Aalto University
School of Arts, Design
and Architecture

Author Nicolas Ignacio Robertson De Ferrari

Title of the Thesis VR and Co-Design: Examining Virtual Reality as a Collaborative Tool for the Early Stages of the Design Process

Programme Master's Programme in Collaborative and Industrial Design

Thesis Supervisor: Kaisa Savolainen, Postdoctoral researcher

Date: 20.11.2023 **Number of pages:** 103 **Language:** English

Abstract

This master's thesis explores the potential of Virtual Reality (VR) as a collaborative tool for iteration and rapid prototyping during the initial stages of the design process as a future integral part of the Design Method. The research is validated using Denzin's triangulation process, involving a review of existing literature on VR, benchmarking and semi-structured interviews with key stakeholders in the design industry and VR software development sector, and the conduction of a series of Usability Testing sessions, observing a select group of industrial designers interacting within an immersive, collaborative workspace developed explicitly for this study.

The findings, derived through the triangulation method, have been categorised into three dimensions that discuss and elaborate on each one of the research questions: *Fitness: How VR is perceived fit as an exploratory tool*; C*o-Design in VR: How VR can add to the design process*; and *Streamlining UX: Considerations for enabling an overall better VR experience.* These provide an overview of how Virtual Reality is perceived in the industry and why the aversion to adopting new technologies from a managerial level might be one of the primary reasons for the slow adoption of VR as a design tool.

The study also includes VR's best use cases, benefits, and current challenges, such as a fragmented User Experience, the technostress derived from extended immersive sessions and the discordance between the physical and virtual spaces. Last, it discusses high-level suggestions for addressing these to foster the use of VR and the immense potential of immersive technologies for collaborative and explorative practices in the creative industry that transcend today's technological constraints.

Table of Contents

Acknowledgements

I would like to express my sincere gratitude to my supervisor, Kaisa Savolainen, for her guidance, encouragement, and patience throughout this research project. Her expertise and insights were invaluable for the completion of this thesis.
I also want to thank my friends and colleagues Natalia Trzmielak, Hidde Griek, Imran Shamsul and Pai-Feng Chen for their support, feedback, and collaboration. They made this journey more enjoyable and rewarding.

Last but not least, I owe a special thanks to my wife, Geraldine Bauer and our son, Beltran, for their incredible support and patience during these two years of our adventure in Finland. They are the source of my inspiration and motivation. I dedicate this thesis to them.

List of Figures and Tables

Abbreviations

AR	Augmented Reality
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CMF	Colour, Material, Finish
DFM	Design For Manufacturing
DMP	Data Management Plan
HMD	Head-Mounted Display
MR	Mixed Reality
UI	User Interface
UX	User Experience
VR	Virtual reality
XR	Extended reality

1. Introduction

Undeniably, the past COVID-19 pandemic cemented remote working in a way that would not have been possible if the entire world had not been obliged. To adapt to this new reality, companies had to rearrange their working practices and rapidly adapt to a novel way of working with the tools available. It led to the rise of videoconference tools like Zoom and Microsoft Teams and industry-specific collaborative platforms like Miro and Figma. Consequently, most tools remain used after the pandemic, though adapted for a hybrid work scenario.

Within this context, tasks that could be considered creative, such as design, advertising or problem-solving, were also forced to adapt to these new working conditions. While most creative work can be effectively conducted in geographically dispersed teams using the tools already available, specific iterative processes, particularly those involving physical artefacts, have proved challenging. According to Kadri (2007, as cited in Rieuf et al., 2017), one cause of this challenge is how laborious it can be for designers to understand and assess the qualities of a future product when they cannot experience it in its three-dimensional and multimodal form. The present research builds on the baseline that Virtual Reality can address what currently available two-dimensional platforms do not: permit the complex sensorial interactions needed to effectively reach that desired communal creative mindset (Rieuf et al., 2015).

Intrinsically creative processes such as co-design and iterative rapid prototyping are fundamental in the early stages of a design project. These stages are crucial in defining and developing human-centred aspects of a product, where team working environments particularly benefit from these findings.

As IDEO (2011) emphasises, prototypes are perceived as tools that can assist in validating and generating ideas throughout the concept development process. These effective mediums encourage designers to think realistically about the interaction of users and the proposed design. Ultimately, prototypes help to articulate the design brief between the problem and solution spaces.

Co-creation, on the other hand, is the act of jointly creating something during collaborative design sessions that involve exploring, planning, and learning together, according to Mattelmäki and Visser (2011). On this subject, Virtual Reality poses a valuable opportunity to foster co-creation; the reviewed literature suggests that telepresence, or co-presence, can elicit a physiological response similar to physical presence, thereby increasing the likelihood of achieving a collaborative state of creative flow (Lee et al., 2019; Rieuf et al., 2017). This could lead to equivalent, if not superior, design outcomes when comparing the results to face-to-face co-design sessions.

Collaborative immersive platforms offer an additional advantage by enabling remote collaborations often hindered by logistical and time-related challenges. Larger-scale product design and manufacturing usually articulate and integrate a series of geographically dispersed actors and suppliers, whereas early explorative stages of the design process usually require in-person meetings to deliberate and iterate on the concept. From an ecological and economic standpoint, this is a misuse of resources that should certainly be addressed. A virtual reality platform could address or at least reduce the time and expenditure for these sessions in environmental and pecuniary terms. In this regard, the literature suggests that moving the design process to fully immersive environments can result in over 90% time savings compared to traditional processes (Varjo Industries, 2021).

This being said, the rate of adoption of VR within the industry remains scarce (Stadler, 2021; Truong, 2021), according to recent research (Chen et al., 2022; Reiners et al., 2021; Schäfer et al., 2023), one of the major setbacks of VR being widely adopted at a professional level is the perceived difficulty in troubleshooting the setup process, whether from a device and connection perspective or from putting together and optimising the virtual scenarios required for these sessions. These are some of the pain points to be discussed in this thesis to contribute to broadening the research and knowledge into this topic in hopes of aiding Virtual Reality to become a future integral part of the design process.

1.1. Research Objective and Questions

This thesis aims to explore and understand the potential and challenges of Virtual Reality (VR) as a tool to foster collaborative creativity and iteration in the early stages of the design process. To validate the utility of VR on intrinsically creative processes such as co-design and iterative rapid prototyping, which are fundamental in the early stages of a design project. These stages are crucial in defining and developing human-centred aspects of a product, and team working environments are particularly benefited from these findings.

From a personal standpoint, the present thesis further explores Virtual Reality for the industry and the technical challenges of enticing immersive experiences. It aims to apply what has been studied in User Experience and Interaction Design principles to a topic of personal interest, following a higher-view methodology that reflects on a research-driven, overarching process rather than solely focusing on

the technical outcome of the design problem. The goal is to establish a foundation for career growth, developing an expertise that bridges physical and virtual problem spaces in a strategic, human-centric approach.
Based on these objectives, three research questions have been raised:

Question 1: What are the advantages associated with using Virtual Reality within the exploratory part of the Design Process?

Question 2: What are the current challenges hindering the integration of VR into the design process?

Question 3: How can Virtual Reality be nudged to be organically incorporated into a Design Workflow, especially in the earlier stages of a project?

The first research question serves as a foundation for validating the actual value and potential of Virtual Reality in the early stages of the design process, particularly in the context of multi-user collaboration. Although existing literature suggests that this is a promising area, it also implies that it is a topic that has yet to be explored thoroughly (Balzerkiewitz & Stechert, 2020; Bernardo & Duarte, 2021; Narasimha et al., 2018; Rieuf et al., 2017; Stadler, 2021).

The second question builds on a qualitative and empirical approach to the subject, comparing the data gathered from literature, interviews and testing to detect the pain points of the User Experience of Virtual Reality that have led to a slower rate of adoption of VR compared to other technologies into the industry (Berni & Borgianni, 2020; Truong, 2021).

The third and final question seeks to answer and reflect on a more practical strategy for the subject. Assuming there is an undeniable potential for VR to enhance the design process, it seeks to open the discussion to elucidate what can be considered to help effectively incorporate Virtual Reality as part of the product design cycle.

1.2. Research Framework

The research focuses on expanding the knowledge in the field by analysing a selection of the current literature on Virtual Reality in the design field, prospecting and benchmarking the actual use of available tools on the market, conducting semi-structured interviews with key stakeholders -both service providers and current users-, and facilitating a series of usability tests to identify and elaborate on the potential pain points and challenges that arise from the adoption of this technology in their user experience. Last, it seeks to reflect further and evaluate the entire process's results to advance academic research knowledge on this topic.

The research framework of this thesis is based on Denzin's Triangulation Method (1970, 1978), collecting valuable data from three different sources: existing literature, semi-structured interviews and usability testing, as a way of triangulating the origin of the information *(Figure 1).* The project documents and analyses the results of the research process, the testing framework design, and the post-rationalization of the results to grow the intelligence of VR for the design industry.

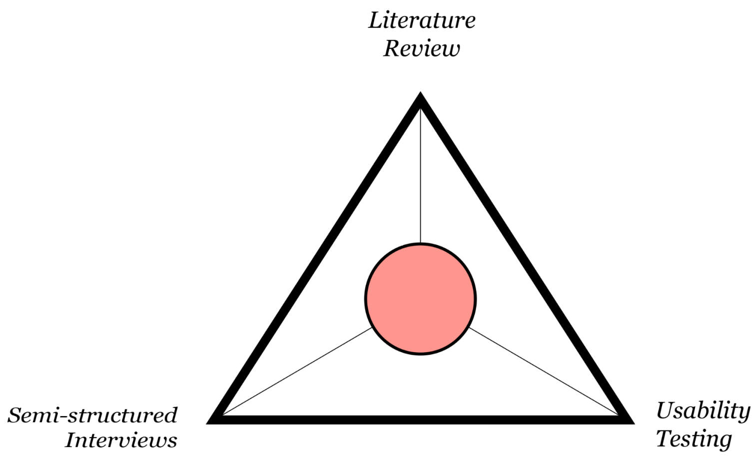

Figure 1. Triangulated Data Collection Inputs

This helps answer and reflect on the research questions while ensuring that the biases arising from using a single data source are mitigated, leading to better-balanced explanations and findings. The research project also combines aspects associated with User Experience Research and Research Through Design, where, according to Stappers (2007), the mere act of creating prototypes has the potential to generate knowledge in and of itself. These insights are intended to be fed back to the disciplinary platforms to grow the theory.

1.2.1. Methods for sampling, design, data gathering and data analysis

Sampling methods vary depending on the phase of the thesis project. The methods include a literature review, benchmarking existing solutions in the Immersive

Reality field, and quantitative semi-structured interview data from key stakeholders, such as design companies and technology providers.
Then, a User Experience Evaluation method phase was conducted to observe in situ the user experience and challenges faced by users within the industry when using VR solutions for their immersive, collaborative design processes.

After each stage, the data from the semi-structured interviews and Usability Testing Sessions was analysed and sorted using quantitative and qualitative methods, such as affinity diagraming into higher-level findings and corresponding subcategories. These helped the sensemaking process and triangulation of information to answer and discuss the Research Questions, broaden the research literature in the field, and encourage the creation of better future solutions within the Immersive Reality field.

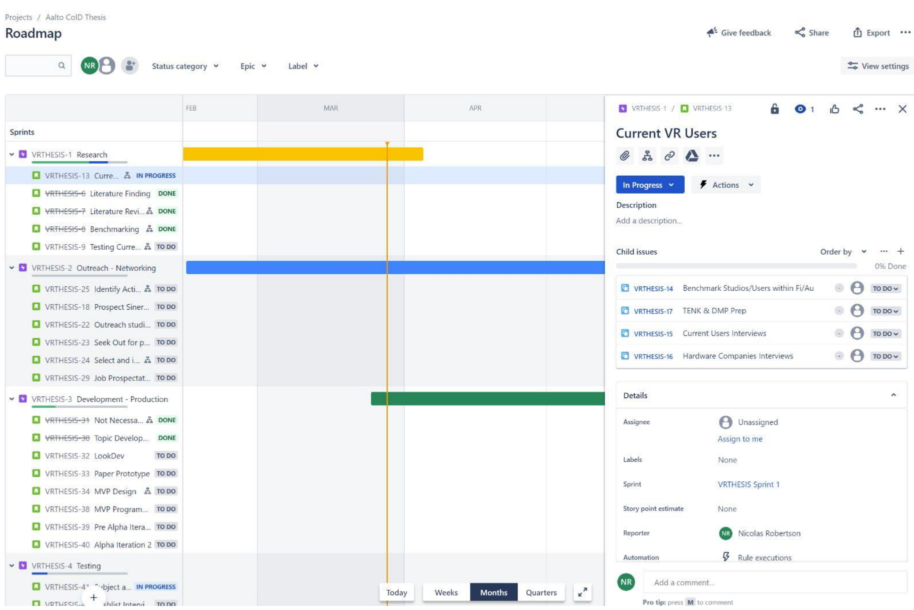

Figure 2. Screenshot of the Agile Project Management Tool Used to Develop the Thesis Project

As a personal preference of the author, the entire research project contained in this thesis has been conducted using agile methodologies to plan, roadmap, and, for the most part, gain better control over the timings of the project and tracking of the iterations, tasks and milestones of the thesis *(Figure 2).*

1.2.2. Ethical considerations.

Ethical considerations for the thesis mainly revolve around user data privacy, particularly during the interview and testing sessions. To address this ethical aspect, detailed evaluation plans, consent forms, and questionnaires have been created following the TENK guidelines. Also, the interviewee's and usability testers' names and roles have been anonymised. Finally, a formal Data Management Plan has been drafted using the Tuuli platform, recommended by Aalto University. The DMP has been done following the General Finnish DMP template, which supports making the data collected during the semi-structured interviews and Usability Testing sessions *Findable, Accessible, Interoperable and Reusable.*

1.3. Structure of the Thesis

This thesis comprises six chapters divided into logical segments of a research project. The approach follows a linear methodology that builds on the information and post-rationalization of the preceding chapter, gathering knowledge and different research sources to finally triangulate the data input. The proposed structure has been designed to deliver results in a timely manner, given the extension and scope of a Master's thesis.

The first Chapter introduces the topic and presents the Research Questions while exhibiting the outcomes from the previous research that served as a base for the one developed for the Thesis.

The second chapter dives into the literature to construct a foundation delineating the research scope to detect valuable insights from pertinent topics to the Thesis. It explores the concepts of co-creation and collaborative practices and analyses how VR can act as an enabler for better design processes in remote working teams. It also explores the actual and potential use-case scenarios for immersive technologies. Last, it benchmarks what the solutions available on the market currently offer, categorising the use cases of each one of the available systems. The latter helped identify key stakeholders within the VR industry, which served as a segway to the next segment of the thesis.

The third and fourth chapters build on the findings identified on the theoretical background and benchmarking and presents the design, documentation and analysis of a series of semi-structured interviews conducted with both key industry VR users and top software providers within the industrial field. The interviews examine their workflows, challenges and plans to adopt immersive reality technologies.
Then, a series of usability testing sessions are also presented, designed to observe in situ the insights from design collaboration and prototyping using Virtual Reality platforms.
The data gathered from these two instances is analysed and categorised, to be triangulated along with the findings from the literature review in the next chapter.

Last, in chapters five and six, the findings and limitations are listed into three Top-Header categories, elaborating the main takeaways of each one of them, the current challenges and limitations of VR, and suggesting how they can be addressed to seek to bring in the technology's best potential into the Industrial Design field. It deliberates on the findings and outcomes from the research topic, their relation to the primary objective and research questions proposed as a basis for the thesis, as well as the theoretical implications and future applications of not only Virtual Reality as a medium itself but also of the takeaways of the thesis project.

1.4. Personal Background

My interest in delving into the Mixed Reality realm stems from a desire to contribute and learn from my industrial design experience to a subject with an undeniable potential to evolve the way we do design. To find novel ways to bridge the Physical and Virtual worlds, foster creativity, and ultimately enhance our role as designers. It also presents an opportunity to broaden my skillset, workflow and critical thinking, enabling me to effectively engage not necessarily in the design of end products but in, as Sanders and Stappers (2008) fittingly articulate, designing systems and strategies for delivering high-impact solutions to any given problem space.

This master's thesis builds upon the knowledge and information acquired on a previous research project conducted during the master's studies at Aalto University, within the context of the DOM-E5163 “Independent Study in VR” course, which explored the feasibility of VR immersive environments for geographically dispersed design teams, the impact on photorealism on such environments, and scouted different design outcomes from those tests.

In that research instance, an early functional prototype was developed to validate and test the assumptions above, focused mainly on specific aspects of the design process, such as the selection of materials (CLM) and the viability of creating genuinely immersive collaborative spaces. Given the limited academic scope and extension of the research, it was tested with four experts in the field and followed by a semi-structured interview, information which was then utilised to generate different findings and shortcomings through affinity diagrams, both in High-level and Mid-level outcomes.

The interaction and feedback of the testing subjects, who were unfamiliar with VR, suggested that while there was indeed a positive reception for such a tool, the actual outcome needed to be worked on to a greater extent and even revised to yield a platform that could effectively elicit and enhance creativity in remote working teams, in hopes of creating co-design sessions that are about collaborative exploration, planning and learning (Mattelmäki & Visser, 2011).

These discoveries have been taken into account -within reason and the scope of the thesis project- when designing and building both the semi-structured interview scripts and usability test sessions, as well as to help narrow down the range of literature reviewed on the theoretical background, to provide a more profound and more robust research project.

2. Theoretical Background

2.1. Literature Review

The following chapter looks into the academic literature that builds the foundation of the research conducted for this thesis. It examines the similarities within design methodologies used in Physical Product Development while emphasising the importance of prototyping as a validation tool and a creative toolset for rapid iteration in the early design stages of a project. Additionally, it explores the co-design framework as a collaborative design process that fosters participation and feedback from all stakeholders and instances of innovation.

Next, the literature review investigates the consolidation of creative practices in remote-working groups and the value of presence, immersion and persistence as crucial requirements for inducing flow states among design teams.

Last, it gives a brief background of Virtual and Mixed Reality, its common uses as a tool in the Product Development industry, and analyses the current state of VR technology for the early stages of design, the economic value and future of the technology according to esteemed researchers in the subject, as well as current limitations within the existing solutions available.

2.1.1. Design Frameworks and Physical Product Development

- Design Methodologies for Product Design

Even though Consumer Hard Products are an integral part of our daily lives, designing such artefacts is a complex process involving many areas of expertise. It requires each speciality to work within a determined framework to align with the requirements needed for that specific brief. To address this complex scenario, over the years, there has been a constant insurgence of design methodologies to help development teams achieve and create successful products that are functional, efficient, cost-effective, and, most of all, meet the end-user's needs. According to Hanington (2012), design methodologies facilitate organised discussions that enable better comprehension and connection with individuals, ultimately leading to the development of more meaningful products.

