size that allows any vehicle to be included for review.

3.4.3 Landscape and exterior of the building

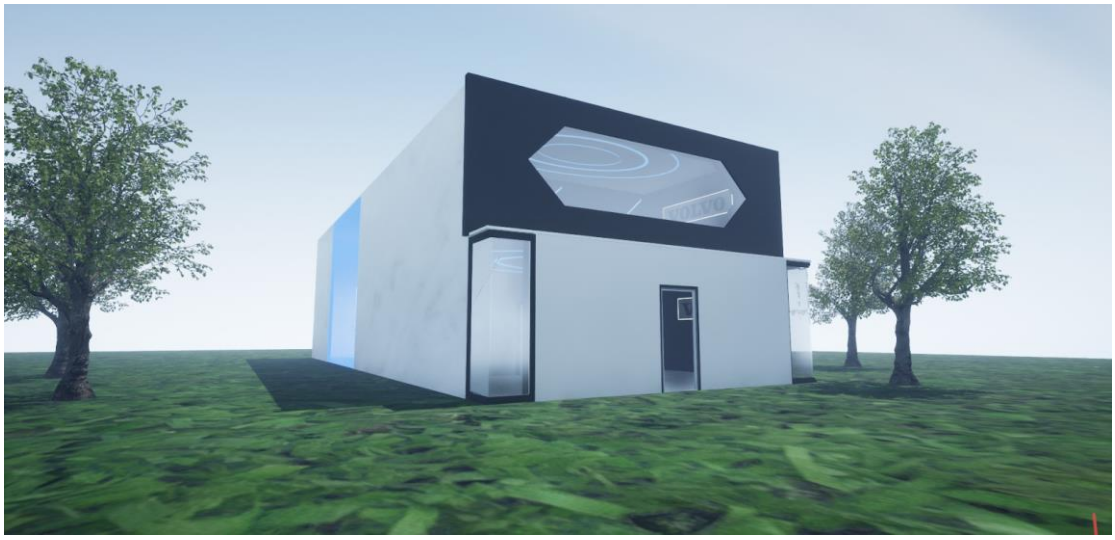

Figure 26: Exterior of the building

A simple landscape of grass and trees was chosen for the exterior of the building. There is no better natural lighting than the sun and overall it is a visually pleasing landscape that is not overloaded with elements and does not distract from the main objective of the design review inside the building. The exterior of the building and the landscape can be seen in Figure 27.

The exterior has square and rectangular shapes that fit together, as does the building, which is also rectangular, as it was more appropriate for the interior and functionality of the building.

In terms of colour, black and white have been used, as trying lighter colours was not very aesthetic and the interior of the rooms hardly stood out.

3.4.4 Room 1

Figure 27: Room 1

The first room, shown in Figure 28, has the minimalist theme required in the specification. It consists of a single fundamental element, the avatar selector, which is represented by a blue human with arms in the shape of a cross on a black background, to distinguish it from any other screen in the building.

Upon entering room 1, another element, located to the right of the room, captures the attention of people entering the room: the company logo, which represents the seriousness and professionalism of the company. In this case, the name Volvo appears, as an example of one of the companies for which this project is being carried out, so in each of the rooms there is something related to this company.

As furniture, there is only a circular chair in one of the corners, in front of the entrance door. The chair is white on the outside, as are the cushions, and the inside is black, to better match the aesthetics of the room. The function of the chair is purely decorative since as it is virtual reality, the avatars do not need to sit or rest.

However, as it represents a room, it is a very common decorative element. To see the chair in detail, it is shown in Appendix F.

To have visible access to the outside and therefore a greater sense of spaciousness and luminosity, large windows have been placed in the lateral corners of the main door, whose function is to make both corners completely transparent, having a total visibility of the outside landscape.

The fact of placing the windows together and in the corners and not separated is to give a feeling of spaciousness and even freedom as if the whole building lacked windows, it would be oppressive and distressing. The only room in which it has been decided not to place windows is the second room but for a specific purpose.

Finally, the lighting in the room is provided, in addition to the brightness from outside, by four oval lights of progressive size placed in the centre of the ceiling. They are modern luminaires, which fit perfectly with the theme, leaving behind the option and possibility of placing typical lamps hanging from the ceiling. The choice of these lights is a step beyond normality.

As for the materials in the room, we have chosen to make the room 70% white, using white marble as the texture, as the selector is dark, so the white walls make it stand out.

The only wall that is different from the rest is on the right side of the room and is a dark, opaque black colour that contrasts with the rest of the walls. The explanation for this colour is based on the fact that the company logo is placed on the wall, which is a white painting with white neon lights around it, which illuminate the painting itself, so that if the wall were white, like the rest, it would not stand out or capture the customer's attention as much as it does now, with a dark background.

The colour used for both the ceiling and the floor is white, a colour that is used in all three rooms. It shares the same objective as the other colours used in the building, to give spaciousness to each area.

As already mentioned, the neon lights that illuminate the logo on the dark wall are white. In contrast to these, the lights that illuminate the room, located at the top of the room, are blue, to give the room a hint of colour.

3.4.5 Room 2

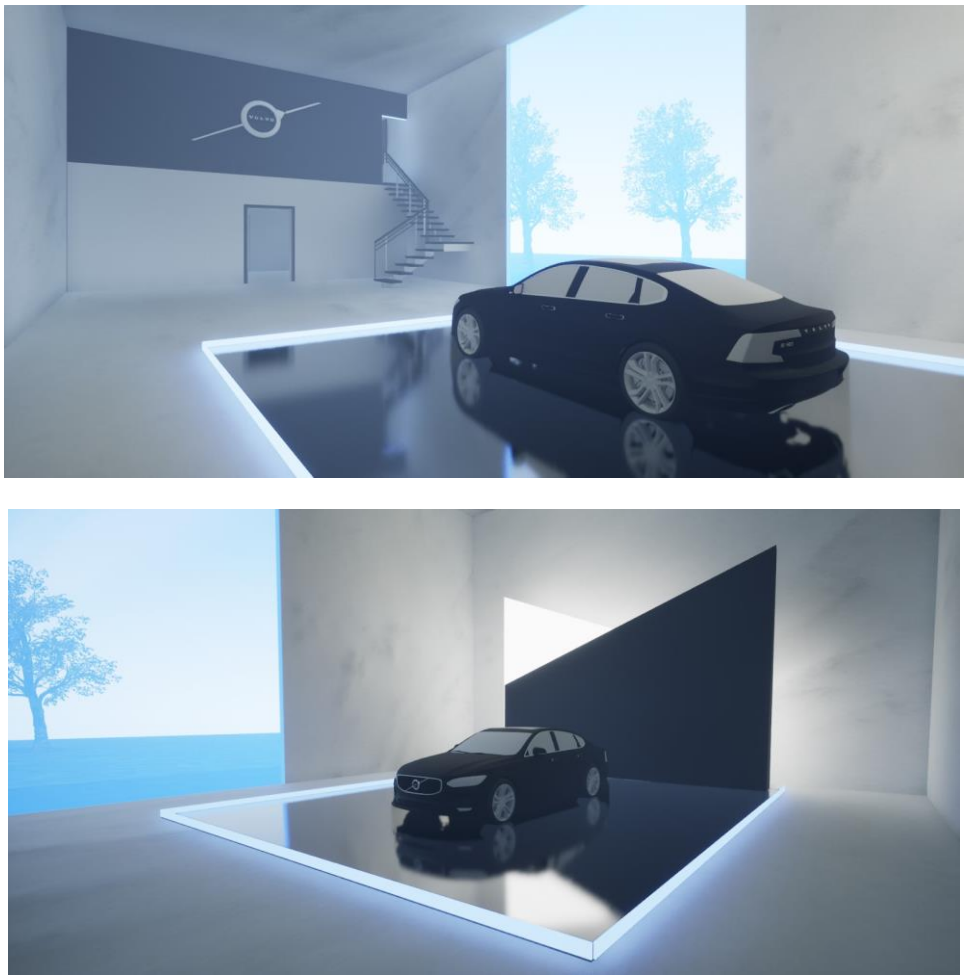

Figure 28: Room 2

Access to room 2 is from room 1, which has a door parallel to the main door, linking the two rooms.

The function of the second room is to observe the prototype, therefore, when entering, the most prominent element in the room is the stand on which the prototype is placed. Room 2 can be seen in Figure 29.

This stand is composed of 2 parts, the first one is a rectangular base in metallic black colour, with the function that any object or element is reflected in it giving the sensation of elegance. This base has white neon lights on its sides to illuminate it and make it stand out inside the room.

The second part is at the back of the stand and is an irregularly shaped wall with pointed ends, which is in turn divided into two parts. The larger part, directly behind the prototype, is matt black to highlight only the prototype in front of it, and the second part, the smaller part, the upper right corner, is used as lighting with white neon lights, just like the lights on the base. This colour combination attracts the customer's attention as they enter the room and also gives a sense of modernity, elegance, professionalism and seriousness.

As mentioned above, in each room there is an element related to the Volvo company; in this room the company is represented by a car with its symbol, which is used as an example of a prototype. In addition, in the upper part of the wall through which the room is accessed, the company's symbol appears in large format.

Due to the large dimensions of the room, other elements related to Volvo could be used as prototypes, such as trucks, buses, and different driving vehicles. As for the prototype support, it can be enlarged or minimized, adapting to the dimensions of any prototype.

In order to display all the information about the prototype, there is a hologram in the centre of the left wall of the room, which, in addition to the information, also displays the specifications and regulations for the prototype, simply by touching any point on the wall. As it is a hologram, you can also see the outside, not as clearly as if it were a window, but you can see the outside elements.

The reason for making the holographic wall smaller than the entire wall of the room is to allow for natural lighting, as there are no windows so the room is not completely enclosed, but without excessive lighting so as not to create unnecessary shadows that could confuse the prototype.

As for the staircase, the style has changed from the previous sketches, as it was previously decided to use a spiral staircase as it took up less space in the room, giving a sense of spaciousness and minimalism at the same time. However, by repositioning the elements, it was decided that a simpler staircase would be more in keeping with the established theme. It is also straightforward to climb, regardless of the mode in which the avatars traverse the room. Of the four modes available (walking, flying, spinning and VR goggles), only walking mode allows you to climb stairs in a realistic way; the other three modes allow you to float up the stairs.

Finally, unlike rooms 1 and 3, this room does not require oval lights on the ceiling, as the hologram and the neon lights on the stand provide sufficient illumination.

3.4.6 Room 3

Figure 29: Room 3

Room 3, shown in Figure 30, is where the design review takes place. It is accessed via the stairs in Room 2.

Upon entering, a futuristic-themed table occupies the center of the room, in black and white tones that reflect minimalism and modernism. Surrounding it are conceptually implemented generation points, places that each member of the design review will occupy as it begins. They have neon blue tones and change color, with the function of highlighting and denoting the interactivity of standing at them.

The first thing you see when you go upstairs is the screen that will support the design review, which is an essential element of the room as it allows the necessary information to be projected, as well as the participants' comments and the exchange of information with the screen in room 2, avoiding the need to move from one room to another and the subsequent deconcentration of the participants if this were to happen.

Opposite is the company logo, whose function is to give the meeting a sense of seriousness, but also to make the employees feel proud to be part of the company and to give them a sense of being together at the forefront of a project. It has been lit around the edges to make it stand out even more.

On the walls there is a modern shaped window that gives the room a futuristic touch and is the main lighting element, allowing the sun's rays to enter and illuminate the room. It also has the dual function of creating a sense of space by providing a view of the landscape outside.

On the opposite wall, linear panels bring light and minimalist decoration to the room, avoiding an overload of elements and giving the room a more aesthetic appearance.

Finally, the luminaires in room 3 have the same oval shape as those in room 1. Their neon lighting contrasts with the dark tones of the walls, which have been carefully chosen so that the neon tones highlight each element in the room.

3.4.7 Reflections

To make an assessment on this project, it is necessary to compare the final result with the specification table in section 2.3. The demand requirements have all been met, i.e. the rooms have large dimensions and windows that fulfil the required feeling of space. In addition, the rooms have been divided into one for each specific function and a good visualisation of the prototype and the necessary information for a design review has been achieved. Although it was originally intended to have a greater flow of information from one room to another, a screen in room 2 that transmits information to the screen in room 3 is sufficient, as the ability to take notes in real time is inherent to each participant once they are in the meeting.

Accessibility is also covered by the different ways of moving around the rooms - there are not one or two, but four, including the possibility, requested in the initial requirements, of connecting to the room using a 2D screen and keyboard, as well as virtual reality glasses.

Wishes such as the aesthetics of the room have also been met, as well as the sense of minimalism that is present, given the small amount of furniture and filling that the rooms have, there being just enough for each room to fulfil its specific function, and nothing beyond that that would distract from the aim of a design review.

Finally, the special functions and the moderator are the only wishes that have been explained conceptually, given the complexity of implementing them in Unreal Engine, and are a future improvement that is perfectly feasible in line with the results of this thesis.

4 DISCUSSION AND CONCLUSION

4.1 Discussion

Designing a 3D virtual space design project is a challenging task as it is not a common project in a design engineering degree. Considerable time was spent in identifying the design method to be followed for the design of a virtual space when making the technical specifications, which could have been used in starting the literature review earlier.

As for the technical specifications, it was a long process of reiteration, and until the brainstorming step and the creation of concepts, it was not finished defining and subdividing them into functional, cognitive, and emotional requirements.

To bring another improvement to the project, the sketches could have been made at a higher level of detail, as more importance has been given to having enough concepts from which to draw the final solution than to the level of detail of these.

If time had been taken away from this task, it would have been added to retouching the sketches.

In the concept section it was necessary to go back in time to bring more virtual reality nuance to the concepts, as initially following the specifications provided by the user studies, it was too realistic in tone and left little to explore of the concept of being immersed in virtual reality, i.e. with screens, tables, chairs, etc. Therefore, due to the ease of iteration of the chosen design process, a new brainstorming technique was used and concepts were created exploring much broader possibilities that would encompass a closer resemblance to virtual spaces. In the 635 method it would have been more useful to have six people instead of just two, as twice as many ideas and therefore thrice as many concepts would have been developed.

Given the amount of time spent on choosing the final concepts for the rooms due to the complexity of the project, the implementation of the designs from Blender to Unreal Engine could not be done earlier, which could have led to a final revision in time in search of an improvement of the rooms. Regardless of the time available, the rooms were included in a modular form, i.e. piece by piece, so that a designer could modify the room to his or her liking. This is a step forward, however, if more time had been available, the room would have been implemented in a fixed form as well and both options would have been available. Another area that could have been improved if more time had been available would have been the placement of the walls. As the rooms are modular, placing the walls is an increased difficulty as it is more tough to place them and gives rise to a greater margin of error.

Finally, an earlier implementation of virtual reality goggles for user testing from the very first moment in order to improve the rooms could have been done. The rooms could have been improved if they had been tested on the users iteratively and their needs had been better analysed. This could have been done if a longer period of time had been available and more time had been devoted to the implementation phase of the rooms.

4.1.1 Sustainability in the virtual space

In the current context, sustainability and environmental protection are fundamental aspects to consider in any industrial design and product development project. Aware of this responsibility, this section aims to highlight the sustainable aspects that address the design of a 3D virtual space for design review using Oculus MetaQuest 2 goggles and Unreal Engine 5 software.

- **Reduced consumption of physical resources:** By moving design reviews to a virtual environment, the need to build physical prototypes is avoided, which implies a significant reduction in the consumption of materials and natural resources. By minimizing the use of raw materials, the environmental impact associated with the extraction, production and transportation of these materials, as well as the generation of waste, is reduced (Luttropp & Lagerstedt, 2006).

- **Energy savings:** The use of a 3D virtual space for design reviews means lower energy consumption compared to traditional methods. Instead of lighting and air conditioning of physical spaces, the virtual representation requires only electrical energy to power the visualization devices. In addition, efficient use of computing resources and software optimization contribute to minimizing energy consumption during project execution (Misra et al., s. f.). While the project seeks to save energy compared to traditional methods of design reviews, it is still necessary to consider the energy consumption associated with the use of virtual reality devices and the operation of the software. Prolonged use of the MetaQuest 2 goggles and the graphics processing required by Unreal Engine 5 may require a significant amount of electrical power, which could contribute to increased consumption of natural resources and carbon emissions, depending on the power source used (Abdlkarim et al., 2023). As the design reviews are of short duration, this problem will not necessarily occur.

- **Reduced carbon emissions:** By avoiding physical travel for design reviews, the emission of greenhouse gases associated with transportation, such as carbon dioxide (CO2), is reduced. This contributes to mitigating climate change and improving air quality in urban areas by reducing emissions of other pollutants related to fossil fuel combustion (Robinson et al., 2018).

- **Remote and global collaboration:** By offering the ability to conduct design reviews virtually, collaboration between people in different geographic locations is facilitated without the need to travel. This not only reduces the carbon footprint of travel, but also encourages inclusion and diversity in the design team by eliminating physical and geographic barriers. Also, remote collaboration can reduce product development times, optimizing resources and increasing efficiency (Luttropp & Lagerstedt, 2006).

- **Reuse and extended life cycle:** Through the use of a 3D virtual space, the reuse and extended life cycle of products is promoted. By avoiding the need to manufacture multiple physical prototypes, the waste generated is reduced and the useful life of the resources used in production is extended. In addition, by utilizing existing virtual reality technology, such as Oculus' MetaQuest 2 goggles and Unreal Engine 5 software, it takes advantage of technological advances and avoids premature obsolescence. On the other hand, the need to have virtual reality glasses and a laptop to access this room is a fact that makes this project less sustainable. However, nowadays companies provide these tools to their employees to ensure the highest quality and adaptation to new technologies. Therefore, not all companies could use this room, but only high-end companies willing to invest in improving the quality of their design department.

In summary, designing a 3D virtual space for design reviews using Oculus MetaQuest 2 goggles and Unreal Engine 5 software has numerous environmentally sustainable aspects. From reducing the consumption of physical resources and energy, to reducing carbon emissions and promoting remote collaboration, this project contributes to a more responsible and environmentally conscious approach, helping to preserve the environment for future generations.

4.2 Conclusion

Finally, a guide has been produced that explains the steps required to develop a virtual 3D space for design reviews. It can be used by companies or organisations.

Virtual room development guide for design reviews

1. **Define the objectives of the virtual space:**

   Before starting the development, it is important to have clarity about the objectives of the virtual space. What types of design reviews will be conducted? What elements and features will be necessary to facilitate these reviews? This will help establish the foundations for designing and developing the space.

2. **Determine the rooms and their functionality:**

   The virtual space will consist of three areas: the avatar selector and company logo room, the product support area with a holographic screen displaying product information, and the design review room with a table and a screen. Each room should have a clearly defined function and provide the necessary tools for design reviews.

3. **Design the avatar selector and company logo room:**

   This room will serve as the starting point for users. It should include an avatar selector that allows participants to choose their virtual representation. Additionally, the company logo should be displayed to reinforce the brand identity.

4. **Develop the product support area:**

   This room should feature a virtual support where the product to be analyzed can be placed. A 3D visualization system can be implemented to allow participants to examine the product from different angles. Furthermore, a holographic screen can be added to display relevant information about the product, such as technical specifications or standout features.

5. **Create the design review room:**

   This room is the main space where the design review will take place. It should include a virtual table where participants can stand around it to be all in one place and concentrate on the review. Additionally, a virtual screen should be

provided to display and discuss the design in detail. This screen can support annotations and markings to facilitate communication during the review.

6. **Integrate interactions and functionalities:**

To enhance the user experience, additional interactions and functionalities can be added. For example, a moderator can be put in place to run the meeting. Measurement or object manipulation tools can also be included to make adjustments and conduct tests during the review, as well as for real-time note-taking.