There are several design frameworks that, for an illustrative purpose following the topic of this thesis, have been tentatively grouped into two broader umbrella terms: *Design Thinking* and *Agile Design*. Each of these has a suite of steps that break down the design process into different stages, and it is up to the design team to choose which methodology fits the design brief better. According to Flick (2014), selecting and implementing certain design methods depends on various factors, including the project's scope, budget, available resources, and the designer's individual preferences.

Design Thinking is a user-centred methodology that puts the end-user at the centre of the design process. This problem-solving approach focuses on understanding their needs and requirements. Its beginnings can be traced back to the late 1960s when Nobel Prize laureate Herbert A. Simon mentioned it in his book, The Sciences of the Artificial (Interaction Design Foundation, n.d.). While it is considered a process rather than a methodology, it involves five stages: *Empathizing with Users, Defining the Problem, Ideating Solutions, Prototyping*, and *Testing*. According to Velásquez (2020), the early design phase usually falls between the first and third phases, which involve conventional industrial design techniques like sketching and storyboarding and more immersive techniques such as persona, journey mapping, and field observation.

On the other hand, while still being human-centric, ***Agile Design*** is a design approach that focuses on flexibility and adaptability. While officially coined in 2001 in the "Manifesto for Agile Software Development" and widely used in the IT industry, this methodology can be traced back to the first half of the 20th century (Rigby et al., 2016). It involves a collaborative strategy where designers work in teams to create products, and it is fairly similar to Design Thinking in the sense that Agile Design is also divided into stages: *Ideation, Prototyping, Testing*, and *Iteration*. This allows designers to respond quickly to user feedback and iteratively implement changes on the fly. One key differentiator, though, is that in Agile Design, the aforementioned stages are conducted in parallel: the processes are broken into small tasks to create a quick and incremental iterative workflow.

While catering to different problem spaces and design problems, certain parallelisms can be summarised into two big overarching themes: *Deep-diving* into the design problem and end-user and *optimising* the processes to deliver and iterate on a project as efficiently as possible. According to E. Sanders and Stappers (2008), the design approach has evolved from simply creating formal products and artefacts to designing for the future experiences of individuals, communities, and cultures now connected in ways that were previously inconceivable even a decade ago. These two terms rationalise and amplify the very iterative nature of human interaction.

To elaborate on the process and segue into the intent of this thesis, one widely adopted design methodology has been selected to dive further into the details of each design phase and the importance of collaboration on each of them.

The ***Double Diamond Framework*** for Innovation *(Figure 3)*, presented by the British Design Council in 2005 and updated in 2019 (British Design Council, 2019), has various similarities with other widespread design methodologies, like Human-Centered Design, a process that has been used for decades to develop new solutions and begins with a deep understanding of the people being designed for (IDEO, 2011). It is a valuable tool for designers to approach problem-solving and innovation in a structured manner. Proposed as a four-stage process, it helps designers focus on problem-solving and innovation by breaking the product design cycle into four steps: *Discovering, Defining, Developing*, and *Delivering*. These function as building blocks for providing a framework to designers for gathering information, defining problems, generating and refining ideas, and ultimately testing solutions. By using this model, designers can improve the quality and effectiveness of their designs with the freedom of a flexible methodology that encourages teams to select their suitable design principles (User Centred Design, Agile, Co-Creation, among others) depending on the scope of the project, thus resulting in better user experiences and outcomes.

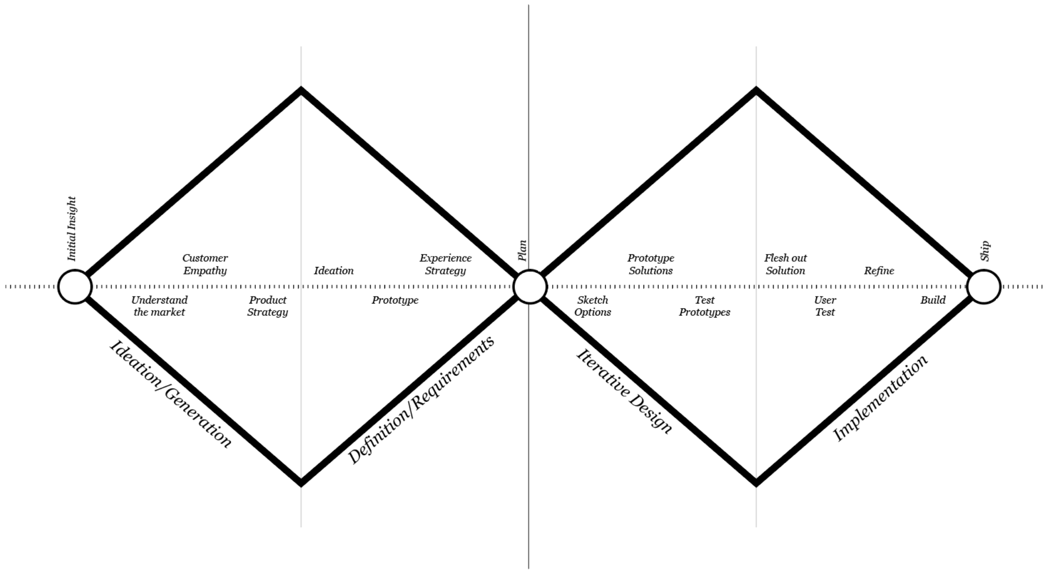

Figure 3. Peter Merholz (2014) adaptation of the Double Diamond Framework by the British Design Council (2019)

Each stage of the Double Diamond can be defined as follows:

Discover: In the Discover stage, design teams gather information, insights, and inspiration to define the problem or opportunity they will address. This stage is characterised by divergent thinking, exploration, and research. Designers use various research methods to collect insights, including interviews, surveys, observation, and secondary research.

Define: For the Define stage, designers analyse and synthesise the insights brought to light in the previous phase to define the problem or opportunity previously defined. This stage is characterised by convergent thinking and synthesis. Designers use various methods, such as affinity mapping, clustering, and persona creation, to identify patterns and themes in the data and build into information that can later deliver better-focused solutions to the design problem.

Develop: In this stage, designers tap on the insights and problem/opportunity statement defined in the previous stages to generate possible outcomes and develop potential solutions. This phase is denoted by divergent thinking and ideation. For this step, various ideation methods, such as brainstorming, mind mapping, sketching, and rapid prototyping are used to generate and refine ideas.

Deliver: As the last stage of the Double Diamond design process, the team refines and tests the solutions developed in the previous stage to prepare them for implementation. This phase is distinguished by convergent thinking and production. *Deliver* revolves around the final concept to conclude with a design outcome of the entire process.

While the Double Diamond approach helps frame the product design cycle in a tidy and somewhat straightforward way, it is important to note that in real-case scenarios, where a wider array of stakeholders (internal and external to the company) are involved, the process is usually chaotic. Methodologies like the described help teams rationalise their internal processes and set common grounds to improve communication among parties and ultimately streamline and cut inefficacies along the way to an end product.

- Prototyping in product development

Prototyping is an essential stage during the design process. It provides designers with a concrete way to evaluate their ideas and refine their concepts before implementing them in their final form (Buxton, 2007). Given the context and scope of this thesis, the author would like to clarify that for all purposes in the present document, Prototyping refers to Physical Prototyping instead of Digital, Service or UI wireframing unless otherwise mentioned.
Understood as a method for creating preliminary or scaled-down models, samples, or lo-fi mockups of a product, system or service, prototyping enables designers to test, iterate and validate design decisions, identify potential issues, and optimise the functionality and usability of their designs. For this same reason, it is widely used in physical product development, including conceptual, functional, and visual prototyping. Each of these types of prototypes has different levels of resolution, as they aim to communicate and validate specific aspects of the product to the different stakeholders involved in the design process.

In this regard, prototyping facilitates collaboration and communication among design team members, helping to ensure that all stakeholders share a common understanding of the design concept and its intended functionality. While in the act of prototyping, design teams combine the logical requirements that were gathered from previous stages of the design process with intuitive and creative approaches. The actual designing of the selected solution approach and its variants happens in these situations, mostly with sketching, CAD models and early modelling for first evaluation tests. Furthermore, alignments with other departments and parties take place. Most of the product properties, such as ergonomics, CMF, and product language, are created in these practical instances (Stadler, 2021).

This activity is usually carried out at different stages of the design process and used for diverse purposes depending on the phase where prototyping is executed. As mentioned in the Human-Centred Design Toolkit, which has been developed by IDEO (2011) to nudge all kinds of companies into incorporating HCD principles in their everyday processes, creating many different prototypes that highlight different aspects of a product or service not only enables people to give honest feedback but also prevents the team from getting attached to an idea prematurely.

Following a chronological rationale of the design process and utilising the above-stated Double Diamond as a reference, prototyping could be clustered into three main groups:

Conceptual prototyping. It involves creating simple and iterative low-fidelity ideas based on what has been defined as the design concept, such as sketches or basic models. This type of prototyping helps explore and validate design ideas early in the design process.

Prototypes at this stage are sought to be purposely simple and ambiguous so that the participant can project his or her aspirations onto the artefacts they make. Early prototypes are not precious and should not be; therefore, for these stages, they should be built quickly and cheaply (IDEO, 2011; E. B.-N. Sanders, 2000). These rapid prototypes are inherently iterative and are often used as quick demonstrations of possible outcomes of the project, eliciting creativity from those involved in the development of said project.

Visual prototypes are understood as models that showcase a more realistic representation of the design concept and involve a more analytical degree of development and time expenditure. Visual prototypes can be CAD 3D models or computer-generated renders that help facilitate the communication and collaboration between designers, stakeholders and users around a more polished design concept by providing a realistic and tangible representation of the final product. At this phase, prototypes are more refined and often present qualities closer to the end deliverable product, such as Colour, Materials, and Finishes to be used. Even though they can be used in different stages of the process, as they inherently require a better-defined set of characteristics, visual prototypes are usually developed when the first stage of rough, iterative prototyping threshold has already been surpassed.

Functional Prototyping: Often conducted in parallel with Visual Prototypes, Functional Prototypes involve the creation of working models of the design concept. This type of prototyping allows design teams to test and validate the functionality of their design proposals before finalising the product, which can help identify and address potential issues and challenges early in the design process, saving time and costs in the long run.

From a methodological standpoint, prototyping in the early stages of the design process is a convergent and iterative process that helps teams shape the ideas and requirements discovered during the exploration and research phase, usually on a higher conceptual level (Rieuf et al., 2017). In contrast, when used in later stages, it is a crucial tool to validate and review every aspect of the design outcome: its usability, ergonomics, and functional aspects peculiar to the Mechanical Engineering and Design for Manufacturing fields.

Since most prototypes in these stages can be produced comparatively quickly and easily in proportion to the actual tooling and manufacturing costs of an end product, designers can create multiple iterations of a design concept and test them to see which iteration works best. These iterations undeniably improve the quality of the end product and allow for more informed decisions to be made earlier in the design process while minimising risks and costs.

2.1.2. Codesign

Co-design is a term used to indicate the idea of collaborative creativity throughout the entire duration of a design project (E. Sanders & Stappers, 2008). It can be described as a participatory design framework that fosters an environment of collaboration, acknowledging and leveraging the diverse perspectives each stakeholder brings to a design project. These can range from designers and end-users to team members and industry specialists, each possessing unique insights and experiences that can significantly impact the design process and its outcomes.

This frame of reference is based on the idea that innovation and practical problem-solving emerge from a heterogeneous influx of ideas, where each participant contributes with their distinct viewpoint to give birth to a shared solution. It emphasises active participation rather than a passive contribution from all parties involved in a project, facilitating a sense of ownership and engagement among participants. This heightened motivation often leads to a deeper exploration of ideas, a more thorough critique of the stated problem, and a potent drive to overcome design challenges, which ultimately enriches the designerly result. Consolidating diverse perspectives creates a holistic picture, enabling the development of products that effectively fulfil the end-user requirements while considering broader industry trends and technical feasibility.

Co-design is essential in amplifying creativity within the design space. Its participatory nature induces a perfect atmosphere for a dynamic exchange of ideas, mutual learning, and collective inspiration. This approach is frequently utilised in a design context where designers are involved, and the activity focuses on design exploration, envisioning, and solution development (Mattelmäki & Visser, 2011). This interaction often triggers unique and innovative problem spaces, pain points and solutions that would otherwise remain undiscovered in a more individualistic work setting. The flexibility of Co-design practices enables stakeholders to transition fluidly between different modes of thinking, challenging assumptions, and exploring diverse problem-solving approaches. This broadened scope of ideation often leads to happy accidents: unexpected insights and breakthrough innovations that enrich the design process and its outcomes.

Human-centred design is encouraged through Collaborative Design practices, as it involves users as informants to inspire and provide insights about their daily lives in relation to a particular topic (IDEO, 2011).

The active involvement of users provides invaluable real-time feedback, enabling the design team to gain a deeper understanding of their context and promptly address potential issues of what is being shaped as output for the project. This user validation is paramount to inform decisions at every stage of the design process, from ideation and concept development to prototyping and final product refinement, a continuous feedback loop that ensures that the final design artefact resonates with the target user base effectively.

One of the standout attributes of Co-design is its capacity to significantly expedite the iterative cycle of design artefacts, prototypes and wireframes, especially in the early stages of the design process. In a traditional waterfall design workflow, prototyping can be labour-intensive and time-consuming. However, Co-design emphasises collective commentary and feedback, allowing for swift, iterative refinements of the solution, often utilising rapid-mockup techniques to define critical aspects of the product being designed without necessarily looking into the detailed -and restrictive- later phase of Design for Manufacturing.

Co-design catalyses innovation. Sleeswijk Visser (2005) mentions that in participatory practices, the end-users are regarded as experts in their experiences. Through this stakeholder involvement and by promoting the exchange of various viewpoints, designers are able to incorporate the context of use into the design studio, stimulating the generation of novel and innovative solutions. Through the collaborative process, these ideas, experiences, and insights can lead to breakthrough innovations that push the boundaries of conventional design thinking.

When done accordingly, collaboration effectively integrates various design tools and techniques, such as brainstorming sessions, rapid prototyping, user testing, and iterative refinement. By aligning these micro-level activities within a broader strategic context, Co-design ensures that the design process remains focused on user needs and industry trends while aligning with the project's strategic objectives.

A thorough Collaborative environment promotes a balance between creative exploration and strategic focus, while encouraging designers and stakeholders alike to explore innovative solutions. It also ensures that these solutions align with the broader project goals and constraints. According to Stadler (2021), designers who engage in participatory activities shift from being creators and translators to becoming facilitators and coordinators, whose role is to empower people to express themselves.

2.1.3. The Challenges of Creative, Remote Working Environments

As mentioned in the introduction of this Thesis, remote work has effectively reshaped the conventional constructs of the workplace, affecting almost all professional landscapes. In this context, physical barriers are blurred within virtual teams -defined by Gebbing et al. (2022) as "groups of geographically dispersed organisational members". Yet, these changes also bring a series of challenges that require a deeper analysis of the dynamics in the working environment to elicit creativity in the best, most organic way possible.

As mentioned by Bernardo & Duarte (2021), in the context of digitalisation, barriers of geography, scale, budget, background, even disabilities and age tend to disappear, solving problems across geopolitical boundaries, thus enriching the cultural mechanics of human interaction. While remote work has countless positive aspects, some elements closely related to creative practices can be challenging. One example is participatory design, which is intrinsically local since it is nurtured, among other things, by the subtle nuances of nonverbal communication inherent in traditional face-to-face collaboration (Schäfer et al., 2023).

In today's digital age, countless collaborative tools and cloud platforms are available for brainstorming, sketching and even prototyping. However, the two-dimensional screen space does not permit complex sensorial interactions; it is mainly restricted to non-spatially-aware visual cues, which leaves other essential stimuli, such as haptic, olfactory, and auditory, out of the design environment. Unfortunately, this usually leaves a void in the creative influx that can certainly impact the design outcome (Rieuf et al., 2015).

Beyond the physical infrastructure of an organisation, which, according to Voigt et al. (2012), should be functional, adaptive and distraction-free in order to enable creative collaboration, it is paramount that its working culture is centred on fostering creativity to create a trust-centric environment in order to elicit innovative thinking in working teams. This is even more evident in hybrid or remote working environments, where, when it comes to creative activities, managers usually "struggle to find the right balance of 'togetherness' and 'apartness' in their online and offline collaboration", leading to a reported decline of productivity in creative teams due to a lack of motivation and proximity to their peers (Gebbing et al., 2022, p. 3).

- Presence and Collaboration

The concept of presence in design extends beyond the mere physical act of sharing a common space; it encapsulates team members' cognitive and emotional engagement. Being present in the same environment with others and the convenience of adding the ability to read the rest of the team's body language is certainly key for reinforcing collaborative practices. When this presence assumes a purely, distinctly two-dimensional digital form, there is an extra requirement for focus and active participation to achieve a comparable result in virtual interactions than in physical presence (Narasimha et al., 2018; Truong, 2021).

Stadler (2021) states a similar interpretation of immersion and presence. Presence, being perceived as a psychological state of being oneself surrounded by an environment, is inherently dependent on immersion, as the interaction derived from this is a continuous stream of stimuli and experiences. Thus, the greater the sense of immersion, the higher the level of presence.

In tandem with the concept of presence, persistent spaces emerge as a significant factor in fostering an immersive collaborative environment. Defined as persistent virtual objects that exist through multiple sessions (Schäfer et al., 2023), these spaces sustain the progression of creative discussions, providing fertile ground for ideas to mature organically. They are deeply intertwined with the collaborative, explorative and creative working modes as "temporary spaces for experimentation and collaborative learning" (Mattelmäki & Visser, 2011, p. 3).

Akin to physical project rooms, which are proven to increase the potential of creative work by providing a sense of freedom, curiosity and inspiration (Amabile, 2006), the digital artefacts produced within these spaces, such as sketches, notes, and prototypes, serve as shared memory reservoirs, enhancing the collective creative capacity of the team.

Persistent spaces simulate the spontaneous interactions typical of a physical workspace, nurturing a shared sense of presence. This interplay of presence and persistent spaces amplifies the immersive nature of the digital environment, leading to enhanced creativity, even to the point of reaching that immersive, psychological state of mind that can even bend time perception when pursuing a truly engaging activity (Csikszentmihalyi, 2000). Paraphrasing IDEO's toolkit for Human Centered Design (2011), the stability of these spaces allows for the natural evolution of ideas, promoting a design process that is dynamic, iterative, and responsive to fresh insights.

The notion of an immersive and persistent digital presence can undoubtedly add to the experience to help catalyse collaborative creativity, ultimately enhancing the overall design quality through the comprehensive integration of diverse perspectives. Such a scenario challenges most two-dimensional collaborative tools available -and widely adopted- on the current market and poses an enticing potential for other XR technologies like Virtual Reality to become an integral part of the iterative and explorative design process. Gebbing (2022) highlights how most interviewees probed as part of his research mentioned the importance of passion and environment in creative work, where, in order to cultivate a sense of passion, it is important for the environment to be stimulating and inspiring, while also allowing for freedom of expression.

2.1.4. VR and Immersive Technologies for the Industry

Extended Reality (XR) technology is understood as an umbrella term for Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR). Defined broadly by Reiners et al. (2021) as a technology that “tries to use computer-generated virtual environments to enhance and extend the human’s capabilities and experiences and enable them to use their capabilities of understanding and discovery in more effective ways”, XR presents an exciting potential for Human-Centered Design (HCD) methodologies, as virtual and boundless immersive environments defy most physical limitations.
In these, users can interact and collaborate seamlessly with others, similarly as they would in the physical world, but enhanced with the limitless possibilities that a virtual environment offers. VR's immersive nature creates an unexplored opportunity to create meaningful yet inexpensive design experiences.

According to Fast-Berglund (2018), Virtual Reality (VR) falls the closest to the Virtual end of the XR spectrum *(Figure 4).* It employs stereoscopic near-eye displays to immerse users into a 3D-generated virtual world. This subchapter provides an overview of VR as a technology, its current usage in Product Development, the potential of Virtual Reality for Collaborative Practices and the Design Workflow, and the economic value of the technology within the industry.

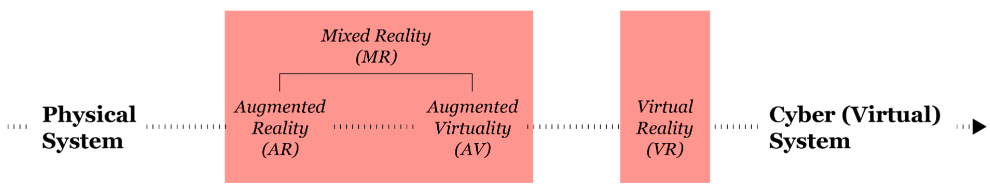

Figure 4. Fast-Berglund's XR Spectrum (2018)

In general terms, modern VR devices are a conjunction of several components, its most recognisable one being the Head Mounted Display (HMD), comprised of mainly two near-eye, high-resolution displays which need to render the real-time graphical interface two separate times. To achieve an immersive, stereoscopic effect, each eye has to be shown a slightly different view of the rendered space while changing in real-time according to the user's input while still keeping high framerates (Hogan et al., 2022). An HMD also has a vast array of motion sensors, cameras, processors and -on the latest models- eye-tracking sensors to simulate and optimise the virtual, immersive experience, the components and processors are not too dissimilar to what can be found on contemporary smartphones and SoC devices.

Because of these requirements, the devices tend to be relatively power and computer-resource-hungry. Therefore, even though they can work wirelessly, most have a short battery lifespan. In order to maintain a relatively high framerate and avoid the adverse effects of poor performance, such as nausea and headaches

(Stadler, 2021), most devices must remain tethered to a capable workstation, especially for extended immersive sessions within an industry usage context.

Besides the headset itself, each VR provider has its own design of handheld controllers for interacting with the virtual environment. Most controllers have similar characteristics, directly inheriting usability aspects from the video game console industry. To the date of submitting this research project, there is currently one standard trying to unify usability and controllers, *OpenXR* (Khronos Group, 2019), presented primarily to aid the development of VR solutions as a better-streamlined process. Leading platforms like Meta's Quest devices, Varjo, Pico and the upcoming Apple Vision Pro are experimenting with hand-tracking devices. However, from the author's practical experience, certain aspects of haptic feedback still have to be addressed for hand-tracking to be superior to their physical controller counterparts.

From a software perspective, VR applications are often developed using real-time videogame rendering engine frameworks such as Unity and Unreal Engine, which, according to Hogan et al. (2022), rely on distinct programming languages and rendering methods to create the intended interactive experience.

While VR can be traced back to the mid-20th century as experimental concepts of immersive, multisensorial experiences, such as Morton Heilig's Telesphere Mask patented in 1960, and The Sword of Damocles, considered the first augmented reality, a stereoscopic head-mounted display created in 1968, by computer scientist Ivan Sutherland at MIT (Balzerkiewitz & Stechert, 2020), the resurgence of VR as viable, commercial technology only happened several years later, after the official launch of the Oculus Rift headset in 2012, and its subsequent Kickstarter campaign to fund the consumer version of the technology, which raised nearly USD 2.5 million with almost 10.000 backers (Oculus VR, 2012).

Arguably, only after Facebook acquired Oculus in 2014 for nearly USD 2 billion, the VR industry took off as a technology that could go beyond the military and mostly experimental use cases towards wider adoption of Virtual Reality for the entertainment and manufacturing industries (Bellini et al., 2016).

A systematic review of literature by Reiners, Reza and Karwowski (2021) found evidence of an expanding implementation rate of immersive technologies across all industries, with a significant increase in indexed academic papers from 2017 onwards, which suggests a tendency towards mainstream adoption of VR. The advancement of VR-related technology, such as screen pixel density, optimisation through foveated peripheral rendering, and the overall minimisation of components, but also the recent pandemic and social distancing, have boosted an industry that is forecasted to grow over 33% in the upcoming five next years (Mordor Intelligence, 2022).

- Usage of XR and VR Across Industries:

The context of the use of immersive technologies varies widely, spanning from forms of entertainment in various degrees of complexity to industry-oriented tools. From relatively simple applications like VR-enabled movies to the design, simulation and analysis of complex scenarios to improve ergonomics on assembly lines in the manufacturing industry (Caputo et al., 2018).

One of the most notorious uses for current Virtual Reality, and in part one of the main drivers of the market development, is related to entertainment, where users can experience total immersion in film, games and social outputs. This trend in developing mass consumer-level headsets from major players has accelerated technology adoption and reduced prices of what was a prohibitive price point for most potential users. In fact, in gaming alone, the global user base of VR and AR games is expected to increase to 216 million users, worth USD 11.6 billion by 2025 (Mordor Intelligence, 2022).

A report from Goldman Sachs (2016) outlined nine use cases for VR/AR detected as the most meaningful markets for Virtual Reality: *Video Games, Live Events and Entertainment, Healthcare, Real Estate, Retail, Education and Training, Military and Defence,* and *Engineering*. These are consistent with recent literature suggesting the technology's better-developed and adopted use-case scenarios (Adenauer et al., 2013; Berni & Borgianni, 2020; Schäfer et al., 2023).

The immersive aspect of VR and the better perception of scale than traditional 2D outlets make Virtual Reality ideal for reducing the risk associated with on-site training in sensible scenarios, such as operating heavy machinery, flight training and surgical training by offering repeatable environments in order to improve the user's performance in various tasks before stepping into a real-world training scenario (Reiners et al., 2021). By being three-dimensional, immersive and skeuomorphic, VR user interfaces draw most of their gestures, graphics and layouts from the physical world. These interfaces enable a natural user interaction by offering a lower learning curve and facilitating recognisable connections, environments and scenarios. Rieuf et al. (2017) suggest this enriches their participation into more meaningful and engaging experiences, leading to higher commitment of the involved users to the provided task. It is precisely for this immersive and emotional engagement that virtual Reality is considered fit for other areas mentioned in the report. In Real State, developers currently employ VR to create virtual tours for end customers, immersive design reviews and property customisation even before the construction begins. A study by Ozcan-Deniz (2019) on the use of VR in the AEC industry has found direct time and cost savings in over 93% of the surveyed projects.

In Retail and Market Research, Virtual Reality is used in multiple instances, for example, to explore and identify the User Experience of shoppers in malls and product testing (Mujber et al., 2004). In addition, psychology studies are utilising VR due to its ability to generate secure and regulated environments for its patients (Loomis et al., 1999).

One other meaningful market of VR for the industry mentioned above is precisely related to the Product Design Cycle and Manufacturing. Stadler (2020) mentions how VR facilitates the creation of immersive virtual prototypes, offering a range of advantages over traditional product-design-cycle processes in time-saving and cost, where the involved teams can create enhanced visualisations of certain products and spaces and review the designs even before building any physical prototypes. "The immersive experience of VR also allows our bodies to be part of this process, making it possible to consider ergonomics early on" (Ekströmer et al., 2018, p. 3). Prototyping in Virtual Reality accelerates the design iteration process and helps teams identify potential issues early, optimising the time-to-market cycle.

Literature suggests immersive, spatialised working contexts induce a higher emotional impact than traditional methods. Therefore, VR processes can help early design decisions by grabbing, moving, testing, and overall exploring around with countless iterations of a proposed design, potentially leading to better and more refined design proposals and ideas (Aikio, 2022; Rieuf et al., 2015).

- VR for Collaborative Practices

As mentioned above, VR is especially suitable for collaborative practices in shared virtual spaces. Here, stakeholders can review and discuss projects and 3D models in real time, with a high level of immersion that removes any usual distractions from the task (Truong, 2021). Immersive Collaborative VR tools enable participation from geographically dispersed teams while harnessing the creativity-inducing benefits of co-presence and the non-verbal cues that are otherwise impossible in common two-dimensional collaborative platforms (Zibrek et al., 2019).

In these contexts, designers and stakeholders from different parties or departments align virtually to combine the requirements from previous brief stages with intuitive and creative approaches akin to face-to-face collaboration. The actual designing of the selected solution approach and its variants can be addressed within these stages, primarily with 3D sketching, CAD models, design reviews or first evaluation tests (Stadler, 2021).

These synchronously shared context scenarios bring real-life social aspects like mutual learning and encouragement, establishing social relationships that are suggested to reinforce creative, collaborative practices (Bernardo & Duarte, 2021; Jimeno-Morenilla et al., 2016; Rieuf et al., 2017). Truong (2021) hints at how immersive VR enhances collaboration between clients, designers and end-users, leading to deeper stakeholder participation in the design process, helping avoid over-designed end products.

Collaborative Immersive Platforms also pose an added advantage to implementing remote collaborations, which are currently challenging in logistics and time. In larger-scale product manufacturing, such as the automotive industry or outsourced manufacturing of mass consumer products -which articulates and integrates a series of geographically dispersed actors and suppliers- the sample and prototype validation processes usually require either sample shipping or in-person meetings to discuss and deliberate on the matter. From an ecological and economic standpoint, this is a misuse of resources that should be addressed. VR collaboration can manage or reduce these sessions' time and expenditure -both in environmental and pecuniary terms-. Literature suggests that moving the design process to fully immersive environments can result in over 90% time savings compared to traditional processes, such as travel costs, time expenditure and carbon emissions (Schäfer et al., 2023; Varjo Industries, 2021).

- VR for the Early Stages of the Design Process

Within the VR for the product design context, the reviewed literature found that most industrial applications currently deployed or in development cater to advanced stages of the design process, such as CAD design reviews or manufacturing simulation and optimisation. While these still benefit from collaborative practices and give way for further iteration of a design outcome, few immersive tools are currently available for the earlier design stages. Virtual Reality's potential for early stages relies on the intrinsically exploratory and inspirational nature of these stages, which highly defines the baselines of a final product (Rieuf et al., 2015).

While sparse, academic research is being done within this stage of the design workflow, where creativity plays a significant role and is less bounded by environmental constraints such as costs and manufacturing limitations. Balzerkiewitz and Stechert (2020) studied this area, and their findings suggest that there are overall positive outcomes from using VR in earlier phases that can lead to enhanced design quality while also reducing the time and expenses involved in the development process. Berni and Borgianni (2020) and Stadler's doctoral research (2021) have also detected these outcomes, underlining VR's importance and positive consequences and its impact on decision-making for better identifying design problems in earlier design development phases.

The literature suggests that using VR early in the design process can increase creativity (Lee et al., 2019; Rieuf et al., 2017; Stadler, 2020, 2021). In addition to this, creative performance has also been suggested to improve when constraining and guiding the creative environment and resources available, making controlled, immersive scenarios ideal for facilitating these tasks and enabling creative flow among team members (Biskjaer et al., 2011; Pilcicki et al., 2021). Interestingly, the research also reveals the underlying limitations and drawbacks of Virtual Reality in later stages of the design process and its overall use as a tool rather than an entertainment medium, some of which are described next.

- VR Challenges and Limitations

There are limitations related to VR as a technology that helps elucidate why Virtual Reality, although proven useful as a tool for design processes, has not entirely taken off and been widely adopted by the industry, even though the renaissance of immersive technologies after the launch of the Oculus Rift happened more than ten years ago.

Some of these challenges are directly related to technical drawbacks linked to the advancements of the technology that, in certain aspects, hinder the usability and overall User Experience of immersive experiences and XR in general, such as HMD fit and weight, battery life, processing power and tethering constraints, and the early developmental stages of fundamental natural interactions such as haptic feedback and hand gesture recognition (Bishop et al., 2001). However, with the constant influx of investment in the Mixed Reality market and the shared CPU and GPU processing platforms and chipsets with more significant, dominating markets such as the mobile phone industry (Mordor Intelligence, 2022), the technical-induced shortcomings of VR should be addressed relatively quickly.

On the other hand, there are psychological challenges related to the extensive use of immersive technologies in the workplace, more specifically associated with stress and overwhelmingness, also known as *Technostress,* which may play a critical role in the adoption rate of VR. Literature suggests how, when features are too complex, and technology is used extensively, some users may experience an overload of information, leading to exhaustion and classic symptoms of stress, which is also known to have an adverse impact on creativity and idea generation (Gebbing et al., 2022). Additionally, adopting VR as part of the design process would mean, for most design teams, adding yet another software and platform to their toolset, fragmenting the User Experience and workflow even more.

One last challenge in this topic can be connected to the workplace structure, how design teams are structured and how they are usually led by seniority within a project. Truong (2021) suggests that one significant factor in the low adoption rate of VR in the Architecture, Engineering and Construction industry is the resistance of decision-makers and upper management to incorporate immersive technologies into their workflow. This assumption correlates with what Rogers et al. (2017) hint with the tendency for the adoption rate of new technologies to decrease with age and, consequently, seniority within an industry.

2.2. Benchmarking

To understand the current offerings within the Immersive Reality realm, a state-of-the-art benchmark *(Table 1.)* has been conducted for this thesis. It helps evaluate the core focus of existing VR solutions primarily catered to the industry rather than for entertainment purposes. They have been classified into five categories that, for the purpose of this research, help better illustrate their core business model and end-user.

AEC and Design Industries. These are solutions catered primarily to Architecture, Engineering and Construction. This category often offers collaborative spaces for design reviews, BIM and CAD data import and has a core focus on later stages of the design process where the Design Project has already reached a level of refinement that justifies entering into more complex CAD models.

Creative Sector. This category has a limited lineup of solutions available, but they cater to earlier stages of the design process, where there is a need for explorative design and rough 3D sketching and modelling to block out spaces and shapes or comprehend spatial aspects of a project. The identified options share much of the features offered on the AEC and Design Industries category, but in a much looser style, in addition to sketching, sketching over CAD, Design Collaboration and FBX Export of the designs made. This bracket is the one that comes closer to this thesis's research scope.

Meeting Spaces. The Meetings group provides solutions for business-oriented VR users, where the features available are focused on meeting tools such as brainstorming, whiteboards and rooms that are similar to what is already available in two-dimensional form, with the added value that non-verbal communication -only available in VR at the moment- brings to the table in terms of organic relationships within the workspace. All of the surveyed solutions within this group allow large numbers of simultaneous users, spatial audio and persistence, which, as mentioned, is the ability to resume from the previously interrupted session while keeping all the changes made.

Metaverse. Focused on content creation, massive gatherings and a generalist take on immersive spaces, this category has a broader array of possibilities for its users. The solutions identified within this group are classified as "world builders", large-scale digital worlds where the developers offer all-in-one platforms to VR service providers to program custom experiences for their clients, whether they need specific product activation activities, virtual fairs or training scenarios.

Custom Service Providers. While only two companies fall into this category for the benchmark, plenty of VR service providers are available. These businesses operate on top of the Metaverse, open-world platforms designing and programming custom solutions that cater to specific clients' needs. These two examples have been included in the list because of the flexibility and ample range of possibilities that can branch out from custom projects, eventually enhancing and enriching the VR ecosystem.

Name	*Summary*	*Features*	*Developer*	*Web*	*Category*
Gravity Sketch	Intuitive 3D design platform for cross-disciplinary teams to create, collaborate, and review in an entirely new way	Cross Platform, Collaborative, Sketch Sketch over CAD, Design Reviews	Gravity Sketch	gravitysketch.com	Creative Sector
XR Presence Inc	Customised VR/XR solutions,	Cross Platform, Collaborative, Training, Design Reviews	XR Presence	www.xr-presence.com	Custom Service Provider
Sketchbox Design	Collaborative content creation in VR, to test and review designs with a proper sense of scale	Sketch, OBJ import, FBX export to game engines. Cartoon low poly vibe.	Sketchbox Inc.	design.sketchbox3d.com	Creative Sector
Virbela	Metaverse-like meeting room system creates custom virtual worlds for remote teams to get together	Unique, customisable avatars, spatialised voice, massive scalability, low definition (lower end headsets can be used) presentation tools, breakout rooms	Virbela	virbela.com	Meetings
Mixtive	XR Developer	Different case scenarios	Mixtive	Mixtive.com	Custom Service Provider
Meeting Room	Virtual Meeting Rooms	Real world spatialised audio, shared interactive whiteboards, 3D design reviews, customisable avatars	MeetingRoom Ireland	meetingroom.io	Meetings
Glue	Finnish company of virtual meeting rooms, pretty well developed	Post-it notes, whiteboards and freehand 3d drawings. Spatialised audio, customisable avatars. 3D model import. Virtual world persistence	FAKE	glue.work	Meetings
Exxar	Cloud-based CAD revision software	Losslesly imports CAD data for design reviews	Exxar	Exxar.cloud	Construction Sector
VR Spatial	Meeting and desktop extension in VR and XR	Meetings, team spaces, team boards	Spatial	spatial.io	Metaverse
Cavrnus	Metaverse VR platform, UE based multiuser immersive experience	All-in-one platform, for developing experiences with less need to program	Cavrn	Cavrn.us	Metaverse
MeetinVR	VR office space for gatherings and collaborative meetings. Host events, workshops and training sessions	Lifelike avatars, all in one meeting platform for business focus collaborative tools. Whiteboards and media sharing. Product reviews, sketching, and brainstorming. Low learning curve	MeetinVR	meetinvr.com	Meetings
Mozilla Hubs	Open source immersive world builder.	Open source, low cost, media sharing and spatial audio for collaborative experiences.	Mozilla	hubs.mozilla.com	Metaverse
The Wild	Architecture and Building Industry immersive design reviewer	Inspect lossless BIM data, synchronous collaboration, text to speech, sketching tools	Autodesk	thewild.com	AEC Industry
3dTalo	Custom solutions for immersive design spaces	Variety of custom designed design spaces for different industries, the company creates partnerships with the interested parties	3D Talo Finland Oy	3dtalo.fi	AEC Industry

Key VR	Collaborative VR CAD reviewer, based on KeyShot's technology.	Collaborative, synchronous design review, product and material variations, XR integration	Luxion	keyshot.com/keyvr	AEC Industry
Arthur	Remote office space, tools for collaborative work based on media creation, brainstorming and presentations.	Lifelike avatars, immersive collaboration and meeting rooms, persistent spaces, miro-like productivity rooms, diagrams and post-it walls	Arthur	Arthur.digital	Meetings
Prospect	Architecture and BIM focused design reviewer in VR	Immersive collaboration, guest join for clients, design reviews	IrisVR	irisvr.com	AEC Industry
Engage	Business-focused metaverse multiplatform builder, provide services directly to employees, customers and suppliers	Virtual offices with spatial audio and lifelike avatars, virtual meeting rooms, media sharing and customisable spaces	Engage XR Holdings	engagevr.io	Metaverse
Twinmotion	UE Based renderer focused on worldbuilding and construction, has cloud VR capabilities.	Ease of use, raytracing, single-user VR with high fidelity.	Unreal Engine	twinmotion.com	AEC Industry

Table 1. State-of-the-Art Benchmark

Out of the 19 benchmarked solutions, the assortment shows a majority, six, of providers in the AEC and Design category, followed by five for Meetings, four for Metaverse, all-in-one platforms, and only two catered to the creative early stage design process.