7. **Optimize accessibility:**

Accessibility should be considered, ensuring that the space is compatible with different devices and platforms.

8. **Conduct testing and gather feedback:**

Before finalizing the development, testing of the virtual space is important. This will help ensure that the space meets the requirements of design reviews and provides a satisfactory experience.

9. **Iterate and improve:**

Based on the test results and feedback received, make iterations and improvements to enhance the virtual space.

5 RECOMMENDATIONS

Due to the limited time available and the fact that this is a new project in the field of final year projects at the University of Skövde, this project has several possibilities for improvement.

To begin with, all the conceptual functions described in this project could be developed. The avatar selector in the first room would be possible to implement. Also, the hologram in room 2 could be programmed to display the product data and specifications, and communication with room 3 would be possible. Furthermore, the moderator functions could be implemented, making it possible to spawn from one chosen point to another. The spawning of room three could also be made, as well as the display of information on the screen.

All these functions and more can be developed in the future by going into more detail in the programming field of Unreal Engine, a field that due to lack of time and knowledge has not yet been entered in depth, only for the creation of materials.

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APPENDICES

Appendix A

Interview and questionnaire

First interview

A total of 5 people were interviewed including: two design engineers, a PhD student in virtual reality, an automatic and electronic engineer, and an industrial engineer to answer questions related to the aesthetics and functions of the room.

Step 1

In step 1, each person was asked if their answers could be recorded.

Step 2

Explaining the final project was the second step.

Step 3

Step 3 was an unnecessary step. It consisted of explaining a previous idea about the layout and functions of the rooms, so the next step, asking questions, were closed questions about the previously discussed layout and functions. The idea explained was as follows:

- **Room 1**: Common area where people arrive and where avatars will be chosen.
- **Room 2**: Room for analyzing the prototype. It includes:
    - Support for the prototype.
    - A tool like a whiteboard to insert visual information, comments, and search for regulations or manuals.
    - A tool for writing in real-time.
    - A tool like a table to insert drawings.
- **Room 3:** Room for correcting issues of the prototype and gathering feedback about the design review. It includes:
    - Feedback framework with ideas, criticisms, questions and improvements for the next design review.

Step 4

The following questions were then asked:

1. Do you like the structure of the rooms? Would you change something or add more?

2. How important do you think it is for the room to have a theme: futuristic, non-themed, realistic, design room?

3. What is your opinion on the devices that we plan to include such as taking notes in real time or sending information from one room to another?

4. Do you consider useful the possibility of giving feedback about the design review?

5. Is there something that you miss and would like to see implemented in the rooms?

6. Do you think it would be useful to implement ARKIO software in the rooms?

After the interviews, the results were summed up and drafted as a list of requirements.

- Making separated rooms inside the virtual space for the tasks of choosing an avatar, seeing the prototype, and having the meeting.
- Making spacious rooms.
- The theme of the rooms should be realistic but inspirational.
- Have a minimalistic aesthetic.
- Have the possibility of taking notes in real time.
- Have the possibility of seeing visual information of the prototype and send it between rooms.
- Have a moderator with special functions.
- Have the possibility of seeing people´s comments.
- Have the possibility of giving feedback on the design review.

First questionnaire

After the interview, users were asked to respond to a questionnaire designed to measure their needs in more concrete terms. The way their results were obtained was through yes/no questions, development questions to justify the choice of a previous question, multiple choice questions, and, finally, questions in which they had to rate a particular feature between 1 and 5, with 1 being a very low score and 5 being a very high score.

The complete questionnaire with answers is explained below:

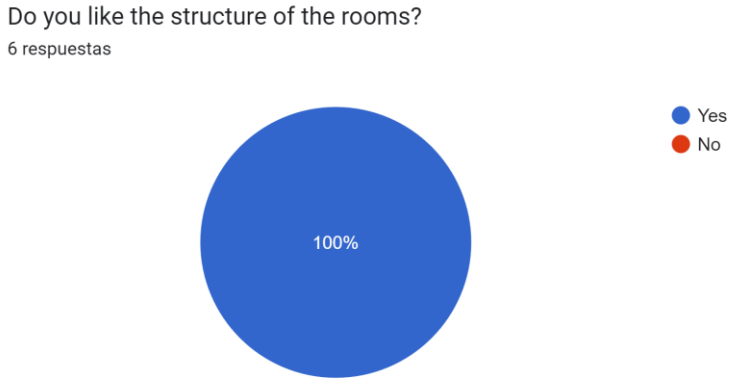


Figure 30: Question 1

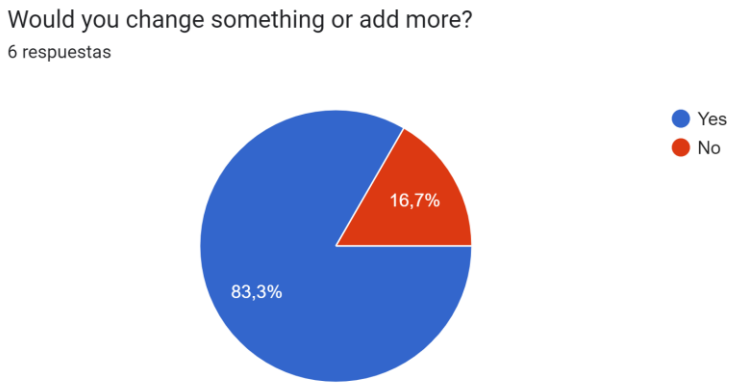


Figure 31: Question 2

As shown in figure 31, for the first question, all users agreed that different rooms should be available for each phase. Regarding figure 32 and 33, 83.3% of users said that they wouldn't change the structure, and the rest gave their own ideas.

Figure 32: Question 3

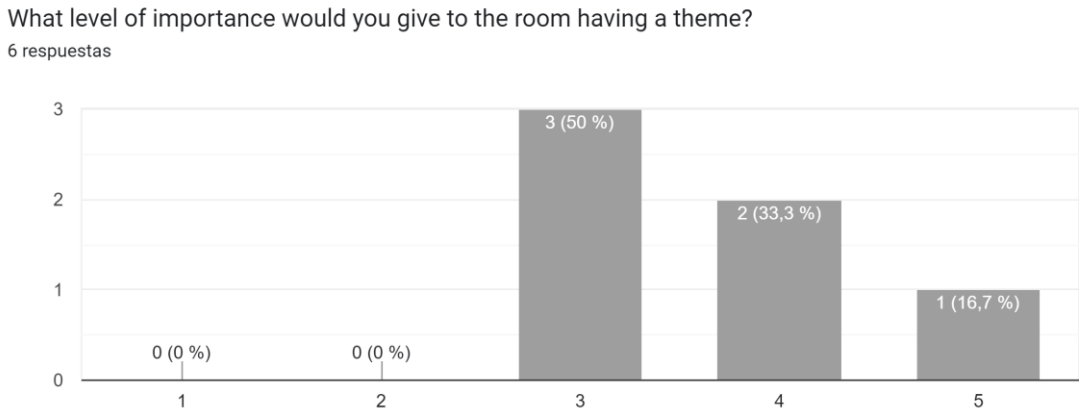


Figure 33: Question 4

In figure 34 the level of importance of having a theme from 1 to 5 was asked, winning the 3 level.

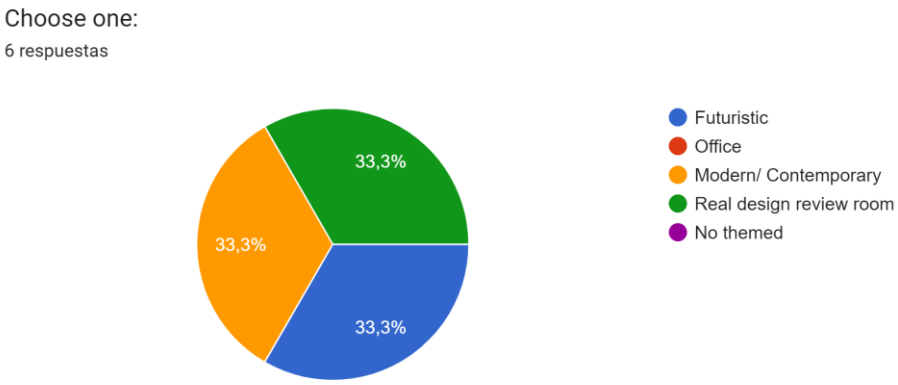


Figure 34: Question 5

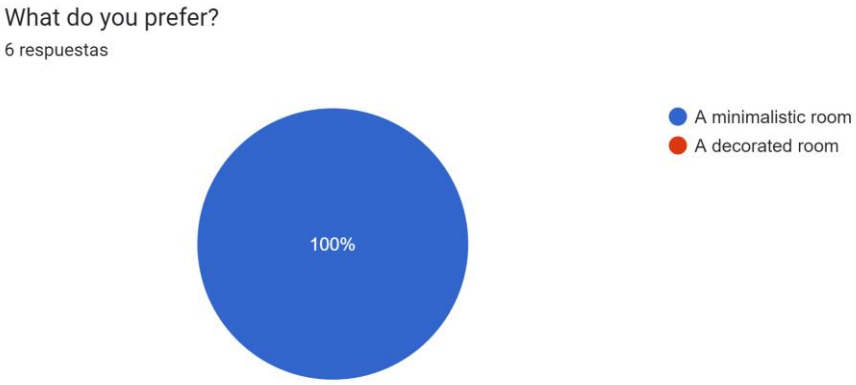


Figure 35: Question 6

Questions regarding the theme of the rooms were asked in figures 35 and 36. 50% of the users placed high importance on the room having a theme, with a tie between the modern, real design room and futuristic. 100% of users agreed that it should be minimalist so as not to lose the focus of the design review, shown in figure 35.