This industry insight and end-product availability curiously diverge from what the literature suggests about the potential of VR in the early stages of the design process. Regardless of the research confirmation that the technology can indeed improve the iterative design process and achieve a higher overall commitment from the team that leads to better results (Balzerkiewitz & Stechert, 2020; Rieuf et al., 2017; Stadler, 2021), the product suites currently on the market, as well as the adoption of Immersive Activities for collaboration remains scarce.

In order to dig deeper into the reasons for this scarcity and learn from an expert, practical side of view the actual workflow of Virtual Reality in the Design Process, a series of semi-structured interviews with key stakeholders have been designed to help shed light on what are the hindrances and pain points of the current VR ecosystem and what can be done for it to develop to its full potential within the design field.

3. Semi-Structured Interviews

3.1. Methodology

To better understand the utility of VR as a design tool in real-context scenarios, interviews were conducted with key industry actors, considering the insights from both ends of the VR spectrum.

On one end, four industrial designers of major Design Studios with a proven record of immersive technologies usage in their product development cycle were interviewed and enquired about their relationship and experience with Virtual Reality. On the other end, representatives of four key technology providers within the realm of VR development were interviewed regarding their assessment of the industry in general, challenges and solutions they were working on at the moment of the meetings.

In total, eight representatives of seven different companies were interviewed *(Table 2)* about their use of VR, their opinions on where in the product design cycle they see immersive technologies fit, limitations and challenges, their perspective on how to improve UX and how do they see the future of Virtual and Mixed Reality. All interviewees had leading roles within their company, working as -in no particular order- *Partners, Senior Industrial Designer* roles*, Lead Concept* and *Product Designers, Head of Product, Head of Design* and *CEO.* Both interview plans can be found appended at the end of this document (*Appendix 1*, and *Appendix 2*)

No. of Interviewees	Industry	Company	Place of the Interview
1	Design Consultancy	Design & Industry (AU)	Online
2	Design Consultancy	Aivan (FI)	Online/Onsite
1	Design Consultancy	Ultra (FI)	Online
1	VR Software Developer	KeyVR (DK/US)	Onsite
1	VR Software Developer	Glue (FI/US)	Online
1	VR Software Developer	3D Talo (FI)	Online
1	VR Service Provider	XR-Experience (FI)	Onsite

Table 2. Semi-Structured Interviewee Details

While most of the interviews were conducted online, three of them were on-site, being the KeyVR one part of a series of meetings and workshops during a two-day visit to Luxion's headquarters in Aarhus, Denmark, following an invitation from the company to present the author's research and work and brainstorm together some of the possible improvements to their software solutions.

It is pertinent to mention that six other high-level designers were also contacted for an interview, some working in leading roles for the largest technology companies (Meta, Google, Microsoft and Intel). While most of them replied and seemed interested in the subject of study, almost none had worked with VR in their industrial design process, regardless of the significant involvement of their employer in the active development of Virtual Reality as a product. The low rate of technology adoption, as perceived from this user benchmark and sampling, is worth looking into.

The structure of the interviews was based on Guion's (2011) and Boyce's (2006) guidelines for conducting interviews for academic purposes. They were intended to be conducted as semi-structured, qualitative interviews, where the online sessions were recorded, transcripted and summarised while being supported by field notes of each instance. In the case of the onsite meetings, only field notes were used as records for non-disclosure terms and the nature of the interviews themselves. All interviewees gave express consent to record the meetings, according to what was stated on the informed consent form prepared for each interview. It is important to note that for practical purposes, for the online meetings, interviewees gave oral consent after being informed about the use and rights of the gathered data.

Figure 5. Testing the latest build of KeyVR in Keyshot's Headquarters, Dk.

Being the interviewees in a work environment, the extent of the interview was designed not to last more than forty-five minutes, leaving enough room to finish the interviews earlier or stretch it to an hour if needed. All interviewees demonstrated interest in the subject and considered themselves technology-savvy. This led to interviews that flowed organically and extended beyond the planned length.

3.1.1. Data Analysis

The data and insights gathered from the interviews were analysed and organised as an affinity map to find possible pain points and opportunities for the development of the project and subsequent tests to validate the hypothesis and research questions. This included analysing field notes, recordings from each interview, and AI-summarised transcripts of every session, to detect overlooked insights that might have occurred. The latter was generated using *Microsoft's Teams* Copilot feature, a Large Language Model AI (LLM) that transcripts and summarises the data from online meetings. While Artificial Intelligence was used for these, the summaries did not surface any further findings that were not already detected by reviewing each recording at full length.

With affinity mapping, different ideas and notes taken from the interviews were broken down into smaller bits of information, sorted and reorganised in groups to find repetitive patterns that might bring important insights into one particular subject to light. Affinity mapping -also known as the KJ method- was created in the 1960s by the Japanese anthropologist Jiro Kawakita, while searching for a method to organise data collected from various cultures (Otieno, 2023).

The primary purpose of this particular set of interviews was to gather insights into the advantages, actual use-case scenarios and limitations of immersive work environments and how and when the tools currently available are used. Moreover, from an end-user and developing standpoint, it served to prospect their response to VR as a supplemental or even a replacement for face-to-face design sessions in the present and near future.

3.2. Results

Valuable findings were found on the topic *(Figure 6)*. There was a generalised consensus on the potential of VR for the design process, as well as for which project types Virtual Reality is considered the most suitable -which curiously enough differs from the author's previous assumptions and with what has been most widely tested in the researched literature (Ekströmer et al., 2018; Rieuf et al., 2017; Stadler, 2021; Velásquez, 2020)-. The challenges and hindrances of adopting Immersive Technologies into the design process also presented similarities among all the interviewed designer-users, and were in part acknowledged by the developers and service providers met for the interview phase.

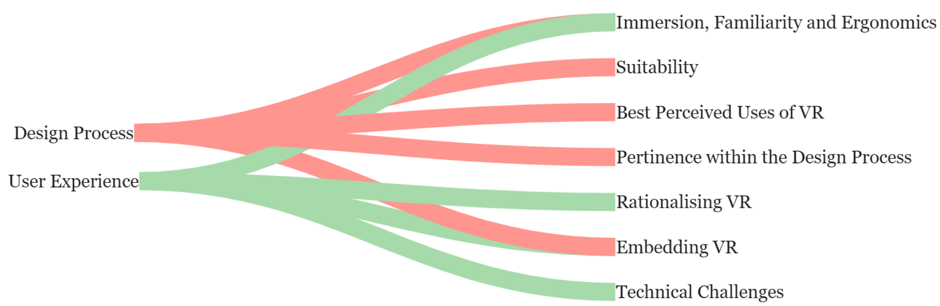

Figure 6. Top and Second Level Header Findings From the Semi-Structured Interview Sessions

The discoveries from this stage have been grouped into two categories, *Design Process* and *User Experience*, and seven different subcategories, ranging from technical aspects of virtual reality to best-perceived uses of VR for iterative processes:

- Immersion, Familiarity and Ergonomics

The interviews suggest that while there is a wide array of tools available, there are certain aspects of how VR is embedded within the design process that has hindered the take-off of the technology despite its availability.

According to one VR developer interviewed, VR still has a long way to go to create experiences that are leveraged to what is already familiar to the users, especially given the wide demographic of parties involved in a design project. This was also corroborated from a user's point of view. Three out of four designers interviewed state that when time presses -which is usually the case in design projects- it is faster to go back to familiar ways of problem-solving. *"When in a hurry, we tend to stick to what we are swift with; VR isn't one of those cases yet",* mentions one of the interviewees.

One of the developers interviewed mentioned how ergonomics, battery duration, the actual weight of current head-mounted displays, and haptic feedback are certain factors to consider that contribute to a slower rate of adoption of Virtual Reality in the design workspace. However, most of it is how UI has to be leveraged to create familiar interfaces that cater to everyone in a company, regardless of their age or level of expertise. Another interviewee stated that *"the people populating the platforms are what makes fifty per cent of the VR experience",* which also helps explain the adoption gap.

- Suitability

Contrary to current 2D solutions catered towards remote work, VR helps immerse and focus one hundred per cent on a project, which also has a drawback regarding VR exhaustion.

In terms of suitability, all users probed agreed that VR makes sense on bigger than hand-scale products, where, when billing a client by the hour, a hand-made cardboard prototype proves less cost-efficient or "*to simulate immersion in places that would otherwise be hard to place a physical mockup.*" It becomes useful when a design team can walk around a product, come inside or interact with certain aspects, where immersion can be benefited from.

In broad terms, the perceived value of VR for most interviewees was not necessarily *"on making things better, but to make things cheaper or faster to iterate and develop".*

- Best Perceived Uses within Iterative Design

Within the iterative and exploratory early stages of the design process, VR is perceived as a handy tool for rough prototyping, akin to the physical rapid prototyping method. *"There is value in limited, rough mockups, as they make concentrating in wrong places almost impossible",* states one interviewee. *"From a concept design aspect, rough VR prototypes give more information than sketching, although they are less visually appealing"*, mentions another one. The probed users discussed VR as being beneficial to block out ideas, ergonomics, spaces or environments for its immersion and sense of scale, to then delegate the technical aspect of further development to the team. It was also mentioned how limited resolution is critical for iteration. In that sense, VR, being virtually infinite in terms of zoom and details, has the risk of limiting the iterative process to just a few concepts because it allows one to go into detail in a design stage where lower detailed prototypes serve a better function. It does, compared to other remote 2D tools, *"help focus one hundred per cent into the task"*. One designer interviewed stated: *"VR for 3D modelling is like seeing through a keyhole. These tools can hinder the natural creative process."*

One last finding that pertains to this category is the idea of VR environments being used as persistent workshop spaces, *"we know how important persistent spaces are, for design reviews this has proven to be of great importance to our customers"* mentioned one of the interviewed developers.

- Pertinence within the Design Process

The perception of the pertinence of VR within the design process, according to the interviewees, is that it currently works better for design reviews. One design lead interviewed states, "*VR prototypes enable clients to cut through assumptions and make tangible decisions*." It works as a complementary technology to cycle between different product configurations when showing a product to a client. Another user also mentioned how they use VR constantly to meet and discuss a project, to immerse, test and interact with some aspects that would otherwise be too expensive to prototype physically.
From the developer side, one of the respondents mentioned how their user base used their platform the most for Design Reviews, Project Kick-offs and Scrum sessions.

- Rationalising VR

One partner at a design agency mentioned that "*for more detailed work, VR spins off as a project on its own instead of being a natural part of the process."* Another interviewee in a similar role stated, *"There is an intermediate step between CAD and VR that someone has to own, in order to optimise the geometry and all aspects of a model in order to achieve a comfortable framerate to work with."* In this regard, even from the developer's end, the top priority is to streamline the VR process, especially for collaboration.

VR is still felt as a project on its own rather than a tool to aid the design process to be factored into a design brief and organically integrated within the design workflow. It feels like a side-track project for the client's amusement rather than the process. So, being part of the project buy-in, a parallel polishing process goes with VR when used in later stages of the product design cycle, like design reviews.

- Embedding VR on a Workflow

All interviewees see the benefits that embedding VR on their workflow would bring, having solved the technical challenges that surface from the currently available solutions. In this regard, one design lead addressed how remote work had fragmented the collaborative process on Hard Consumer Goods design projects.

"*To incorporate VR in your team, you need to nudge your team into it, not force the use of Virtual Reality just for the sake of it*", mentions another interviewee. There are actions to be taken in software and dedicated desk -or floor- physical space to consider Virtual Reality as a tool rather than *"a gadget, a dismissable accessory".*

- Technical Challenges

The interviewees mentioned particular technical challenges that became transversal with both Users and Developers. As one of the latter mentions, *"we are constantly battling the limits of the hardware"*. These include both connection and UX. Streaming VR content, while it takes less bandwidth than a video call, has a more significant impact on the user experience, where latency issues can lead to overall discomfort and nausea compared to the lower risk of an intermittent call. All developers hinted at delay issues when connecting users on different continents.

On the User Experience aspect of it, all users mentioned how current VR solutions for the design industry are usually cumbersome to set up. Many variables must be considered for remote collaboration on more complex scenarios involving CAD models, which are mostly not optimised for VR. *"A one-click solution is still a long way off, unfortunately"*, comments one of the interviewees. For most of them, the biggest challenge is the current lack of practicality of the available solutions, where for VR to be considered feasible, it *"has to be better and easier than looking up something on YouTube".*

Following the triangulation research framework, the inclusion of a third source of research, a practical User Experience Usability Test, has been designed to investigate the topic further or even shed light on new significant points of the VR for the Design Industry user journey.

4. Usability Test - Fieldwork Design

Virtual Reality has already been widely researched and has a generally large amount of literature regarding UX and VR as a technology (Schäfer et al., 2023). This being said, during the literature review process and semi-structured interview analysis, a pattern that is not often mentioned in the reviewed publications started to emerge, which could eventually help elucidate the reasons why VR has not yet been unfolded to its full potential as a mainstream tool for the industrial design process. Stadler (2021) addresses the slow adoption rate of XR regardless of how convenient it has been demonstrated to be in Industrial Design and leaves open questions of how VR can be implemented in the activities of industrial designers during product development.

An argument deducted from the research that could justify this phenomenon is based on the finding that the reviewed literature tends to focus on the software solution rather than the entire setup process of a Virtual Reality co-working session. This fragmentation of the user experience leads to potential synthetic use scenarios, where the results and perception from the end-users and testers can be limited and biased.

To avoid possible confirmation biases and validate User Experience aspects from the very start of an Immersive Reality session, the Usability Test has been designed to consider -within the reason and scope of each test- the whole setup process of an HMD device, taking into consideration the fit and connection of the devices themselves, as well as troubleshooting and connection to a previously designed Collaborative Session hosted in one of the benchmarked existing VR suites. This has been designed to address and test the potential challenges more closely related to practicalities rather than the software on itself, which has already been hinted at in previous user testing sessions (Aikio, 2022; Truong, 2021).

4.1. Methodology

The structure of the usability test is based on the guidelines proposed by Nielsen (2023) and the US Government Department of Health and Human Services (2013) for conducting effective usability tests. They were intended to be executed as one-to-one instances, where the tests were recorded, transcribed and summarised, supported by field notes and a retrospective interview of each session with two Likert Scale questions that helped better compare the responses for each interviewee.

Regarding the metrics used to evaluate each session, besides the observational data and probing mentioned above, complementing the quantitative data gathered, *Time on Task*, *Successful Task Completion*, and *Critical and Non-Critical Errors* that lead to effective troubleshooting from the tester were measured.
A problem-solving task was added to the last task of the testing sessions to evaluate creativity. The facilitator also registered the number of iterations achieved within a certain time.

The observational data, recording analysis, probing and field notes were used as material for developing an emotion map based on Rusell's circumplex map of emotions (1980) and an affinity map in order to find patterns and validate the pain points and opportunities detected in the literature review and semi-structured sections of the research for the development of the thesis project. Complemented with the quantitative data analysis, these metrics aim to create a well-grounded, triangulated data set that might help grow the available content on the research of Virtual Reality for the design processes. This third instance of probing was also central to finding the answers to the thesis research questions.

The usability test considered an already defined user from the previous thesis chapters. Considering the scope and topic of the research, a simple overarching scenario was presented to the participants to give them an easier-to-follow context of use of the device. This decision is based on what Nielsen recommends for tests like the one presented, where overcomplicated scenarios can be counterproductive and lead to biased test sessions.

The pre-screening of testing users ensured a certain familiarity with VR. In any case, this knowledge was leveraged by a quick onboarding during the test session. The participants were selected on a technical and seniority basis to keep the sample as similar as possible to the composition of a design team in a professional context. This aimed to test younger and older designers to gather data from top-down decision-making scenarios and horizontal, collaborative ways of approaching a design project.

Figure 7. Usability Testing Session

After the pre-screening, eight people were approached for the test, with an equal gender distribution. Two testers were booked for the pilot run, and four were booked for the testing. Although the remaining two invitees expressed interest in the subject, they had to cancel because of scheduling conflicts. In addition, another two passersby with an Architecture background tested the immersive experience *(Figure 7)*. Even though they gave valuable feedback to the project, their testing procedure was relatively informal. Therefore, the information gathered from these last two users was not considered for the analysis and findings of the test.
In total, Designers of six different backgrounds, age brackets and levels of expertise were probed, summarised in *Table 3*.

The usability test was designed to last around seventy minutes, leaving enough room on each task to give room to the organic behaviours of the testers and possibly lead to interesting discoveries within the VR usability realm.

Tester Number	*Industry*	*Age*	*Testing Session*	*Session Date*
1	Design Student	25	Student	27.09.2023 - Pilot
2	Design Student	26	Student	27.09.2023 - Pilot
3	Design and Strategy Consultancy	25	Jr Level Consultant	28.09.2023
4	Industrial Design - UX	36	Senior Designer	03.10.2023
5	Industrial Design	40	Lead Designer	04.10.2023
6	Industrial Design - Service Design	31	Senior Designer	05.10.2023

Table 3. Usability Test Subjects

The test task scenario was designed to achieve a fair amount of iteration while offering a brief simple enough for the testers not to feel overwhelmed *(Figure 8)*. It has been built up on the guidelines Stadler (2020) used on his ImPro tool for testing the 3D modelling capabilities and simplicity of use in VR scenarios, compared to currently available commercial design suites. The tools available to the users and UI were purposely configured to be limited in both shapes and possibilities, based on what Balzerkiewitz and Stechert ((2020) suggest about the value of simple models to represent concepts and potential solutions in the early (2020) intentional purpose of serving as foundations for further design development.