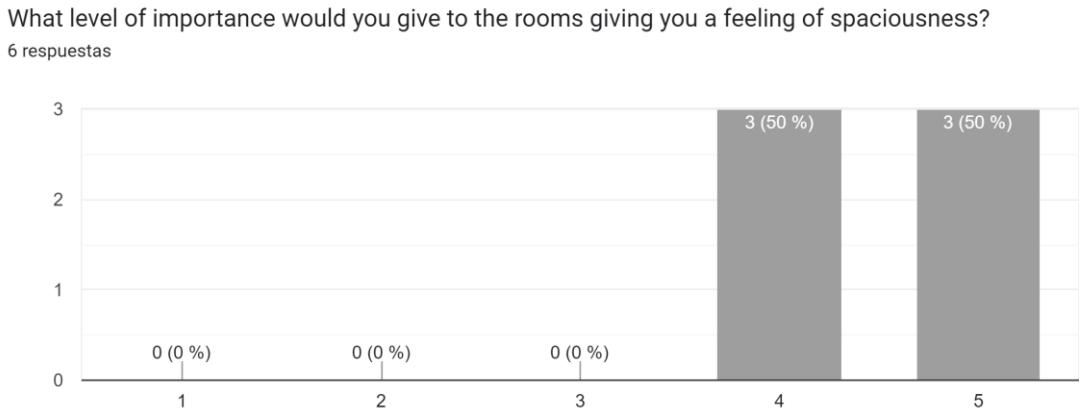


Figure 36: Question 7

Figure 37: Question 8

As for the level of space in figure 38, all users gave a high score to the attribute of spaciousness. Having separated rooms for each task was given a high score too, shown in figure 38.

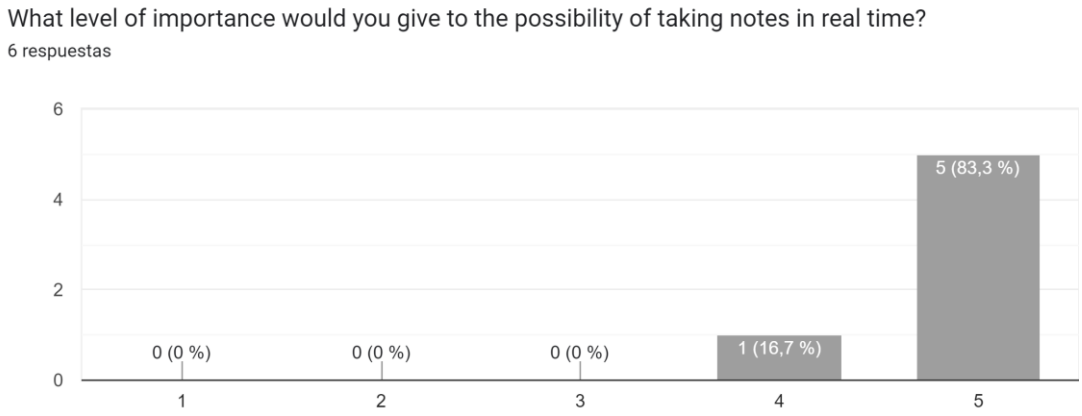


Figure 38: Question 9

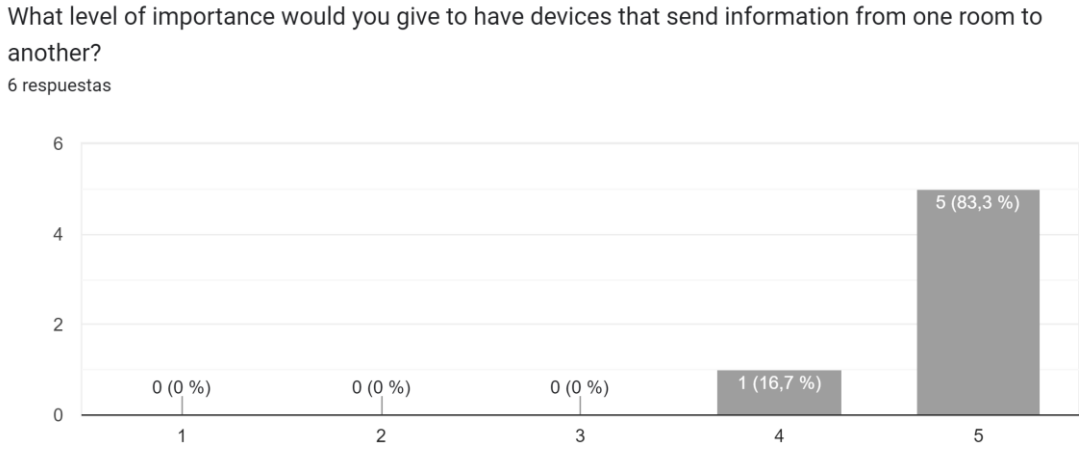


Figure 39: Question 10

In terms of the room's functionalities, asked in questions 9 and 10, 83.3% of users voted that the ability to take notes in real time and to view the information needed for a design review (such as plans, specifications) as well as being able to send it from one room to another was of vital importance.

What level of importance would you give to the possibility to give feedback on the design review?

6 respuestas

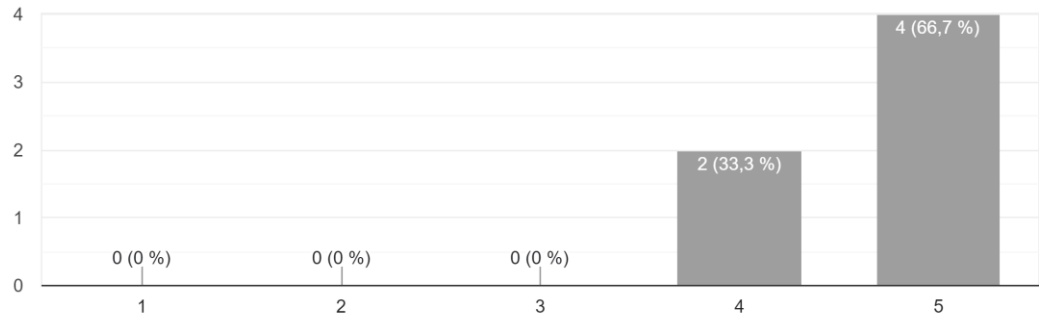


Figure 40: Question 11

What level of importance would you give to have a moderator who guides the participants and has special functions?

6 respuestas

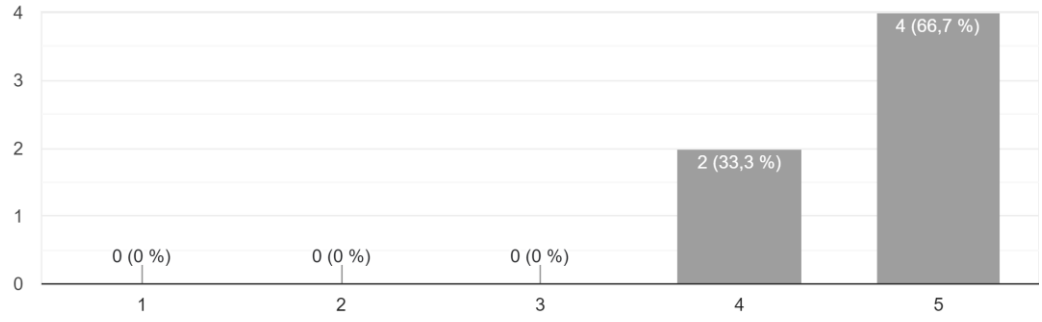


Figure 41: Question 12

What level of importance would you give to the possibility of seen the participant's comments in a device such as whiteboard?

6 respuestas

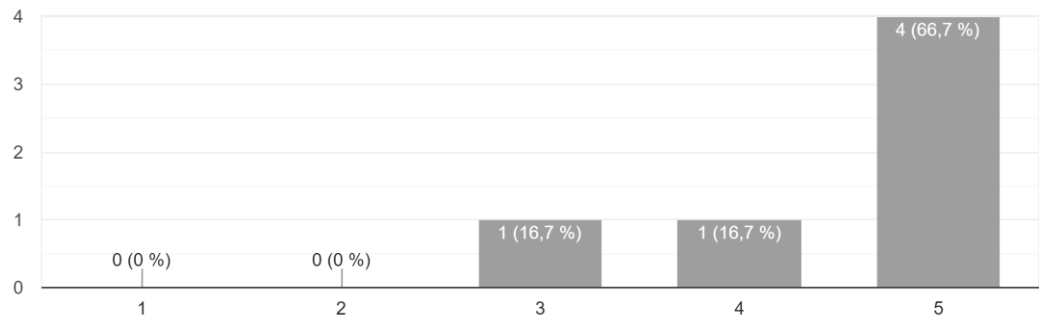


Figure 42: Question 13

66.7% gave a high level of importance to being able to give feedback on the design review and to be able to see the participants' comments. Finally, all agreed on the role of a moderator to guide the participants and to have special function. This can be seen in figures 41, 42 and 43.