The main design brief designed for the test sessions involved the rapid iteration and proposal of newer versions of a wheelbarrow. This particular object and task were carefully chosen to carry out a design activity that took the most advantage of the VR immersion and its advantage over designing bigger scale objects while keeping the assignment within a relatively simple boundary, by asking the users to design based on a familiar product with rather basic functions and ergonomics.

Figure 8. Overview of Immersive Usability Testing Scenario

With the intent of keeping the software aspect of the test as simple as possible, and based on the qualitative assessment of each tool benchmarked on the research chapter, it was decided to use *KeyVR* from *Luxion* as the testing tool of choice, as it is one of the simplest ones available, where in terms of the onboarding process and learning curve for first-time users, it is one of the few that claimed a one-click-to-VR feature. In line with Aikio's (2022) goal in his project, the aim of learning *KeyVR* to create VR content was not necessarily to become an expert content creator but to gain adequate knowledge about the subject to conduct usability tests to find valuable findings for the present research.

Although it was initially meant for the onboarding process to be a separate part of the testing, during the pilot test, a higher ease of use of the VR tool than assumed when designing the usability sessions was perceived. On account of this, and to streamline the testing process to leave more time for the testers to carry on with the third task of the session, the onboarding was embedded into the VR experience, using visual aids and a guided tour from the test facilitator.

It is crucial to disclose that although KeyVR is paid software, Luxion, after being contacted by the author regarding the Usability Tests for this thesis, kindly offered three cloud-based licences and free support for the entire duration of the master's project.

During the testing sessions, and after assessing the familiarity and ease of each subject with the VR tool in order to avoid possible accidents with dissociation between the physical and virtual environment, the facilitator virtually joined some of the subjects on the collaborative immersive scenario, adding an enhanced layer of reality to the prototyping experience, supported by some of the principles for creative thinking suggested by Adenauer et Al. (2013) on his research about Virtual Reality Technologies for Creative Design. Even though this was carefully conducted to affect the least amount of the natural interaction of the testers with the environment and task at hand, it is important to acknowledge the confirmation bias that the direct participation of the facilitator on a test can introduce to the results.

The specifics of the Usability Test Plan, how each task was designed, the Consent Agreement, and semi-structured interview questions are available for further study as *Appendix 3* to this thesis.

4.1.1. Practical and Ethical Considerations and Limitations

The testing sessions were done at the VR Hub, from Aalto Studios, a dedicated space for VR experiences with access to computers, HMDs and everything needed to successfully run the designed Usability Test. The test setup used two *Varjo Aero* headsets and two workstations equipped with tenth-generation *Intel i9* processors, 32GB of RAM each, and *Nvidia's RTX2080ti* GPUs. Even though these can still be considered on the high-end spectrum, they were launched over five years ago, in 2018, and therefore, some performance issues were present during the tests.

In addition to the ethical considerations regarding data privacy already been mentioned in a previous chapter, these usability tests are mindful of the "Evaluation apprehension" phenomenon, which predicts that "the awareness of being evaluated and judged by others, a member of a creative group might not associate ideas as freely and uninhibited for fear of being judged" (Gebbing et al., 2022, p. 7). This deviation from the results, as it would compare to a fly-in-the-wall experiment, is considered, especially given the limited number of test sessions being run, given the scope of the thesis.

The author recognises the limitations and biases introduced from such a small test sample. It is also acknowledged that the time allocated for the practical segment of the test session does not compare to a real-life scenario of explorative design and can only hint at the potential for design iteration on immersive experiences, which has been further discussed with each tester on the retrospective probing section of the test. This has been intentionally designed to keep the tests within a restrained time limit, considering that while an extended practical session would certainly give light to new findings within the topic, it would mostly corroborate what has already been suggested in the academic literature reviewed for this thesis (Adenauer et al., 2013; Rieuf et al., 2017; Yilmaz & Goken, 2016)

4.1.2. Testing Data Analysis

All the data recovered from the Usability Testing sessions has been coded and categorised into quantitative and qualitative data. From these, certain findings have been found that certainly help elucidate interesting aspects of the suitability of VR as a tool for the early stages of the design process.

- Quantitative Data

The information gathered from each tester questionnaire, coded in *(Figure 9)* as a spider graph, hints at a correlation between age range and familiarity with existing digital tools such as Miro or Figma; this assumes that being the testing sample rather small, this correlation could be a mere coincidence.

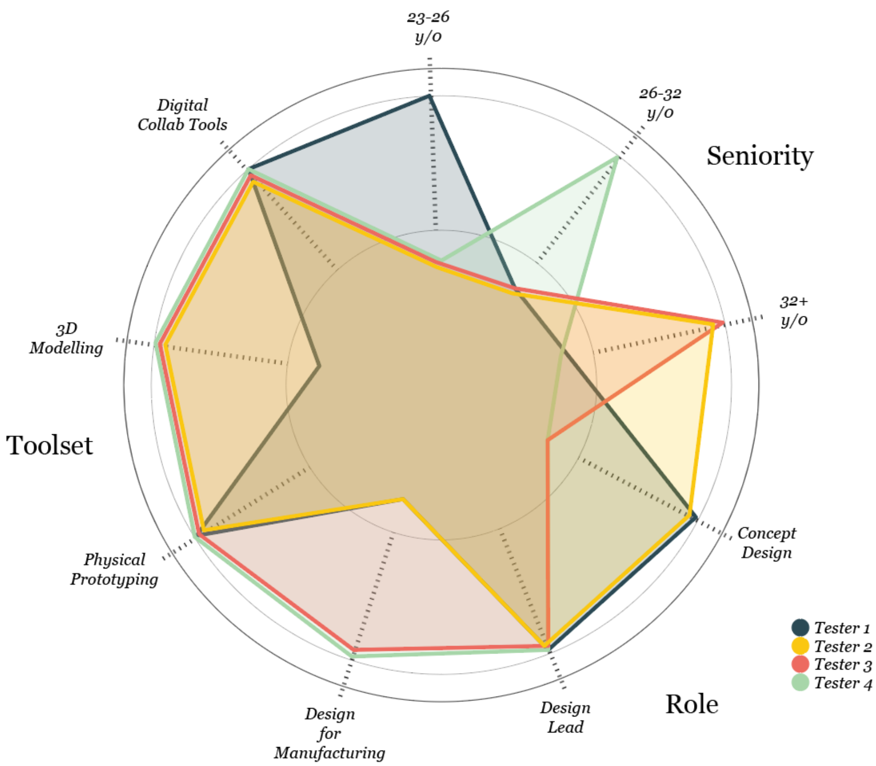

Figure 9. Spider Graph With Ethnographic Data of Testers

On the other hand, quantitative, measurable aspects of the testing sessions, such as Time to Complete, Critical Errors, Non-Critical Errors and Number of Iterations - specified in *Table 4* also shed light on valuable, objective insights about the immersive experience that demystified some preconceived assumptions about the setup and troubleshooting on VR platforms.

Setting up tasks in the testing sessions was a straightforward process, although it is worth mentioning that all testers commented on their tech-savviness. It was also mentioned that the number of steps and different software involved for the HMD to work correctly was high. This could eventually become a problem with less technology-driven members of a design team or senior stakeholders involved in a design project. Overall, there was a perception of a fragmented user experience regarding setup, even though it was easy for all four test participants to overcome.

Task 1: Setup	*Tester 1*	*Tester 2*	*Tester 3*	*Tester 4*	***Average***
Time to complete	1.5	6.5	5.4	4.1	**4.375**
Critical Errors	0	2	1	0	**0.75**
Non Critical Errors	2	4	3	1	**2.5**
Task 2: Exploration					
Time to complete	3	5	4.5	3	**3.875**
Critical Errors	1	0	1	0	**0.5**
Non Critical Errors	2	1	2	2	**1.75**
Task 3: Iteration					
Time Immersed	27	32	29	48	**34**
Number of Iterations	3	1.5	2	4	**2.625**
Critical Errors	0	2	2	1	**1.25**
Non Critical Errors	3	3	3	0	**2.25**

Table 4. Quantitative Data From Testing Sessions

It is important to note one of the shortcomings of the test; the testing scenario and design brief were prepared in advance, and it took four days for an experienced designer to set up and optimise the environment and assets for its use in VR, developing the scene and environment from scratch, to fit the design brief that was chosen to work with. This and the hand-holding approach to the onboarding process might have biased the exploratory Time-to-completion performances of the test, as it can have leveraged the field and made the whole process more straightforward and synthetic than originally planned.

On exploration, testers spent an average of *3.875* minutes getting used to the software, ten minutes less than what was originally planned. This suggests that the learning curve is substantially easier than expected. The tools available were purposedly limited, and therefore, the interaction skills to master were restricted to just two: Teleporting (movement) and grabbing. All testers mentioned their previous experience in gaming and how this gave them an advantage in their learning experience by making the proceeding a familiar task.

On average, testers spent ten more minutes than planned initially for the testing, even after being notified of the time that had passed. There may also be a correlation with the distorted perception of time when immersed.

While highly dependent on circumstances and computer performance, the number of iterations surpassed the author's expectations for the limited length of each testing session. The most iterations in one session came from the tester with the highest seniority.
As mentioned before, after assessing that the tester felt at ease and did not risk accidents while being immersed, the author joined the collaborative sessions in VR and purposely acted as a passive assistant to the tester to observe and understand the working dynamics that happened during the sessions. This was possible in three of the four sessions, with positive results and natural interactions akin to a physical design session.

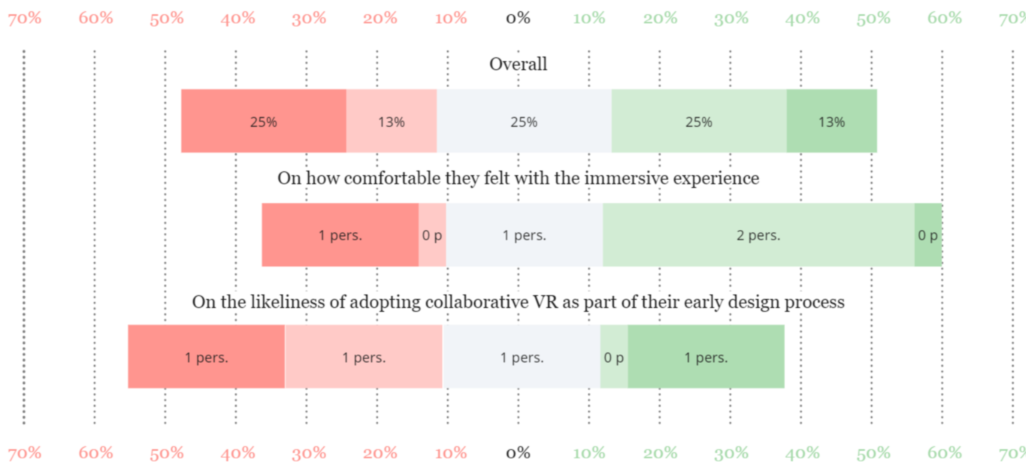

Figure 10. Likert Scale Answers From Usability Testing Sessions

In general, critical errors in all tasks were related to software instabilities caused by hardware processing power which mainly caused perception or motion sickness. Critical errors in all tasks were generally related to software instabilities caused by hardware processing power, which mainly caused perception or motion sickness. However, three out of four testers mentioned that those glitches were a determining factor when using VR for performing longer design sessions.

Besides the technical glitches already mentioned, there is a common denominator when further probing the reasoning behind each score. All testers mentioned that convincing the rest of their design team to adopt this tool for collaboration, significantly higher up the management hierarchy, could become a nuisance. All four also mentioned factors regarding monetary and accessibility costs to the technology. This last finding is interesting in the sense that it contradicts what literature suggests about the considerable cost reductions a VR tool would add to the product design cycle in general
(Balzerkiewitz & Stechert, 2020; Schäfer et al., 2023; Varjo Industries, 2021).

- Qualitative Data

Each field note extracted from the tests was analysed in conjunction with each session's recording and used for conducting two coding methodologies which helped surface non-objective aspects of the Usability Test.

First, out of 248 field notes, 178 were considered for assigning an emotion to them, following James Rusell's circumplex model (1980) to help map these in two axes and generate a heat map of how the entire process of prototyping in VR was perceived during the test sessions, and what where the major pain points that could potentially lead to an overall negative experience. The subjective nature of this analysis is recognised by accepting the accuracy problem of emotion identification and estimation. However, it aided in detecting major pain points of the experience while helping avoid confirmation bias from previous assumptions and instances of this research project.

The notes were clustered accordingly into the graph, leaving a fairly even distribution between *Negative* and *Positive* emotions, with 95 and 83, respectively *(Figure 11)*.

Out of the negative emotions, a vast majority were assigned to feelings of annoyance, distress and frustration. On further analysis, most of these pain points were directly related to performance issues and software glitches originating from hardware shortcomings that could be considered specific to the test. Said glitches caused motion sickness from low framerates, random software crashes and instances of overall discomfort.

Fourteen notes were assigned to the feeling of fear. These were related primarily to the fear and alarm emotions triggered by the differences between the physical and virtual space, where free movement led to a few instances of tripping or bumping into a wall.

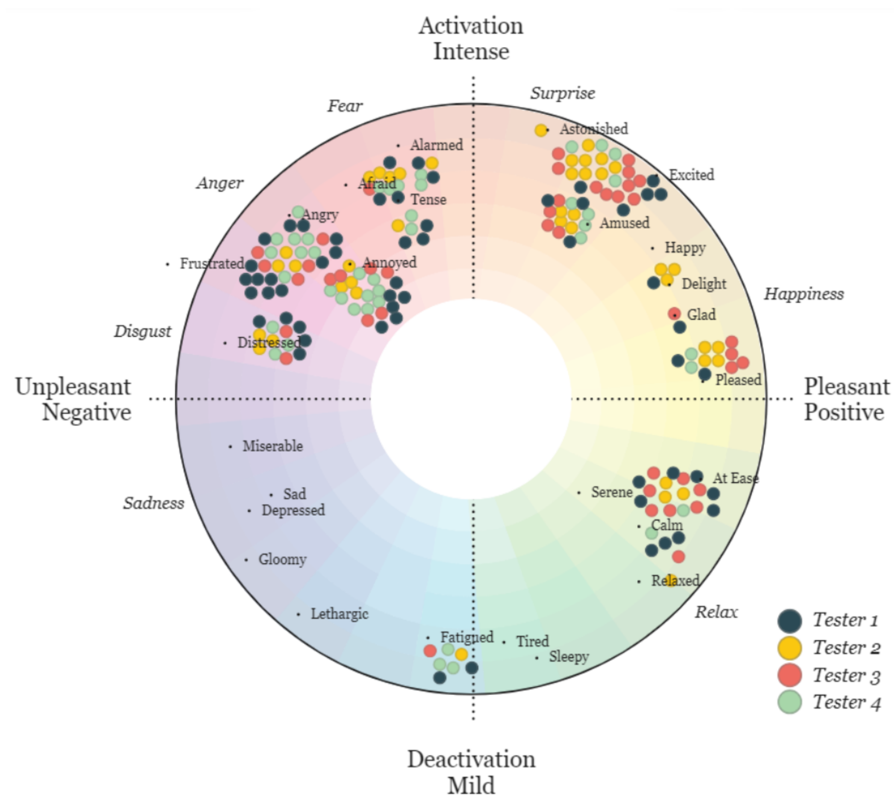

Figure 11. Emotion Distribution Graph According to Russel's Circumplex Model (1980)

All testers mentioned at least once the fatigue and intensity derived from long immersive sessions and how these factors could hinder a sustained use of VR as a design tool. One tester sent a message 30 minutes after the session stating that he was still feeling unstable, which, according to him, would mean he could not engage in any working activities for a sizeable amount of time after the test.

All participants felt at ease on the positive emotions axis with the low learning curve, straightforward setup process and short onboarding. Coincidentally, all four mentioned previous experiences in gaming, which made their navigation considerably easier and natural.

Even though all participants mentioned they had certain familiarity and had tried Virtual Reality for entertainment purposes before, all four showed surprise and excitement during the immersive sessions about the potential the VR tool could have for the early stages of the design process, pointing out how easy it was to iterate in three dimensions quickly, and how natural the interactions between the users online felt.

Furthermore, every test subject also demonstrated amusement when discussing the power and potential of constraining certain freedom of choice during the interaction to act as a catalyst for creativity, noting how limiting the available building blocks and the way they were displayed within the immersive scenario was vital for a streamlined, collaborative experience.

4.2. Results

Conducting an affinity map took three iterations to cluster and detect valuable patterns, insights and pain points from the testing sessions. These were categorised into three Top-Level headers and nine sub-categories that helped organise the data. Due to its nature, some clusters were shared between the main categories *(Figure 12)*. The main groups and subsequent sub-categories go as follows:

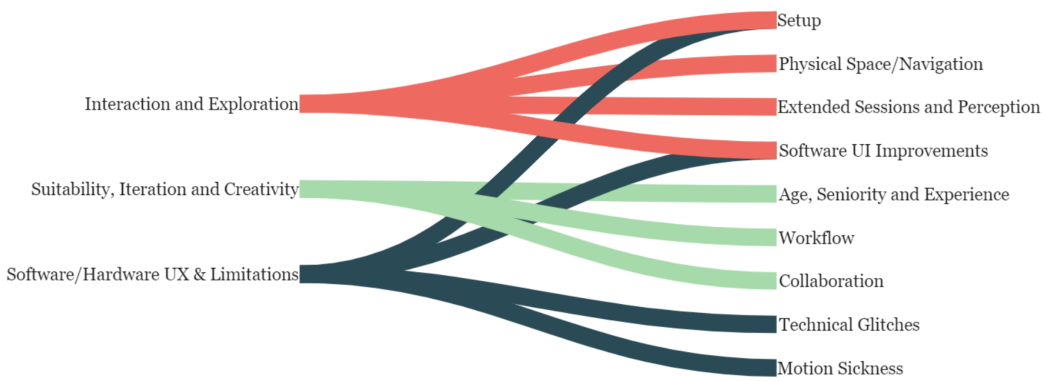

Figure 12. Top and Second Level Header Findings From the Usability Testing Sessions

- Interaction and Exploration

Contrary to what was assumed beforehand, the interaction and exploration of all users were intuitive, and no one found any major UI issues. In fact, they only took a brief moment to learn the controller basics and start exploring the scene immediately. One of the test subjects even mentioned how the realism of the virtual space prompted exploration.

Setup: Overall, the fitting and setup process felt smooth and familiar, although all participants mentioned how there were too many steps to achieve the goal. This hints at a generally fragmented experience with VR devices, as every brand has its own set of steps and proprietary software to run in the background to enable an immersive experience.

Physical Space and Navigation: One of the testers phrased the navigation in a way that clearly summarises what was observed during all the testing sessions: "*It is hard to discriminate the virtual from the physical world. It tricks your mind and takes you out of the flow*". While there are VR headsets that already offer virtual boundaries that work in conjunction with Mixed Reality, all participants felt distracted by the difference between the physical room and the virtual scene, remaining constantly aware of their movements to avoid bumping into the walls, tripping with the tethering cables, or hitting the desk with the controllers. This meant a repeated break in their workflow, potentially hindering the creative process.

Another navigation aspect worth mentioning was how mixing teleporting and physical movements to navigate the scene felt overwhelming and disorienting for most, at least during the first acclimation minutes.

Extended Sessions and Perception: During the tests, there was a general perception of exhaustion after extended use of the VR headset, which was primarily related to HMD discomfort and weight but also to immersion nausea and technostress. This might have been partly aggravated by the constantly occurring glitches and crashes of the software. For professional environments, this is certainly an aspect to have in consideration.

Testers also mentioned how time perception gets distorted, which can be corroborated by the Time to Complete quantitative metrics of the test and findings from the previous research project conducted by the author.

Software UI Improvements: All participants suggested UI and feature improvements concerning the software used for the tests, which could vastly improve their workflow and functionality. While these are specific to *KeyVR*, they all unintentionally mentioned the same categories: object grouping, picking and pasting, scaling and basic shape modifiers, and a more efficient way of pulling and pushing parts and pieces instead of being obliged to physically move them.

- Suitability, Iteration and Creativity

There was a consensus in the usability test sessions about how a collaborative VR tool like the one tested would vastly improve the exploratory and prototyping aspects of the design process. Contrary to their expectations, all participants appreciated how fast it was to iterate and create their own workflows while praising the purposedly limited array of shapes and features available as creative catalysts. The testers mentioned how the suitability of such a platform could benefit the exploration of bigger-scale objects, corroborating the insights gathered from the semi-structured interviews conducted earlier in this research project. It was also brought up how Virtual Reality does make sense as a tool only if the user experience is streamlined and optimised to the point of being comparable in speed and ease of use to commonly used methods such as CAD and Design Sketching. There were also talks of how the configuration of the space and its persistence can influence each user's creativity. However, creating a room for a particular brief would require a dedicated specialist or allocating working hours for this matter.

Workflow: Concerning the workflow, the overall perception was that while the learning curve was relatively low, the challenge was discovering each own - or each team's - workflow and that the experience from years of CAD work certainly influenced this process. One insight hinted at by one participant that is worth mentioning is that even though the prototyping process in itself might not have been faster than other methods like sketching or rapid physical prototyping, the immersion, scale and dimensionality of the experience gave the users an advantage over these, by providing a better understanding of each virtual iteration.

Collaboration: Upon analysis of the recordings, the online interactions within the immersive experience felt natural, and even though two subjects were present in the same physical space, the communication in VR tended to address the virtual avatar instead of where the sound came from in the physical room. One tester mentioned *"how these non-verbal cues of collaboration play an important role in the prototyping process"* and how this synchronic collaboration can lead to inspiration, especially compared to non-VR remote sessions.

Another notable aspect of collaboration was associated with how the testing scenario was configured, where having a shared displayed library of objects to build the prototypes with was considered, across all four participants, crucial for engaging in creative interaction with the rest of the team.

Age, Seniority and Experience: Coincidentally, all testers considered themselves tech-savvy and had previous experience in gaming, which might have helped lower the threshold and learning curve towards a positive experience. Two of them expressed concerns in this same subject when asked about the feasibility of implementing VR tools for teamwork, as they deemed it could be challenging for older team members, who can be assumed from a seniority standpoint tend to be higher on the decision-making hierarchy of a team, to naturally and effectively integrate Virtual Reality in their processes.

- Software & Hardware UX and Limitations

Most of the pain points and topics detected in this category, such as haptic feedback, reliability, ergonomics and other limitations, are areas that have already been discussed and developed in the Virtual Reality technosphere. One pain point came to light during the four testing sessions regarding the UX limitation and inconvenience of using the HMD with prescription lenses. While this could be tangential to the core topic of this research, it is certainly an interesting aspect influencing a considerable proportion of the VR user base.

Technical Glitches: Although the collaborative sessions were often plagued with technical glitches such as jittering, low framerates, and sudden crashes, most of these issues were caused by the outdated components and GPUs of the workstations used, which did not fully support the processing requirements of the tests. These shortcomings are currently being solved by cloud computing solutions, which outsource the processing power to remote servers, potentially leading to lighter, more comfortable Virtual Reality Headsets.

Motion Sickness: As a consequence of the aforementioned technical glitches, all testers experienced motion sickness, nausea and discomfort. This can be challenging in longer design sessions, and it is certainly a topic that needs to be looked into.

5. Discussion

The results from the three sources of research used for this project surfaced a series of findings that can help elucidate the suitability of VR as a collaboration tool for the early stages of the design process. The information gathered from the semi-structured interviews and usability testing sessions supports what the literature suggests about creativity and immersion (Gabriel, 2020; Gebbing et al., 2022; Rieuf et al., 2017; Stadler, 2021) but also gave way to previously undocumented advantages and challenges of these platforms, to the author's knowledge. As mentioned earlier in this document, the research follows Denzin's triangulation framework to validate the assumptions and research questions that arose as a starting point for the thesis by helping overcome the biases that might surface from a single research method.

These findings have been categorised into three dimensions that ultimately discuss and elaborate each one of the research questions: *Fitness: How VR is perceived fit as an exploratory tool*; C*o-Design in VR: How VR can add to the design process*; and *Streamlining UX: Considerations for enabling an overall better VR experience* (Figure 13).

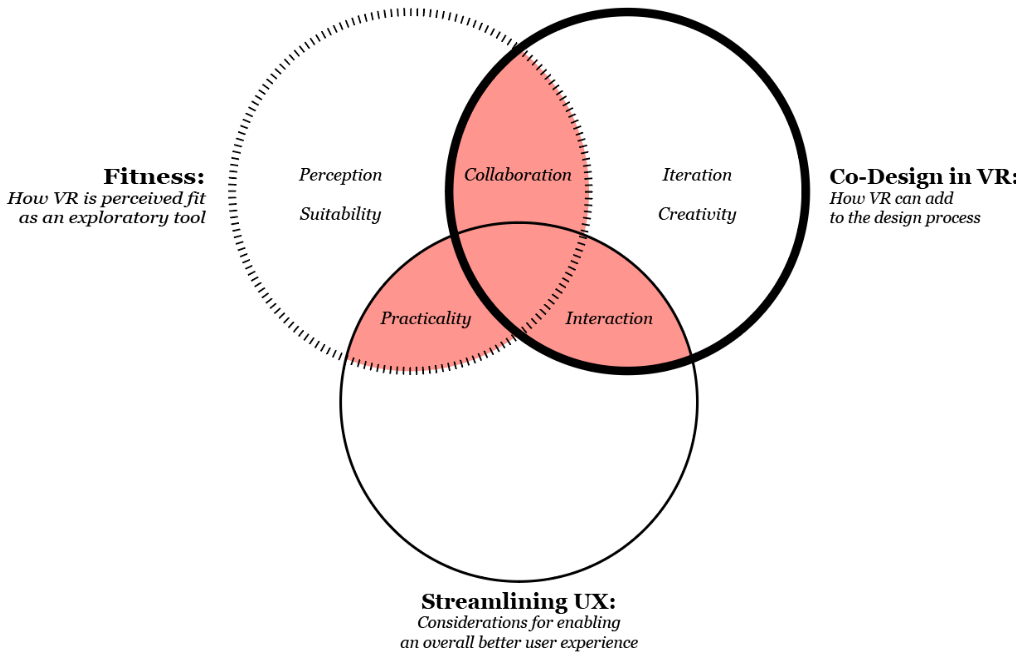

Figure 13. Three Dimensions of Findings

There is a fourth dimension regarding current technological challenges and limitations that significantly influence and hinder the overall VR experience and has been transversally mentioned throughout the research. According to Chen et al. (2022), users in the industry often suffer motion sickness as their most common symptom, which is triggered mainly by the low resolution and often choppy framerates that derive from limited processing power and poorly optimised scenes. Nevertheless, the consistent market growth over the last eight years, especially at a consumer level, is rapidly driving innovation and technology forward (Bellini et al., 2016; Mordor Intelligence, 2022), which, for the scope of this thesis, can support the assumption that most findings directly related to technology advancements -such as low framerates, HMD discomfort and processing power- are currently or will be addressed in the near future.

The discussion chapter is divided into three subchapters that elaborate on each of these dimensions mentioned above to, in section 5.4, summarise and answer the thesis' research questions.

5.1. Co-Design in VR

How can VR add to the design process?

It is pertinent to suggest that VR can elicit creativity in the early stages of the design process. While the literature on this particular topic is scant (Balzerkiewitz & Stechert, 2020; Stadler, 2021; Velásquez, 2020), it hints at the tool's effectiveness for the product design cycle. This statement has been substantiated by all three research methods conducted for this study, demonstrating Virtual Reality as a tool that encourages rapid iteration and adds a natural factor of spatiality to the process, enabling a better understanding of dimensions and proportional aspects of a design project, compared to other commonly used design tools (Ekströmer et al., 2018; Jimeno-Morenilla et al., 2016).

Analysing the gathered data from the semi-structured interviews and the user testing sessions, collaborative, immersive interaction has proven natural and intuitive for most probed users in this study. In this regard, the configuration of the immersive collaborative space has been suggested to play a significant role in enhancing co-creation. Aspects like the disposition of the elements on the scene and a communal library of virtual "building blocks" were shown to drive communication and collaboration. Furthermore, a psychological aspect of non-verbal cues characteristic of face-to-face meetings is also triggered in Virtual

Reality, mainly because the presence of avatars is critical for generating the empathetic response inherent in collaborative practices (Rieuf et al., 2017; Yoon et al., 2019). One of the developers interviewed also corroborated this assumption, stating that hand gestures and avatar interaction are crucial to maintaining empathy and engagement in VR meetings.

When designing a tool specific to the early stages of the design process, an ideal platform should limit the features and resolution of its prototyping tools to elicit creativity and circumvent choice overload. For these cases, the data from all three sources of research suggests that the lower the resolution of a prototype -and arguably the more limited the tool is- the better chance a designer (user) has to iterate fast and generate a creative workflow that avoids pigeonholing into fewer proposals with greater detail. What Gebbing (2022) suggests about deliberately constraining the prototyping tools and creative environment to increase performance can also be confirmed by what was gathered from the interviews and usability testing sessions. Rough prototyping is a fundamental stage of the design process, and Virtual Reality -within certain scales and product typologies- has a clear advantage over CAD and other available tools because of the added dimensional advantage that immersion brings.

One last benefit of Virtual Reality as a tool for the early, explorative stages of the design process that is worth mentioning is its potential as a persistent space to create pockets and workshops of creativity and iteration. *"You could purposely create a room for a specific brief"*, mentioned one tester. A persistent immersive studio, similar to what a collaborative Whiteboard is on platforms like Miro or Mural, can certainly add to the collaborative processes, emulating what has been suggested by the literature as ideal practices for collaboration and co-creation in the real world (IDEO, 2011; Mattelmäki & Visser, 2011).

5.2. Fitness

How VR is perceived fit as an exploratory tool?

The research conducted for this thesis suggests an aversion to adopting Virtual Reality as a tool in the industry that could be correlated to the concepts of familiarity with the technology and seniority -understood as years of professional experience and, therefore, age-. It could be argued that it has a close relationship with the perception and relationship that Design Lead roles have with Virtual Reality (Chen et al., 2022; Rogers et al., 2017), understanding that teamwork assumes top-down, hierarchical decision-making in terms of tools and methods to be used upon a design brief. The hypothesis is corroborated by studies carried out by Noghabaei et al. (2020) and Zaker & Coloma (2018) that have found a perceivable resistance from the managerial teams to the adoption of Virtual Reality in the AEC industry, most probably due to a lack of awareness on the topic (Truong, 2021).

The data gathered from the semi-structured interviews and Usability Testing probing hint at this hindrance too. One probed tester mentioned that even though he sees the potential of VR as a tool, "*it takes time to set up a scene, and I would have to convince other people from the team to join, especially up at a management level*". "*When in a hurry, we tend to stick to what we are swift with, not being VR one of those*", also commented a partner at a major design studio during the semi-structured interviews.

For Virtual Reality to be appreciated and adopted as a competitive alternative, it has to be perceived as simple and swift as other widely used tools such as sketching, rapid prototyping and CAD. Currently, to the extent of the benchmarked solutions, the available VR tools require optimisations and preparation for each project to operate seamlessly in a collaborative workspace. Even though this sense of cumbersomeness has a technological angle, there is also a significant influence related to the familiarity with Virtual Reality and the previous experiences current or potential users have had when the market was in its earlier phases, where the User Experience was still under early development. *"Even though VR has a lot of potential, it still lacks the practicality that would justify using it daily"*, adds one of the interviewees, a partner at a medium-sized Design Studio in Helsinki. In this regard, one key challenge to overcome is about UX and simplicity and how a unified user experience, instead of a fragmented ecosystem like the one present today, might help overcome the perception of a VR tool taking off as a project on itself.

Solving this problem and considering the suggestions made in the literature on Virtual Reality, which proposes that it is cost-effective within a product development budget by reducing expenses across the board, could increase the adoption of this tool. Despite the current usability challenges, Virtual Reality has been found to have great potential for exploration, collaboration, and iterative processes.

The user study and interviews revealed a consensus that Virtual Reality is not the universal, ultimate tool. It fits best for a particular scale of products, mostly bigger than hand-scale objects, such as hard consumer goods, medical and industrial equipment, automotive and sailing, architecture, and specific workplace dynamics with geographically dispersed stakeholders or remote work flexibility. This fitness categorisation might also help explain why, out of all the Designers contacted for the semi-structured interviews -even design leads that worked on the design of actual HMD devices- only the design practices that had a line of work that fell in these categories had, or currently use Virtual Reality in their workflows.

5.3. Streamlining UX

Considerations for enabling an overall better VR experience.

It is acknowledged that there are certain challenges when it comes to streamlining the process of setting up a VR collaborative session, which may be beyond the control of the users, such as bandwidth and processing power. However, some difficulties may be attributed to the users' preconceived notions and past experiences, as Chen et al. (2022) and Truong (2021) suggested. The results from the testing sessions suggest that most of these setbacks are more straightforward to overcome than the interviewed users initially suggested. This assumption is subject to further studies, as all the subjects from the semi-structured interviews and usability tests also mentioned they overall felt competent with technology and troubleshooting. While all the triangulation sources could confirm it, the sample size for both research methods was limited, so it cannot constitute a generalised statement.

Regardless, in order for a Virtual Reality tool to achieve transversal adoption across all design studios and levels of seniority, it has to become a consistent and stable platform: the UX must be flawless not only from an end software perspective but on every step of the user journey, from the very first time the end-user turns an HMD on. For this to be solved, one central pain point to address is the fragmentation of the VR ecosystem, which, due to scarce unifying usability standards and platforms, is highly dependent on which brand of headset is selected.

Physical space and navigation are paramount to a well-designed immersive experience. One major detected challenge in Virtual Reality is the incongruence between the physical and virtual space. Due to the immersive nature of VR, during the test sessions, there was a constant state of awareness from the users to avoid tripping or bumping into physical objects. Although not mentioned in the reviewed literature, this distraction might cause a break in the flow state looked for in the exploratory stage of the design process. There is an interesting topic related to collaboration to discuss in this regard. The degree of freedom of movement a Mixed Reality set-up confers by overlaying the 3D objects on top of the physical space is challenging to emulate in shared virtual spaces, where there is a need for one unifying scenario to work with that could equalise the sheer amount of possibilities and configurations of each remote worker's physical workplace.

In this regard, VR could also be organically nudged into the workspace to remain a top-of-mind tool. Technical disadvantages aside, insights from the semi-structured interviews suggest that dedicated physical space within the office could aid in its adoption while also helping solve navigation restrictions that result from the mentioned discordance between the physical and virtual space.

Last, and from a software perspective, an ideal VR platform should be developed with consideration of extended use sessions, the intensity of being hyperfocused and the distortion of time perception, which can be bent when engaged in an immersive activity (Csikszentmihalyi, 2000). This last phenomenon was also present in all usability test sessions, and curiously enough, the amount of time spent immersed was not directly related to the physical well-being of the testers. The time distortion could be addressed to good advantage on a collaborative instance by subtly marking time progression on a meeting by adding a day/night cycle on the render engine, which would provide an added layer of realism to the whole experience and would, therefore alleviate the technostress and overwhelm associated with the extensive use of Immersive Experiences (Gebbing et al., 2022).

5.4. Meeting the Objective and Research Questions

This subchapter answers the research questions with the insights that surfaced from the development of this thesis project. The advantages, challenges, and recommendations for using VR as a tool for the early stages of the design process are highlighted and outlined.

Question 1: *What are the advantages associated with using Virtual Reality within the exploratory part of the Design Process?*

Virtual Reality has several benefits as an exploratory tool for the design process over traditional, widely used tools. It has been found to stimulate creativity, encourage rapid iteration and add a dimensional edge to form exploration. It also allows design teams to remotely achieve a comparable empathy to physical meetings when immersed, which serves as one of the foundations for collaborative practices. In addition, VR enables flexibility in the workspace to create "pockets of innovation" by creating persistent spaces and virtual dedicated workshops that do not require the physical space for creating an iterative and rich experience during a product design cycle.

Last, Virtual Reality tools have been found to bring significant cost reductions in over 90% of the projects that have utilised the technology, streamlining, and optimising specific processes such as prototyping and travel costs in both time and pecuniary terms.

However, VR is not a one-size-fits-all solution. It is best suited for designing larger-scale products, such as hard consumer goods, medical and industrial equipment, automotive and sailing, architecture, and specific workplace dynamics with geographically dispersed stakeholders or remote work flexibility. VR can provide the significant benefits mentioned above for these products, including cost savings, improved collaboration, and a more efficient and, ultimately, more creative design exploration process.

Question 2: *What are the current challenges hindering the integration of VR into the design process?*

Despite how Virtual Reality has been found to be a valuable tool for collaborative and explorative stages of the design process, this study has detected a series of challenges that need to be addressed to ensure the widespread adoption of the technology within the industrial design practice. The most prominent one is technological limitations, which lead to performance issues (and, therefore, increased motion sickness) and exhaustion derived from short battery life and weight restrictions. It could be argued that it is a challenge currently addressed by the natural progress of technology and consistent growth of the market, which will inevitably drive innovation in this subject.