Appendix B

Objective Tree

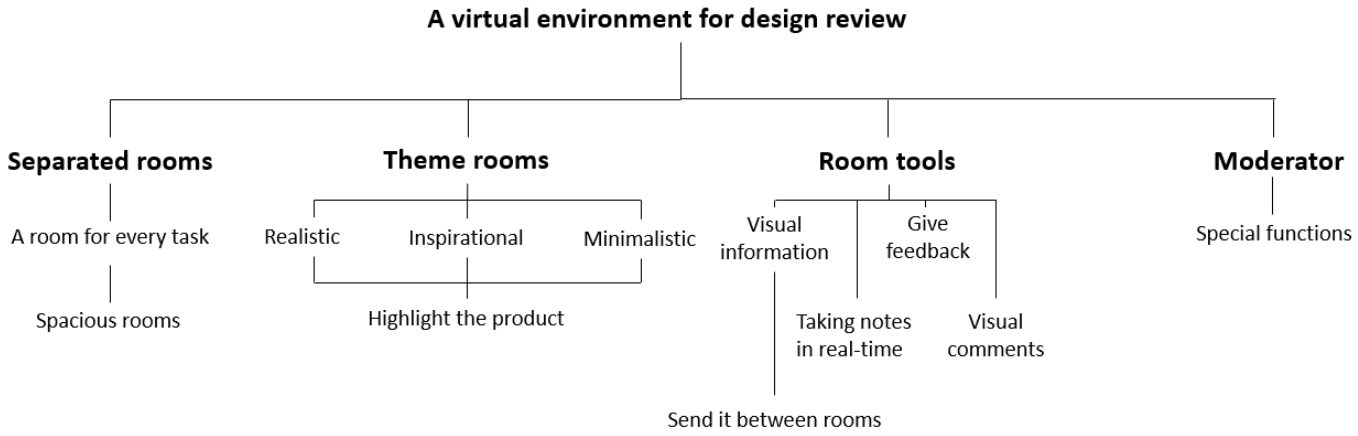


Figure 43: Objective Tree

Appendix C

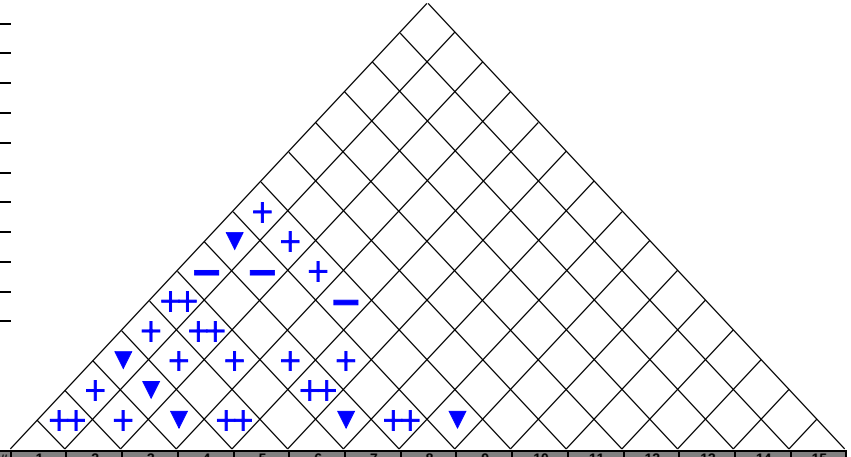
QFD Matrix

Title: _____

Author: _____

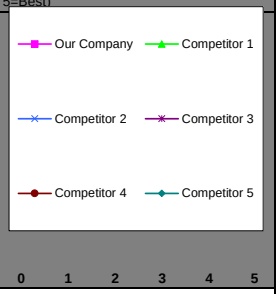
Date: _____

Notes: _____



Legend		
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
X	Objective Is To Hit Target	

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	1 Rooms with large dimensions	2 Few furniture	3 Separated rooms	4 Visualization from any points	5 Placing devices	6 Be able to move	7 Special functions	8 Real-time note taking	9 Themed rooms	10	11	12	13	14	15	Our Company	Competitor 1	Competitor 2	Competitor 3	Competitor 4	Competitor 5
				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15						
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)			▲		▲		▼		▼							**Competitive Analysis** (0=Worst, 5=Best)					
1	9	11,2	9,0	Spacious	Θ	Θ	O	▲	O	Θ	▲		O												
2	9	8,7	7,0	Minimalist	Θ	Θ	▲	▲	Θ	▲	▲		Θ												
3	9	11,2	9,0	Comfortable	O	Θ	Θ	O	Θ	O			▲												
4	9	12,4	10,0	Visualization				Θ	Θ		O	▲													
5	9	12,4	10,0	Accessible	O		O			Θ															
6	9	10,6	8,5	One moderator					▲		Θ	O													
7	9	12,4	10,0	Annotation							Θ	Θ													
8	9	8,7	7,0	Aesthetic	Θ	Θ	▲		O				Θ												
9	9	12,4	10,0	Good communication between rooms			Θ	▲	Θ	O	O	▲													
10																									
				Target or Limit Value																					
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)																					
				Max Relationship Value in Column	9	9	9	9	9	9	9	9	9												
				Weight / Importance	328,0	357,8	300,6	177,6	472,7	291,9	301,2	168,3	201,2												
				Relative Weight	12,6	13,8	11,6	6,8	18,2	11,2	11,6	6,5	7,7												



Appendix D

Morphological chart

Table 7: Possible sub-solutions

AS1	Smart mirror selector	S1	Double screen with support
AS2	Smart table 1	S2	Wall-mounted screen
AS3	Smart table 2	W1	Wall-mounted whiteboard
AS4	Screen selector	W2	Blackboard with mobile support
CL1	Square screen	W3	Blackboard with support
CL2	Stand with screen	W4	Blackboard on wheels
CL3	Rectangular screen	T1	Round conference table
PS1	Low modern table	T2	Modern conference table
PS2	Modern table	T3	Open rectangular conference table
PS3	Modern table 2		

AS: Avatar Selector

CL: Companie´s logo

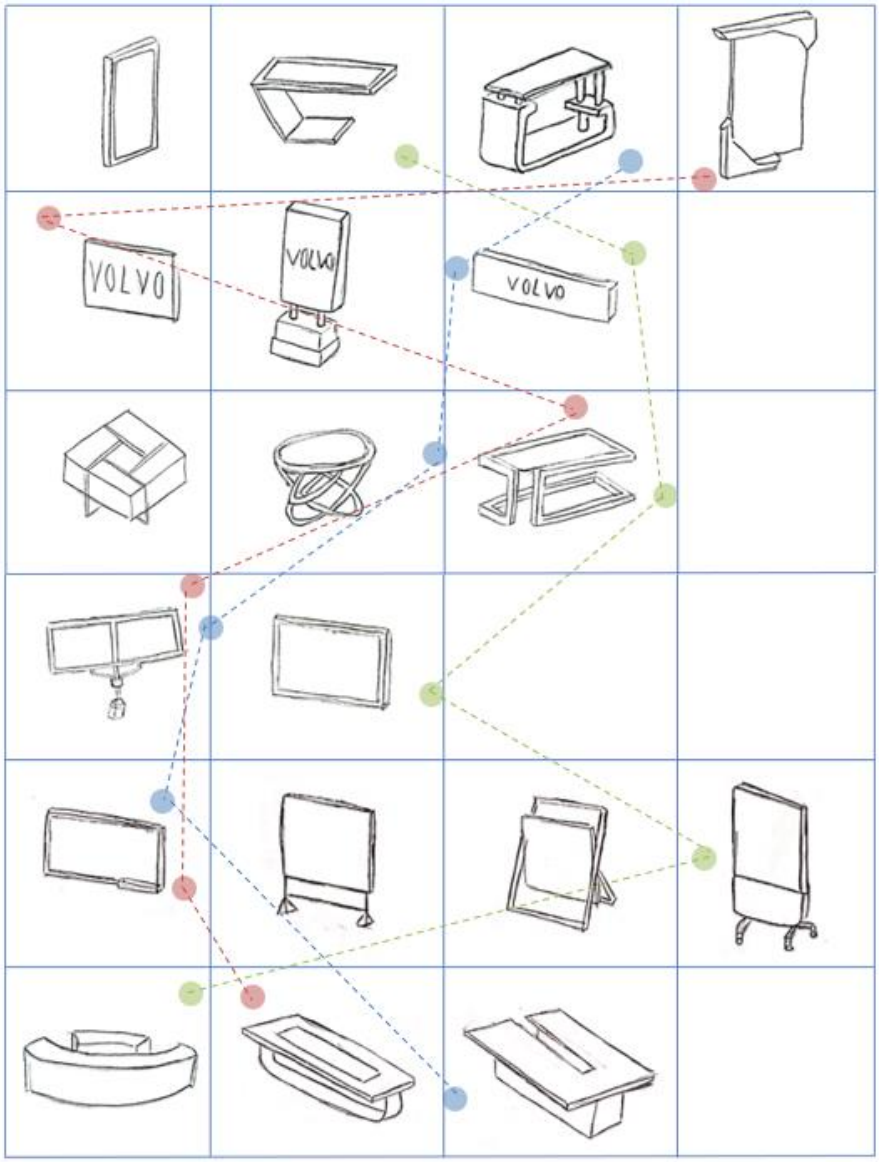
PS: Prototype support

S: Screen

W: Whiteboard

T: Table

Table 8: Morphological chart



Concept 1	
Concept 2	
Concept 3	

Appendix E

The Weighted Objectives Method

Table 9: Concept selection room 1

Factors	Relative Weight (%)	Concepts room 1			
		1	**2**	**3**	**4**
Spacious	12	7	8	9	10
Minimalist	10	5	9	7	9
Comfortable	12	8	6	8	7
Visualization	12	9	8	6	6
Accesibility	12	10	10	10	10
One moderator	9	x	x	x	x
Annotation	12	5	5	5	5
Aesthetic	9	8	8	7	9
Good communication	12	5	5	5	5
TOTAL SCORE		6,5	6,66	6,49	6,87

Table 10: Concept selection room 2

Factors	Relative Weight (%)	Concepts room 2			
		1	**2**	**3**	**4**
Spacious	12	9	9	9	10
Minimalist	10	7	7	8	9
Comfortable	12	7	7	7	7
Visualization	12	8	8	8	9
Accesibility	12	10	10	10	10
One moderator	9	x	x	x	x
Annotation	12	9	9	9	9
Aesthetic	9	7	5	6	8
Good communication	12	10	10	10	10
TOTAL SCORE		7,69	7,51	7,7	8,22

Table 11: Concept selection room 3

Factors	Relative Weight (%)	Concepts room 3			
		1	**2**	**3**	**4**
Spacious	12	6	9	5	7
Minimalist	10	6	7	6	7
Comfortable	12	7	7	6	8
Visualization	12	8	6	7	10
Accesibility	12	10	10	10	10
One moderator	9	9	9	9	9
Annotation	12	7	7	7	9
Aesthetic	9	7	8	7	9
Good communication	12	10	10	10	10
TOTAL SCORE		7,8	8,11	7,44	8,8