Another major challenge has to do with a currently fragmented User Experience and the perceived sense of clunkiness of the technology from the decision-makers in Design Companies and the AEC industry, which, at the current stage of development, still feels less polished or practical than widely used exploratory methods.

A third challenge to overcome is related to the technostress and distorted time perception inherent in extended immersive sessions, which could even -according to the experience of one of the test subjects- impede the normal labour function after a VR meeting.

Last, a significant obstacle is related to the discordance between the physical working space -usually limited- and the potentially infinite virtual scenario, which tends to break the flow state by making the user constantly aware of their physical surroundings, with fear of bumping or tripping into any objects present. This is exceptionally particular in remote working scenarios, where the available physical space of each team member can vary greatly.

Question 3: *How can Virtual Reality be nudged to be organically incorporated into a Design Workflow, especially in the earlier stages of a project?*

Virtual Reality has great potential to be incorporated into a Design Workflow once some of the challenges associated with the technology are overcome. The following is a series of high-level recommendations that surfaced from the three research approaches of this thesis that could aid in nudging VR as a widely adopted tool for design.

Overcoming Preconceived Notions: Address the challenges and preconceptions about setting up a VR collaborative session, targeting mainly managerial and leading roles. This could involve providing clear instructions, troubleshooting guides, and reassurances about how Virtual Reality's setup process and learning curve are becoming as swift as other widely adopted exploratory tools. Another recommendation would be strategically communicating the cost reductions and return on investment that Virtual Reality brings to a project, as the academic literature has evidenced.

Address the Ecosystem Fragmentation: Work towards further developing and unifying usability standards and platforms to address the fragmentation of the VR ecosystem. An industry-wide standard can certainly help to ensure a flawless user experience from the moment the end-user turns the Head-Mounted Display, which has been proven paramount to achieving the *practicality* aspect of Virtual Reality, which will ultimately influence the decision-making of the end-users when selecting a design tool for their processes.

Dedicated Physical Spaces: Whenever possible, to nudge VR to become a top-of-mind design tool, consider allocating a dedicated physical space for Virtual Reality in office setups. A hub could also help address the navigation restrictions due to the discordance between the physical and virtual spaces observed during the usability testing sessions.

Physical Space and Navigation: It is essential to pay special attention to the design of virtual space and navigation within the VR environment. Consider the incongruence between the physical and virtual space users might encounter, and find ways to minimise distractions that might break the flow state during the design process.

Software Considerations: One last recommendation in the software realm is to develop collaborative VR platforms with extended use sessions in mind. Consider the intensity of being hyperfocused and the distortion of time perception when engaged in an immersive activity. For instance, subtly marking time progression could provide an added layer of realism and alleviate the technostress associated with the extensive use of immersive experiences.

5.5. Limitations

Given the technical limitations, the process's usability testing and probing stage has been designed to look into only one specific aspect of a complex technology. Nonetheless, the data gathered from this should suffice to answer and validate what has been presented as research questions within the reach and limited scope of a Master's thesis.

This being said the present document acknowledges and assumes the shortcomings and biases from the literature review, semi-structured interviews and usability testing sessions that can emerge from smaller research datasets, small testing samples, and the use of only one type of HMD to test and validate hypotheses that pertain to a whole category of devices. The limitations of the UX testing sessions have also been mentioned in detail in that particular chapter of this study.

5.6. Application and Further Steps

The recommendations for VR experiences presented in this chapter could be further developed using the three dimensions mentioned *(Co-Design in VR, Fitness and Streamlining UX)* as guidance to present a framework for good Virtual and Extended Reality practices, hoping to contribute not only to the research and literature of the use of VR for the early and exploratory stages of the design process but also to the development of a robust VR ecosystem that could aid designers to enhance their roles in the industry and foster creativity in novel and enticing ways.

It is worth mentioning that throughout the progression of the study, the product team from one of the leading tools currently available, Luxion's KeyVR, demonstrated an active interest in the outcomes of this thesis. The data gathered, recommendations, and project outcomes could further improve their -already incredible- products by enriching their knowledge of VR usage from an end-user perspective.

6. Conclusion

This study has investigated the use of VR as a collaborative tool for exploration, iteration and rapid prototyping in the early stages of the design process. The scope of the thesis was based on the British Design Council's Double Diamond framework, limiting the research to the Definition/Requirements and Iterative Design stages of a design process.
Denzin's triangulation method was used to validate the research, gathering data and insights from a literature review on the subject to define and prospect the feasibility of the topic, a benchmarking and semi-structured interview process from key stakeholders in both the design industry as end-users and VR software development players. Third, it included a series of Usability Testing sessions that followed a selected sample of industrial designers while setting up and interacting in an immersive, collaborative workspace developed by the author specifically for this study.

The insights generated through the triangulation method of this thesis presented an overview of how VR is currently perceived in the industry, its actual usage and benefits, but also challenges that have been demonstrated to be significant contributors to the slow rates of adoption of Virtual Reality as a tool, regardless of the consensus of immersive technologies being of great potential for collaborative, explorative practices in the design industry that go beyond current technological limitations.

There is a discordance between the academic and professional worlds in the knowledge regarding virtual reality, which is reflected by the amount of research on the technology versus its actual, practical usage within the industry. In order to align this and foster the adoption of VR as a tool, further research should be conducted focusing not only on the practicalities of Immersive, Collaborative experiences, which its overall User Experience will only get refined with the actual professional end-users actively driving these platforms forward but perhaps in the empirical and analytical studies of how cost-effective the implementation of Extended Reality can be for a project, to cater to the managerial and leading roles in the Design Industry, which are the ultimate decision-makers in the adopted design methodologies and tools to be used in the product design cycle.

References

Adenauer, J., Israel, J. H., & Stark, R. (2013). Virtual Reality Technologies for Creative Design. In A. Chakrabarti (Ed.), *CIRP Design 2012* (pp. 125–135). Springer. https://doi.org/10.1007/978-1-4471-4507-3_13

Aikio, H. (2022). *Possibilities of extended reality in product development processes in a technology company, state of the art and projections*. Aalto University.

Amabile, T. (2006). How to Kill Creativity. In J. Henry, *Creative Management and Development* (pp. 18–24). SAGE Publications Ltd. https://doi.org/10.4135/9781446213704.n2

Balzerkiewitz, H.-P., & Stechert, C. (2020). THE EVOLUTION OF VIRTUAL REALITY TOWARDS THE USAGE IN EARLY DESIGN PHASES. *Proceedings of the Design Society: DESIGN Conference*, *1*, 91–100. https://doi.org/10.1017/dsd.2020.159

Bellini, H., Chen, W., & Sugiyama, M. (2016). *Virtual and Augmented Reality* (Equity Research 1; Profiles in Innovation, p. 30). The Goldman Sachs Group, Inc. https://www.goldmansachs.com/intelligence/pages/technology-driving-innovation-folder/virtual-and-augmented-reality/report.pdf

Bernardo, N., & Duarte, E. (2021). Immersive Virtual Reality in an Industrial Design Education Context: What the Future Looks Like According to its Educators. *Computer-Aided Design and Applications*, *19*(2), 238–255. https://doi.org/10.14733/cadaps.2022.238-255

Berni, A., & Borgianni, Y. (2020). Applications of Virtual Reality in Engineering and Product Design: Why, What, How, When and Where. *Electronics*, *9*(7), 1064.

https://doi.org/10.3390/electronics9071064

Bishop, I., Wherrett, J., & Miller, D. (2001). Assessment of path choices on a country walk using a virtual environment. *Landscape and Urban Planning*, *52*, 225–237. https://doi.org/10.1016/S0169-2046(00)00118-3

Biskjaer, M. M., Onarheim, B., & Wiltschnig, S. (2011). The Ambiguous Role of Constraints in Creativity: A Cross-Domain Exploration: Design, Development and Research 2011. *Proceedings of Design, Development and Research 2011 : Annual Research Conference of the Faculty of Informatics and Design*, 104–114.

Boyce, C., & Neale, P. (2006). *CONDUCTING IN-DEPTH INTERVIEWS:*

British Design Council. (2019, May 17). *Framework for Innovation: Design Council's evolved Double Diamond*. https://www.designcouncil.org.uk/our-work/skills-learning/tools-frameworks/framework-for-innovation-design-councils-evolved-double-diamond/

Buxton, B. (2007). Where Is the User in All of This? In *Sketching User Experiences* (pp. 143–144). Elsevier. https://doi.org/10.1016/B978-012374037-3/50060-2

Caputo, F., Greco, A., D'Amato, E., Notaro, I., & Spada, S. (2018). On the use of Virtual Reality for a human-centered workplace design. *Procedia Structural Integrity*, *8*, 297–308. https://doi.org/10.1016/j.prostr.2017.12.031

Chen, Z., Chen, K., & Cheng, J. C. P. (2022). ISM-based analysis of VR-AEC adoption barriers and their inner mechanisms. *Engineering, Construction and Architectural Management*, *ahead-of-print*(ahead-of-print). https://doi.org/10.1108/ECAM-01-2022-0085

Csikszentmihalyi, M. (2000). *Beyond boredom and anxiety* (pp. xxx, 231). Jossey-Bass.

Department of Health and Human Services. (2013, November 13). *Usability Testing*. Department of Health and Human Services. https://www.usability.gov/how-to-and-tools/methods/usability-testing.html

Ekströmer, P., Wängdahl, J., & Wever, R. (2018). *VIRTUAL REALITY SKETCHING FOR DESIGN IDEATION*.

Fast-Berglund, Å., Gong, L., & Li, D. (2018). Testing and validating Extended Reality (xR) technologies in manufacturing. *Procedia Manufacturing*, *25*, 31–38. https://doi.org/10.1016/j.promfg.2018.06.054

Flick, U. (2014). *An Introduction to Qualitative Research*. SAGE.

Gabriel, A. (2020). *Evaluating the utility of multi-user VR in product development*. Aalto University.

Gebbing, P., Lattemann, C., & Siemon, D. (2022, June 17). *Creativity Drivers: Design Principles for Virtual Creative Collaboration*.

Guion, L. A., Diehl, D. C., & McDonald, D. (2011). Conducting an In-depth Interview. *EDIS*, *2011*(8). https://doi.org/10.32473/edis-fy393-2011

Hogan, J., Salo, A., Rzig, D. E., Hassan, F., & Maxim, B. (2022). *Analyzing Performance Issues of Virtual Reality Applications* (arXiv:2211.02013). arXiv. http://arxiv.org/abs/2211.02013

IDEO (Ed.). (2011). *Human-Centered Design: Toolkit* (2nd ed). IDEO.

Interaction Design Foundation. (n.d.). *What is Design Thinking?* The Interaction Design Foundation. Retrieved 3 April 2023, from https://www.interaction-design.org/literature/topics/design-thinking

Jimeno-Morenilla, A., Sánchez-Romero, J. L., Mora-Mora, H., & Coll-Miralles, R. (2016). Using virtual reality for industrial design learning: A methodological proposal. *Behaviour & Information Technology*, *35*(11), 897–906. https://doi.org/10.1080/0144929X.2016.1215525

Khronos Group. (2019, July 29). *OpenXR - High-performance access to AR and VR —collectively known as XR— platforms and devices*. The Khronos Group. https://www.khronos.org/openxr/

Lee, J. H., Yang, E. K., & Sun, Z. Y. (2019). Design Cognitive Actions Stimulating Creativity in the VR Design Environment. *Proceedings of the 2019 on Creativity and Cognition*, 604–611. https://doi.org/10.1145/3325480.3326575

Loomis, J. M., Blascovich, J. J., & Beall, A. C. (1999). Immersive virtual environment technology as a basic research tool in psychology. *Behavior Research Methods, Instruments, & Computers*, *31*(4), 557–564. https://doi.org/10.3758/BF03200735

Martin, B., & Hanington, B. (2012). *Universal Methods of Design: 100 Ways to Research Complex Problems, Develop Innovative Ideas, and Design Effective Solutions*. Rockport Publishers.

Mattelmäki, T., & Visser, F. S. (2011). Lost in CO-X - Interpretations of Co-Design and Co-Creation. *Proceedings of IASDR'11, 4th World Conference on Design Research, Delft University,*. https://research.aalto.fi/en/publications/lost-in-co-x-interpretations-of-co-design-and-co-creation

Moran, K., & Nielsen Norman Group. (2023, July 20). *Qualitative Usability Testing: Study Guide*. Nielsen Norman Group. https://www.nngroup.com/articles/qual-usability-testing-study-guide/

Mordor Intelligence. (2022). *Virtual Reality (VR) Market—Growth, Trends, COVID-19 Impact, and Forecasts (2022—2027)* (p. 120) [Market Report]. Mordor Intelligence. https://www.researchandmarkets.com/reports/4745431/virtual-reality-vr-market-growth-tr ends#src-pos-5

Mujber, T. S., Szecsi, T., & Hashmi, M. S. J. (2004). Virtual reality applications in manufacturing process simulation. *Journal of Materials Processing Technology*, *155–156*, 1834–1838. https://doi.org/10.1016/j.jmatprotec.2004.04.401

Narasimha, S., Scharett, E., Madathil, K. C., & Bertrand, J. (2018). WeRSort: Preliminary Results from a New Method of Remote Collaboration Facilitated by Fully Immersive Virtual Reality. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *62*(1), 2084–2088. https://doi.org/10.1177/1541931218621470

Oculus VR. (2012, November 28). *Update on Developer Kit Technology, Meta Quest Blog*. https://www.oculus.com/blog/update-on-developer-kit-technology-shipping-details

Otieno, M. A. (2023). Affinity Research Approach. In J. M. Okoko, S. Tunison, & K. D. Walker (Eds.), *Varieties of Qualitative Research Methods: Selected Contextual Perspectives* (pp. 21–28). Springer International Publishing. https://doi.org/10.1007/978-3-031-04394-9_4

Pilcicki, R., Siemon, D., & Lattemann, C. (2021, August 9). *How Virtual Teams Collaborate Creatively under Communication Constraints*.

Reiners, D., Davahli, M. R., Karwowski, W., & Cruz-Neira, C. (2021). The Combination of Artificial Intelligence and Extended Reality: A Systematic Review. *Frontiers in Virtual Reality*, *2*. https://www.frontiersin.org/articles/10.3389/frvir.2021.721933

Rieuf, V., Bouchard, C., & Aoussat, A. (2015). Immersive moodboards, a comparative study of industrial design inspiration material. *J. of Design Research*, *13*(1), 78. https://doi.org/10.1504/JDR.2015.067233

Rieuf, V., Bouchard, C., Meyrueis, V., & Omhover, J.-F. (2017). Emotional activity in early immersive design: Sketches and moodboards in virtual reality. *Design Studies*, *48*, 43–75. https://doi.org/10.1016/j.destud.2016.11.001

Rigby, D., Sutherland, J., & Takeuchi, H. (2016, April 20). The Secret History of Agile Innovation. *Harvard Business Review*. https://hbr.org/2016/04/the-secret-history-of-agile-innovation

Rogers, W. A., Mitzner, T. L., Boot, W. R., Charness, N. H., Czaja, S. J., & Sharit, J. (2017). UNDERSTANDING INDIVIDUAL AND AGE-RELATED DIFFERENCES IN TECHNOLOGY ADOPTION. *Innovation in Aging*, *1*(Suppl 1), 1026. https://doi.org/10.1093/geroni/igx004.3733

Russell, J. (1980). A Circumplex Model of Affect. *Journal of Personality and Social Psychology*, *39*, 1161–1178. https://doi.org/10.1037/h0077714

Sanders, E. B.-N. (2000). Generative Tools for Co-designing. In S. A. R. Scrivener, L. J. Ball, & A. Woodcock (Eds.), *Collaborative Design* (pp. 3–12). Springer London. https://doi.org/10.1007/978-1-4471-0779-8_1

Sanders, E., & Stappers, P. J. (2008). Co-creation and the New Landscapes of Design. *CoDesign*, *4*, 5–18. https://doi.org/10.1080/15710880701875068

Schäfer, A., Reis, G., & Stricker, D. (2023). A Survey on Synchronous Augmented, Virtual, andMixed Reality Remote Collaboration Systems. *ACM Computing Surveys*, *55*(6), 1–27. https://doi.org/10.1145/3533376

Stadler, S. (2020). IMPRO: IMMERSIVE PROTOTYPING IN VIRTUAL ENVIRONMENTS FOR INDUSTRIAL DESIGNERS. *DS 102: Proceedings of the DESIGN 2020 16th International Design Conference*, 1–1384. https://doi.org/10.1017/dsd.2020.81

Stadler, S. (2021). *The Integration of Virtual Reality into the Design Process*. TUM School of Engineering and Design.

Thomas Jefferson University, & Ozcan-Deniz, G. (2019). Expanding applications of virtual reality in construction industry: A multiple case study approach. *Journal of Construction Engineering, Management & Innovation*, *2*(2), 48–66. https://doi.org/10.31462/jcemi.2019.02048066

Truong, P. (2021). *Proof-of-concept demo for collaborative machine room planning in Virtual Reality*. Aalto University.

Varjo Industries. (2021). *Virtual and Mixed Reality for Industrial Design [White paper]*. Varjo. https://varjo.com/e-book/white-paper-using-virtual-and-mixed-reality-in-industrial-design/

Velásquez, C. (2020). *Examining Virtual Reality As An Empathizing Tool for Early Ideation Stage in Design*. Georgia Tech School of Industrial Design.

Visser, F. S., Stappers, P. J., van der Lugt, R., & Sanders, E. B.-N. (2005). Contextmapping: Experiences from practice. *CoDesign*, *1*(2), 119–149. https://doi.org/10.1080/15710880500135987

Voigt, M., Niehaves, B., & Becker, J. (2012). *Towards a Unified Design Theory for Creativity Support Systems*. 152–173, Springer, Heidelberg. https://doi.org/10.1007/978-3-642-29863-9_13

Yilmaz, B., & Goken, M. (2016). Virtual reality (VR) technologies in education of industrial design. *. . Virtual Reality*.

Zibrek, K., Martin, S., & McDonnell, R. (2019). Is Photorealism Important for Perception of Expressive Virtual Humans in Virtual Reality? *ACM Transactions on Applied Perception*, *16*(3), 1–19. https://doi.org/10.1145/3349609

Appendices

Appendix 1a. Key Industry Players Interview Plan - VR for Co-Design

by Nicolás Robertson De Ferrari, Master Thesis Project.

Collaborative and Industrial Design.

Aalto University School of Arts, Design and Architecture

The structure of the interviews is based on Guion's (2011) and Boyce's (2006) guidelines for conducting in-depth interviews for academic purposes. They are intended to be conducted as semi-structured, qualitative interviews, where the sessions will be recorded, transcripted and summarised while being supported by field notes of each instance. These will be used as data to develop an affinity map in order to find possible pain points and opportunities for the development of the thesis project and subsequent tests to validate the hypothesis and research questions.