Appendix E

Detail renders of the first rooms

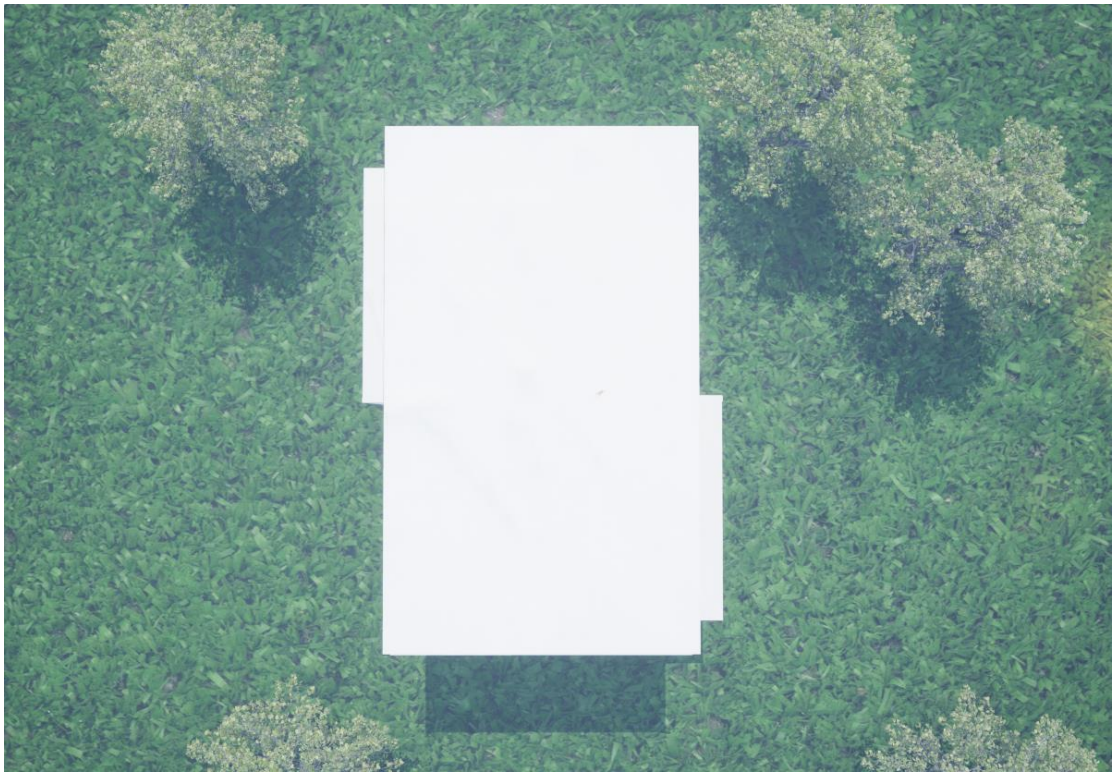


Figure 44: Detail render 1

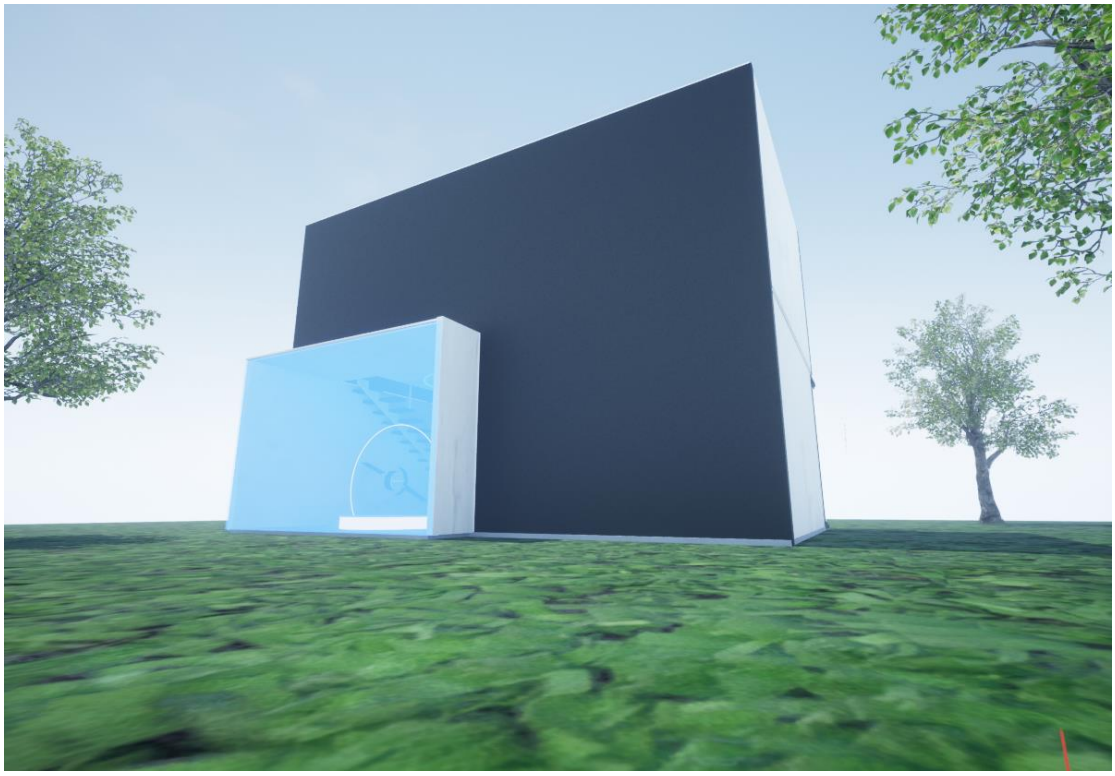


Figure 45: Detail render 2

Figure 46: Detail render 3

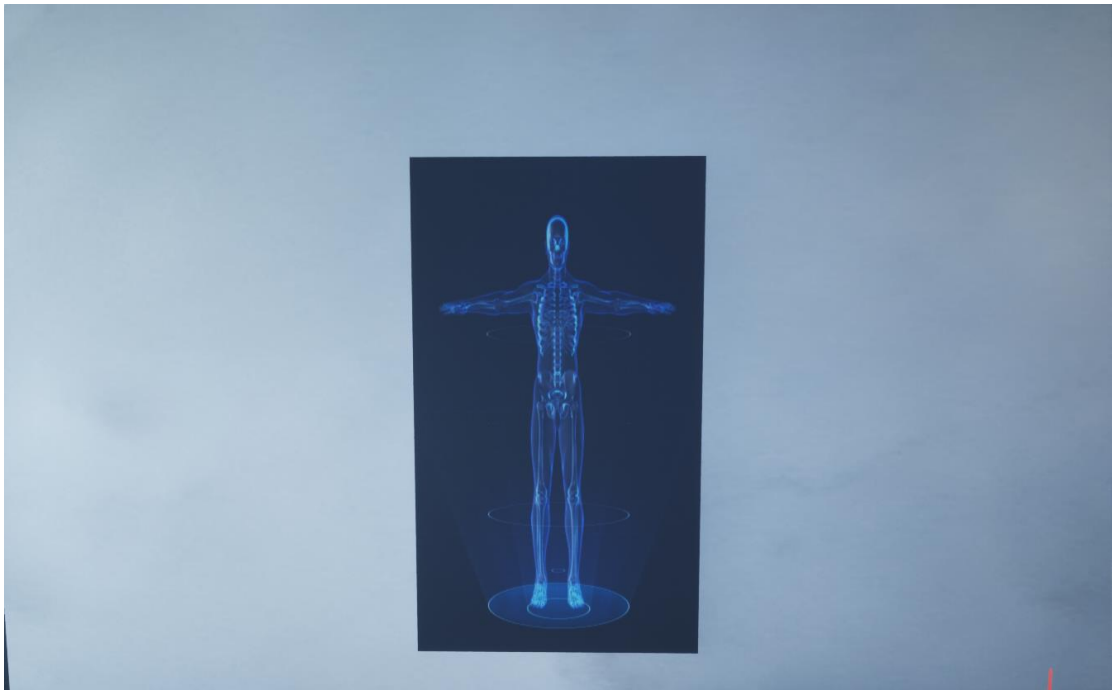


Figure 47: Detail render 4

Figure 48: Detail render 5

Figure 49: Detail render 6

Figure 50: Detail render 7

Figure 51: Detail render 8

Figure 52: Detail render 9

Figure 53: Detail render 10

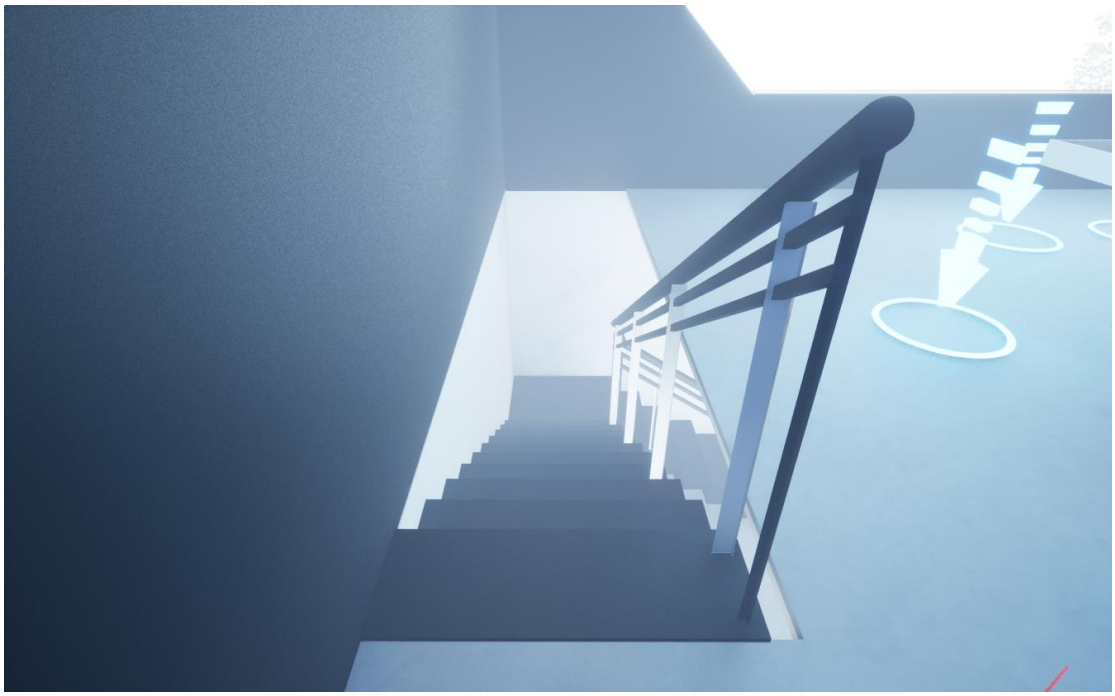


Figure 54: Detail render 11

Figure 55: Detail render 12

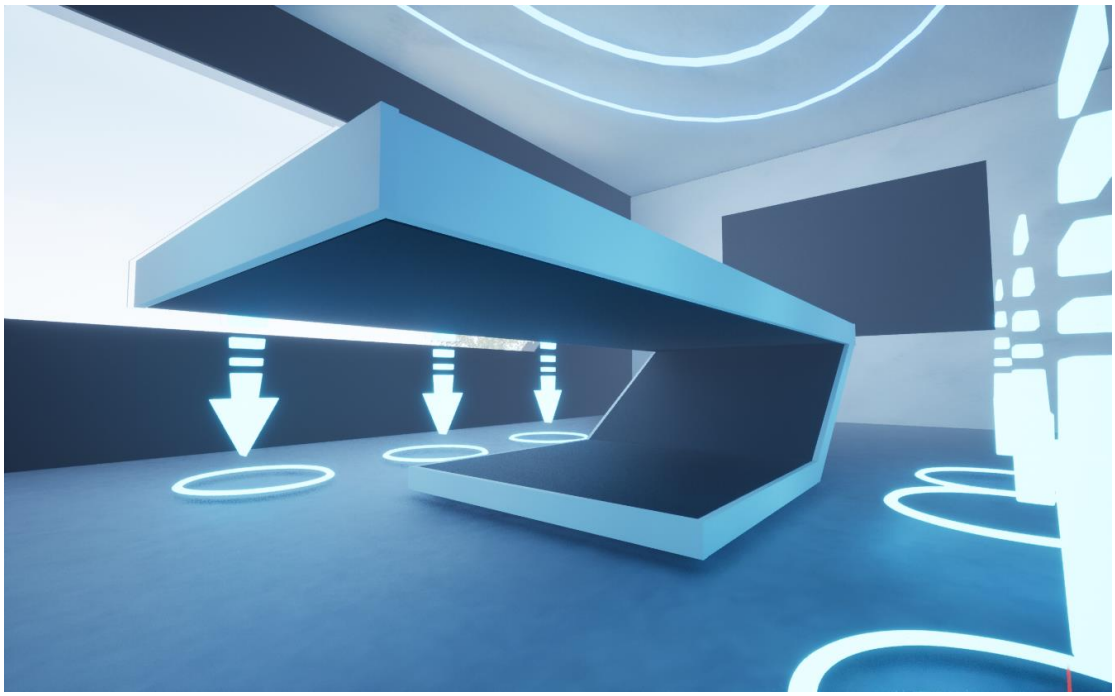


Figure 56: Detail render 13

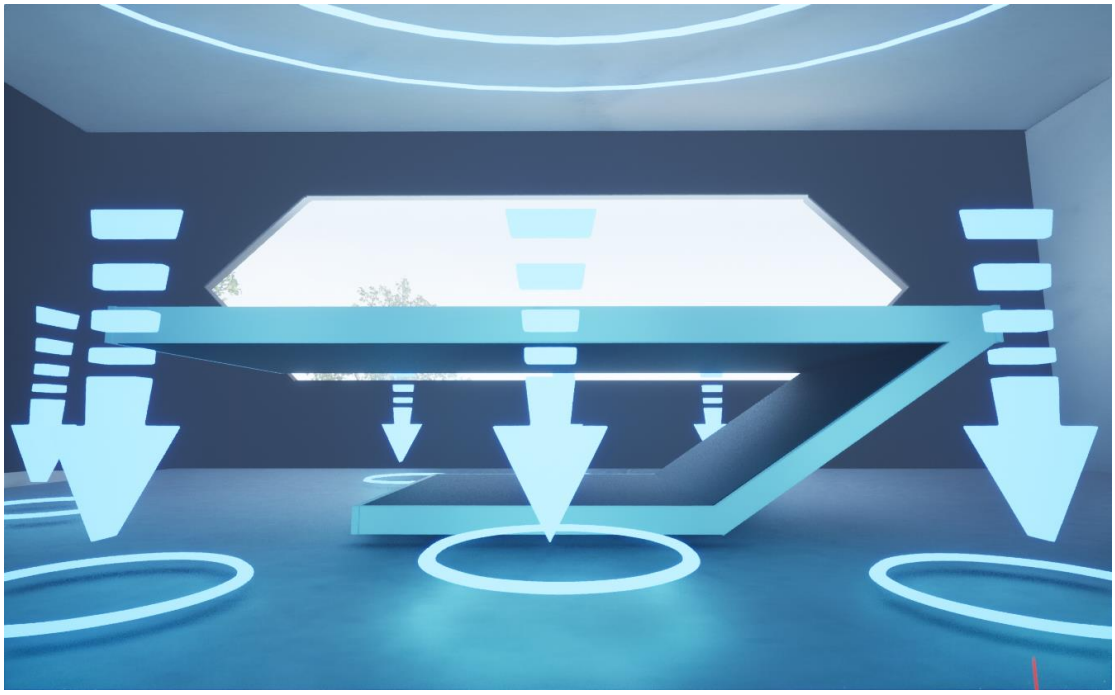


Figure 57: Detail render 14

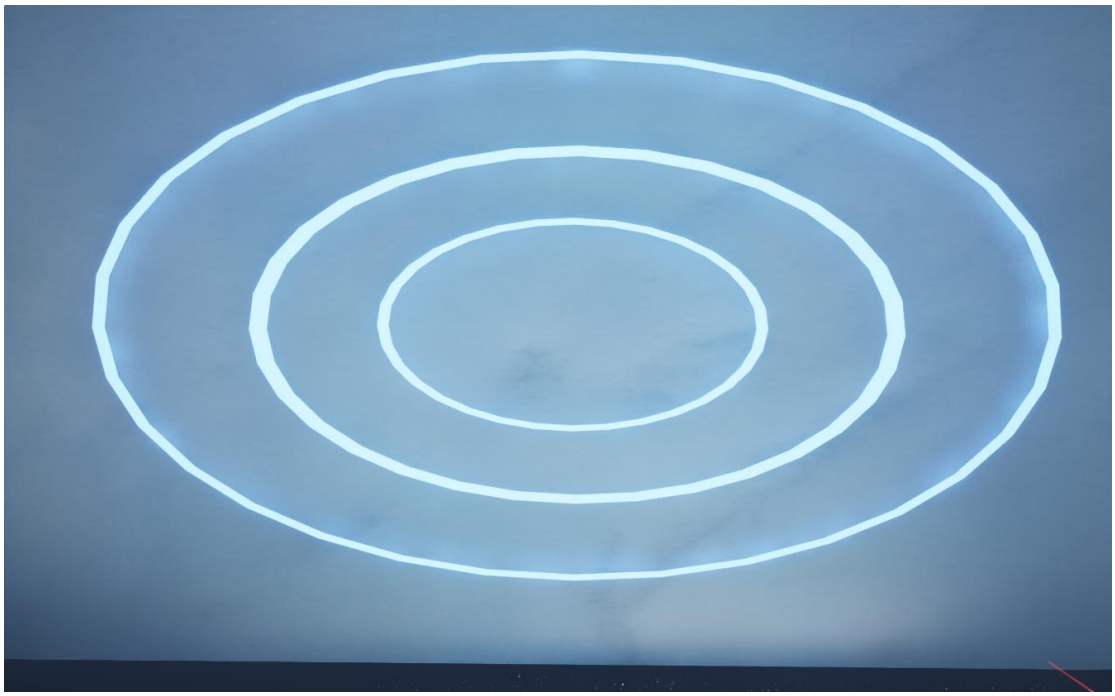


Figure 58: Detail render 15

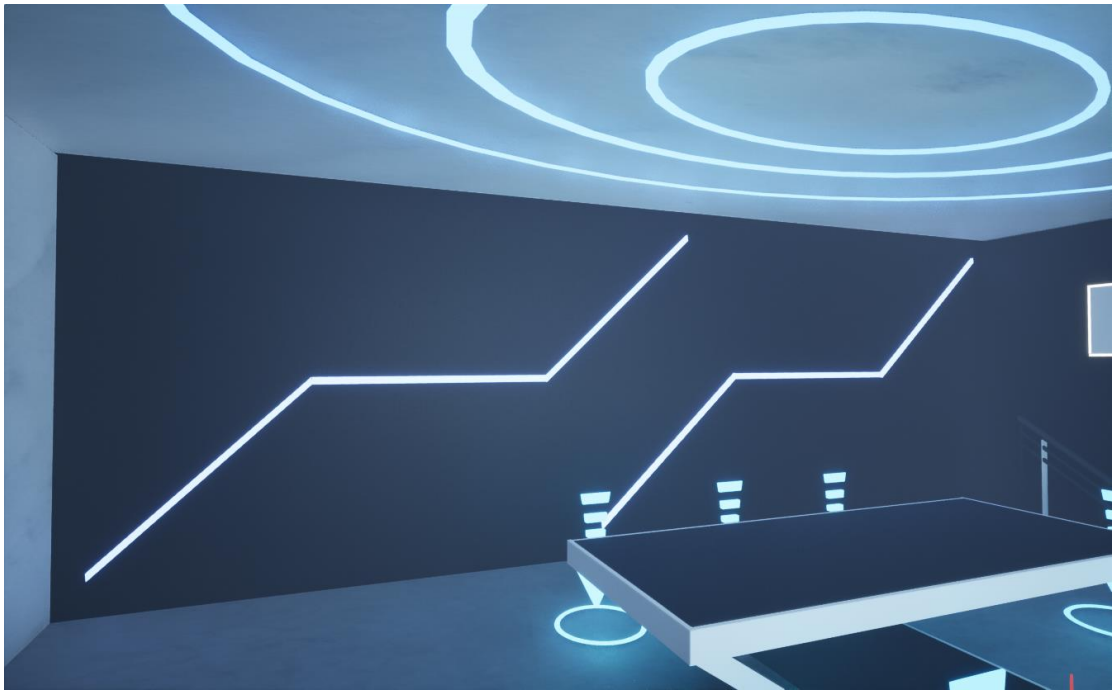


Figure 59: Detail render 16

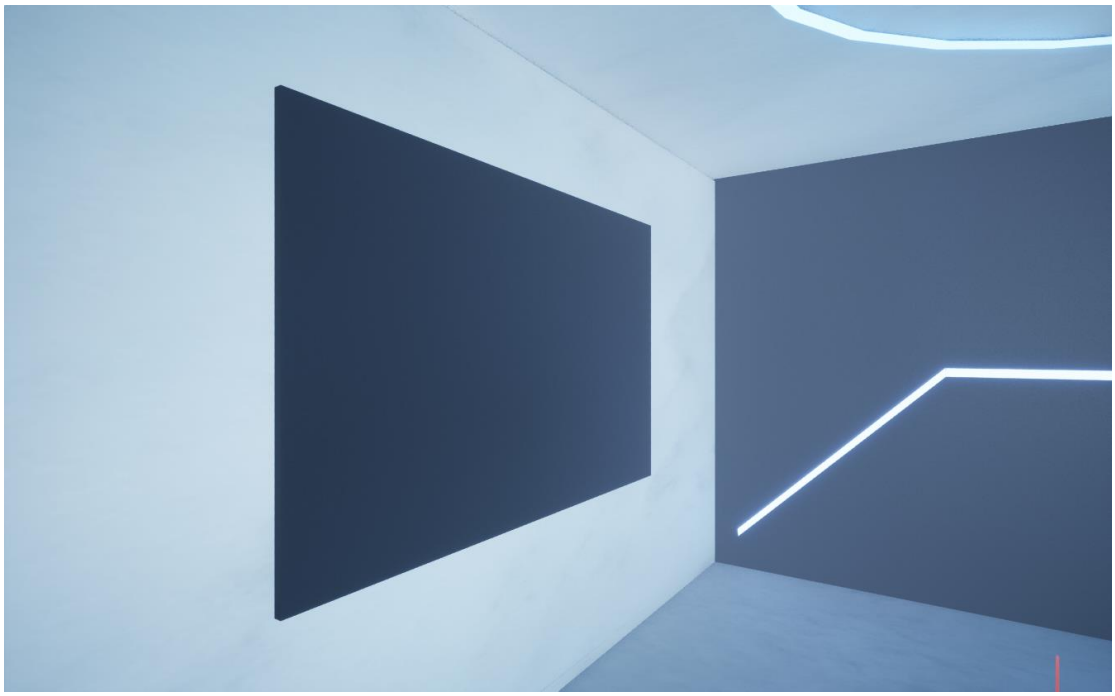


Figure 60: Detail render 17

Appendix F

Detail renders of the second rooms

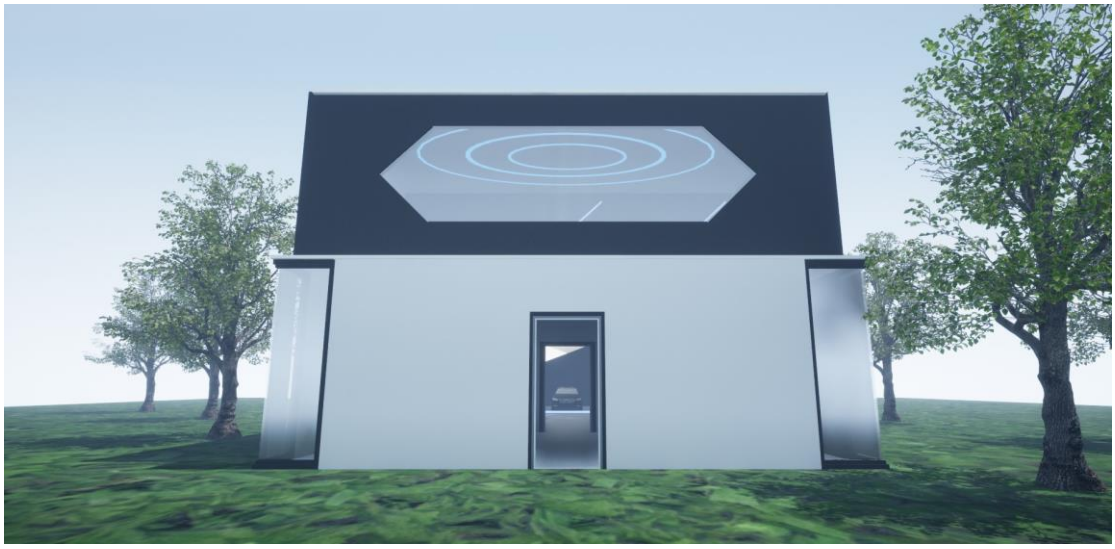


Figure 61: Detail render 18

Figure 62: Detail render 19

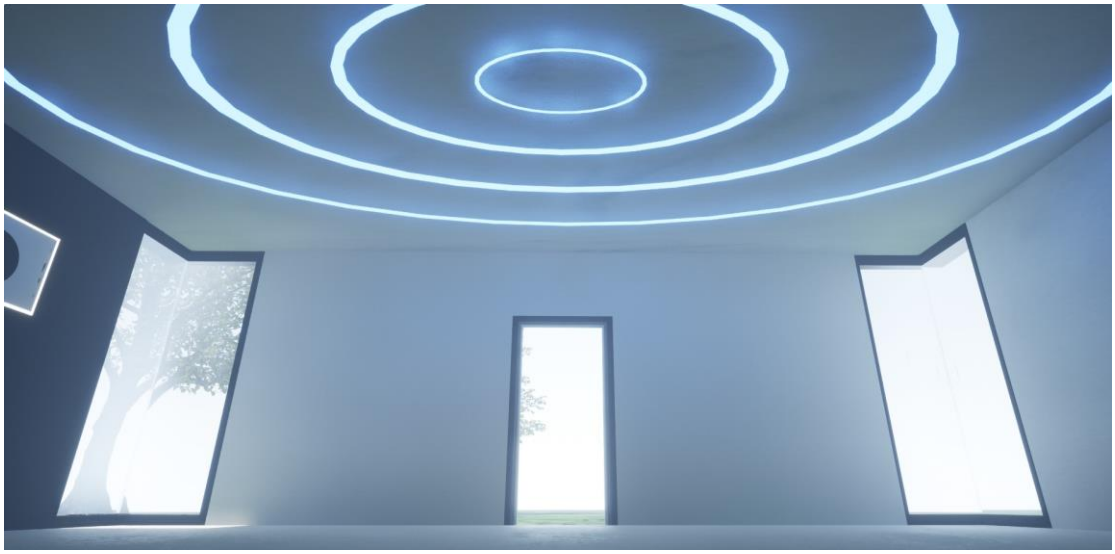


Figure 63: Detail render 20

Figure 64: Detail render 21

Figure 65: Detail render 22

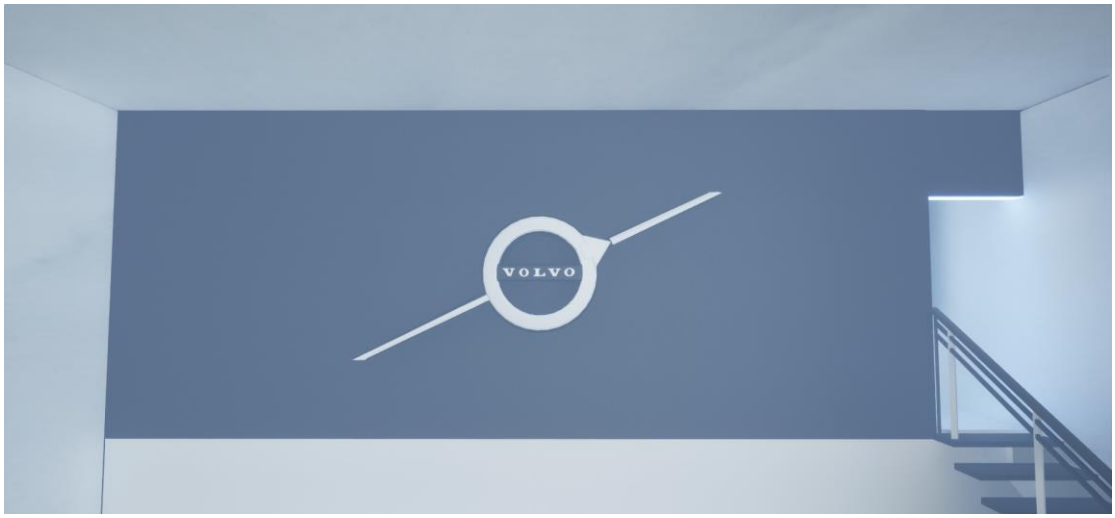


Figure 66: Detail render 23

Figure 67: Detail render 24

Figure 68: Detail render 25

Figure 69: Detail render 26