Being the interviewees in a work environment, the extent of the interview has been designed to last no more than 45 minutes, leaving enough room to finish the interview earlier or extend it to an hour if needed.

Participants

- Place of interview:
  Ideally, face-to-face, Remote Call also possible

- Recruitment
  Personal Invitations

- Profile
  VR Software Development industries focused on productivity tools that ideally cater to creative practices such as Design and Architecture.
  Interviewee with a technical or academic background.

Procedure

- Introduction: Brief introduction to the interviewer, written consent for recording the session, and context of the Thesis (05 min)

- Ice-Breakers: Concise questions regarding the area of expertise of the interviewee to break the ice and segway into the main topic. (05 min)
- Main Interview: Open-ended questions regarding VR, its use in remote working environments, creativity, current limitations and where the technology is headed towards. (30 min)
- Closing: Leading to the last comments, closing words and greetings (5 min)

Collected Data

- Oral consent from the interviewee.
- Recording or taping, depending on the interview context.
- Field notes on the interview.
- Interview transcript and summary.

Details	
Interviewee Name	
Company	
Role	
Place of the Interview	
Date of the Interview	

Script/Guide Questions	Field Notes
1. **Consent** (2 mins) Thank you so much for agreeing to this meeting, I have	

been researching and working on this subject for quite some time, and to have the point of view of an expert on the area is of so much value to my project. I'd like to ask you first if I could record this meeting and sign this written consent giving permission for it.

This is just for personal use, so I can go through the conversation afterwards and write down and summarise some important aspects that I might have missed.

Needless to say, if you mention something that you'd like to leave out of the summary, please let me know, and I'll take note of that. I'll be especially careful to leave out any sensitive information in terms of developments and proprietary technology, so there is nothing to worry about 🙂.

Do you have any questions before we start?

2. **Introduction** (3 mins)

As a quick introduction, my name is Nicolas Robertson, and besides my day Industrial Design/Product Viz job, I'm doing my master's thesis at Aalto University (in Finland), in Collaborative and Industrial Design.

To give you a bit of context on my thesis topic, I'm currently working on a VR tool to validate how creativity is elicited when working in remote teams in the Design Industry. The plan is to build upon a collaborative, immersive scenario of the early stages of the design process (namely moodboarding or rapid mockup) and A/B test how a design team would work on VR versus face-to-face and validate if VR can elicit or enhance creative activities.

I'm aware -and have tried some- that there are a wide variety of design-review-focused VR tools available on the market, hence my idea of elaborating on these earlier stages, which are more on the building together freely aspect of design. Much blurrier and less structured framework if you ask me.

The hypothesis is that an immersive environment addresses a broader array of non-verbal cues that are linked to creative activities than current collaborative tools such as Miro or Teams, being especially true for consumer hard goods design processes, to the point that telepresence in these cases can be directly comparable, or as effective as to being face to face

3. **Ice Breakers** (5 mins)

Enough of myself! Would be great if you could tell me a bit more about yourself, your current line of work and -if possible- what you are working on nowadays?

What led you to develop VR solutions?

4. **Main Interview** (30 mins)

To your experience, have you used, or do you see VR as a tool for creativity in product development?

For what phases of this product cycle do you see VR being best suitable?

What are the current limitations to Virtual Reality that still need to be addressed for it to take off to the business mainstream?

How do you think User Experience can be tuned to make the transition from physical to immersion closer to seamless?

How do you see the future of VR, especially with the latest newcomers to the market? *[See if it leads to* *organically mention Apple's and Meta's newest additions to the ecosystem. If not, direct if needed]*

And related to this, what are your plans for future VR research topics?

Is there anything you would like to add or a topic we haven't discussed that you think is important to address?

5. **Closing words** (5 mins)

Hey, I think I've taken way too much of your time; thank you so much for all these valuable insights! I think we had a genuinely brilliant chat that will undoubtedly help me with identifying and tackling some of the challenges I am trying to address with VR and creative teams.

Any final words of advice?

Also, would you like me to keep you in the loop about the process and what's the outcome of the project? It may lead to something really insightful

Again, thank you so much for meeting with me.

Informed Consent

I ______________________________________ voluntarily agree to participate in this interview.

I understand that even by agreeing to participate now, I can withdraw at any time or refuse to answer any question without any consequences of any kind. I also acknowledge that I can withdraw permission to use data from my interview within two weeks after the interview, in which case all material will be deleted.

I agree that participation involves a semi-structured interview, and I give consent to the session being recorded.
I give permission for disguised extracts from my interview to be quoted in presentations and final thesis documents.
I understand that under freedom of information legislation, I am entitled to access the information I have provided at any time while it is in storage as specified below.

All information provided for this study will be treated confidentially, and in any report on the results of the Thesis project, the interviewee's identity will remain anonymised. This will be done by, if required by the participant, changing the interviewee's name and disguising any details of the session which may reveal the identity or the identity of the people mentioned.

All original recordings will be retained by the researcher, to be accessible only by him and his Thesis Supervisor until the end of the Thesis project (autumn 2023).

Please feel free to contact the researcher (nicolas.robertsondeferrari@aalto.fi) to seek further clarification and information.

Signature of Interviewee ______________________________________ Date____- __________2023

Appendix 2. Industry VR Users Interview Plan - VR for Co-Design

by Nicolás Robertson De Ferrari, Master Thesis Project.
Collaborative and Industrial Design.
Aalto University School of Arts, Design and Architecture

The structure of the interviews is based on Guion's (2011) and Boyce's (2006) guidelines for conducting in-depth interviews for academic purposes. They are intended to be conducted as semi-structured, qualitative interviews, where the sessions will be recorded, transcripted and summarised while being supported by field notes of each instance. These will be used as data to develop an affinity map in order to find possible pain points and opportunities for the development of the thesis project and subsequent tests to validate the hypothesis and research questions.

Being the interviewees in a work environment, the extent of the interview has been designed not to last more than 45 minutes, leaving enough room to finish the interview earlier or extend it to an hour if needed.

The objective of this particular set of interviews is to gather actual insights into the advantages and limitations of immersive work environments and how and often are the tools currently available used. Last, to prospect the feasibility of VR as a replacement for face-to-face design sessions in the present and near future.

Participants

- Place of interview:
  Ideally, face-to-face, Remote Call also possible

- Recruitment
  Personal Invitations

- Profile
  Design and or stakeholders in creative areas that use VR as part of their everyday work environment. Focus on Consumer Hard Goods design studios.

Interviewee with a senior or mid-level design role that oversees and understands the operational aspects of the company, as well as the higher-order thought taxonomies of the studio.

Procedure

- Introduction: Brief introduction to the interviewer, written consent for recording the session, and context of the Thesis (05 min)
- Ice-Breakers: Concise questions regarding the area of expertise of the interviewee to break the ice and segway into the main topic. (05 min)
- Main Interview: Open-ended questions regarding their usual design workflow, the use of VR in the office, the extent of it, creativity, current limitations and where the technology is headed towards. (30 min)
- Closing: Leading to the last comments, closing words and greetings (5 min)

Collected Data

- Oral consent from the interviewee.
- Recording or taping, depending on the interview context.
- Field notes on the interview.
- Interview transcript and summary.

Details	
Interviewee Name	
Company	
Role	
Place of the Interview	
Date of the Interview	

Script/Guide Questions	**Field Notes**

1. **Written Consent** (2 mins)

Thank you so much for agreeing to this meeting, I have been researching and working on this subject for quite some time, and to have the point of view of an expert on the area is of so much value to my project. I'd like to ask you first if I could record this meeting and sign this written consent giving permission for it.

This is just for personal use, so I can go through the conversation afterwards and write down and summarise some important aspects that I might have missed.

Needless to say, if you mention something that you'd like to leave out of the summary, please let me know, and I'll take note of that. I'll be especially careful to leave out any sensitive information in terms of developments and proprietary workflows, so there is nothing to be worried about 🙂.

Do you have any questions before we start?

2. **Introduction** (3 mins)

As a quick introduction, my name is Nicolas Robertson, and besides my day Industrial Design/Product Viz job, I'm doing my master's thesis at Aalto University (in Finland) in Collaborative and Industrial Design.

To give you a bit of context on my thesis topic, I'm currently working on a VR tool to validate how creativity is elicited when working in remote teams in the Design Industry. The plan is to build upon a collaborative, immersive scenario of the early stages of the design process (namely moodboarding or rapid mockup) and A/B test how a design team would work on VR versus face-to-face, to ultimately validate if VR is feasible to elicit or enhance creative activities.

I’m familiar with the wide variety of design-review-focused VR tools available on the market, hence my idea of elaborating on these earlier stages, which are more on the building-together-freely aspect of design. Much blurrier and less structured framework if you ask me, and therefore harder to grasp.

The hypothesis is that an immersive environment addresses a broader array of non-verbal cues that are linked to creative activities than current collaborative tools such as Miro or Teams, being especially true for Consumer Hard Goods design processes, to the point that telepresence in these cases can be directly comparable, or as effective as to being face to face

3. **Ice Breakers** (5 mins)

Enough of myself! Would be great if you could tell me a bit more about yourself and what’s your actual role in the company.

What led you to (industrial design/product development/mechanical engineering/...)?

4. **Main Interview** (30 mins)

How does your team or company use Virtual Reality during the product development cycle?

At which stage of the product design process does this happen, how do you think the use of VR impacts on this?

How would you compare it to a non-VR process? How was this approached before you integrated the technology into your workflow?

What do you think are the benefits of using VR during this stage?

Where would you like to use VR, or in which part of the product cycle do you think it has the most potential?

What are the current limitations to Virtual Reality that still need to be addressed for it to take off to the mainstream within the business ecosystem?

What is the overall reception and strategies at your company regarding Virtual Reality?

5. **Closing words** (5 mins)

Hey, I think I've taken way too much of your time; thank you so much for all these valuable insights! I think we had a genuinely brilliant chat that will undoubtedly help me with identifying and tackling some of the challenges I am trying to address with VR and creative teams.

Is there anything you would like to add or a topic we haven't discussed that you think is important to address? *[If it feels right, ask about someone else they think I should interview regarding the topic, the more industry insights I have, the better the outcome I can produce]*

Also, would you like me to keep you in the loop about the process and what's the outcome of the project? It may lead to something really insightful

Again, thank you so much for meeting with me.

Informed Consent

I ______________________________________ voluntarily agree to participate in this interview.

I understand that even by agreeing to participate now, I can withdraw at any time or refuse to answer any question without any consequences of any kind. I also acknowledge that I can withdraw permission to use data from my interview within two weeks after the interview, in which case all material will be deleted.
I agree that participation involves a semi-structured interview, and I give consent to the session being recorded.
I give permission for disguised extracts from my interview to be quoted in presentations and final thesis documents.
I understand that under freedom of information legislation, I am entitled to access the information I have provided at any time while it is in storage as specified below.

All information provided for this study will be treated confidentially, and in any report on the results of the Thesis project, the interviewee's identity will remain anonymised. This will be done by, if required by the participant, changing the interviewee's name and disguising any details of the session which may reveal the identity or the identity of the people mentioned.

All original recordings will be retained by the researcher, to be accessible only by him and his Thesis Supervisor until the end of the Thesis project (autumn 2023).

Please feel free to contact the researcher (nicolas.robertsondeferrari@aalto.fi) to seek further clarification and information.

Signature of Interviewee _____________________________________ Date___- _________2023

Appendix 3. VR Usability Test Plan - VR for Design Processes

by Nicolás Robertson De Ferrari, Master Thesis Project.

Collaborative and Industrial Design.
Aalto University School of Arts, Design and Architecture

Participants

- Place of testing:
  Aalto Studios VR Hub (to be confirmed)

- No. of people needed for/ participation type:
  4+ (minimum)

- Recruitment
  Personal Invitations
- Profile
  The test subjects screened for the usability test should comply with the following requirements:
    - Designer or working in creative industries, a core focus on Hard Consumer Goods and spatial design.
    - Junior to Senior expertise, focusing on any of these three specialities: Technical design, Concept design, Managing or Leading roles.

- Ages
  23+
  Background: technical, non-technical, higher degree of education

Schedule

Task	Date and Details
Implementation	<Sept 22; V2>
Pilot Test	18 Sept 2023, TBD
Evaluation	TBD
Analysis	25-27 Sept 2023
Presentation/Report	<expected on October 13rd 2023>

Procedure

- Introduction: Introduction & pre-session questionnaire and agreement (5 min)

- Onboarding: [Optional] Brief onboarding of HMD fitout and connection (5 - 10 min)
- Tasks: Ask participant(s) to perform three sequential tasks (35 - 40 min)
- Retrospective Probing: semi-structured individual interview, questionnaire (10 min)

Collected Data

- Background (demographic) information
- Video of participant(s) **exploring** and conducting the tasks required
- screen recording
  - semi-structured **interviews** (if consent is given)

- Pictures of the participant(s) using the test scenario
- Field notes
- Interview transcripts
- Likert Scale answers
- Quantitative data such as Succesful Task Completion, Critical and Non-Critical Errors, and Number of Iterations on the last task exercise.

Forms / Questionnaires

- Background information form and Consent form

Arrangements

Task	Details
Location: VR Hub Harald Herlin Learning Centre	Test Oculus Link Connection, Test KeyVR session, test Framerate.
Equipment:	KeyVR test scenario, HMD, Oculus Link Connection, Cameras, tripod, Second Laptop for control/participant #2 and screen recording.
Recruitment:	Personal Invitation
Facilitator/Lead:	Initiating, laying background, giving tasks + help (wherever needed)
Observer + Note-taking:	Recording Transcript and Analysis, Field notes
Rewards:	Coffee, Snacks for the testers
Analysis:	Including the interview; reports based on feedback, affinity diagram to detect emerging patterns derived from the sessions.
Report	Analysis on thesis document

Testing Script

1. **Introduction** [INTERNAL] (5 minutes)

   A. *Hey, thanks a lot for participating in this testing session!*

   I welcome all of your feedback for this session because it will help me understand the VR experience better. So, please be as open and honest with your feedback as possible. Don't hold back!

   Tell aloud what you think, what you would do, what you see on a particular screen, and how you would overcome any challenge that might or not appear.
   One key aspect to consider is that the ***purpose of this test is not to test you but the Usability of VR*** *as a tool for design.*

   To be able to test the user experience of a professional designer like yourself is of so much value to my project. I'd like to ask you first if I could record this meeting and sign this written consent giving permission for it. This is just for personal use, so I can go through the conversation afterwards and write down and summarise some important aspects that I might have missed.

   Needless to say, if you mention something that you'd like to leave out of the summary, please let me know, and I'll take note of that.

   If you happen to click on something that doesn't work, just tell me what you were expecting it to do.

   B. Exploratory Questions [INTERNAL] (5 minutes)

      a. *Would you mind sharing with me what you do professionally?*

      b. *What is your age?*

2. **VR Onboarding** (5-10 mins)

A. *Before we start with the test, are you familiar with VR at all?* **[If not, continue with onboarding]**
If you have never used it, I can give you a quick onboarding of how the headset is set up and some basic navigation tips so you feel more familiarised with the controls, navigation and headset.

B. [Show the tester how the HMD is fitted and connected to the computer, and launch the Demo scene]
If you notice, on each controller, there's a trigger where you can point and select objects, two buttons and a joystick.
To move around, there's a system called teleportation. Aim the left controller, press and hold the trigger, point towards where you would like to move, and release the trigger, the arrow pointing on the floor points towards where will you be facing.

With the right trigger, you can move any object that is highlighted around.

[The purpose of this onboarding is to leverage the knowledge of all testers with their first approach to VR, to emulate an organic use of the technology in a real-life context]

Thanks! Now that you have that first approach, let's continue with the testing, shall we? Please take the headset off; it will be just one second.

A. **Test Tasks** (35-40 mins)
[Record screen and room]

Context scenario [INTERNAL]
Imagine you have been invited to a remote team meeting in VR to discover and design a series of iterations for a wheelbarrow.
Think aloud, I'd like to know whatever you think & feel about this process.

Task 1: Setup (10-15 min)

Please fit, adjust and connect the Headset to the computer, then log into the collaborative platform.
Leave the login code at hand, or give it to the tester when prompted

[Check time, measure time to complete]

[Note and count critical and non-critical errors]
[Observe the interviewee, if she/he is not actively trying to interact with the projection, guide them with these questions:]

- *I noticed you did ..., would you explain to me why?*
- *How clear or intuitive was the setup connection process for you?*
- *Was there anything you would improve from the task?*

Task 2: Free Exploration (15-20 min)

Feel free to explore the environment freely, get familiarised with the menu, how to move around, select objects, move objects, etc. Please think out loud.

[Note and count critical and non-critical errors]
[Document observational data]

Task 3: Design Task (20-25 min)

This is a rapid iteration exercise, with the primitive blocks and shapes available, build as many wheelbarrow options as you'd like. Tell me whatever comes to mind, whether it is from the design process or from the VR platform itself.

[Check time, measure time to complete]
[Note and count critical and non-critical errors]
[Note number of iterations]

[Observe the interviewee, if she/he is not actively trying to interact with the projection, guide them with these questions:]

- *I noticed you did ..., would you explain to me why?*
- *Which options did you find the most useful?*
- *Would you change, add or remove something here?*

[Answer questions if there are any]

3. **Retrospective Probing (10 mins)**
    - preparing and reorganizing the questions
    - interview session (10 mins)
    - Wrap-up

4. **Debriefing** (25-35 mins) [INTERNAL]
    A. About [***What is the usefulness perception of this interaction?*** *(How do the reactions convey the internal goal of facilitating material selection?)*
      - What are the emotions felt/perceived by participants?
      - What is the perception of the researcher of the goal?
      -

    B. About [***Do they think the gestures of the interaction are intuitive and simple to learn?***]

      - Do they discover on their own? If not, how do we tweak our teaching/instructions to make it open and unbiased?
      - What are the most used tools and actions? Why?
      - Which gestures testers felt un-intuitive? Why?

    C. About [***Environment, Scene and Immersion***]
      - Did participants feel immersed? How? Why?
      - What are their perceptions of the visual style/attributes?

Informed Consent

I _______________________________________ voluntarily agree to participate in this test.

I understand that even by agreeing to participate now, I can withdraw at any time or refuse to answer any question without any consequences. I also acknowledge that I can withdraw permission to use data from the following testing and interview within two weeks after the session, in which case all material will be deleted.

I agree to participate in the test, which involves both a Usability Test Session and a later semi-structured in-depth interview, where I give consent to both sections being recorded.
I give permission for disguised extracts from the session to be quoted in presentations and final thesis documents.
I understand that under freedom of information legislation, I am entitled to access the information I have provided at any time while it is in storage as specified below.
All information provided for this study will be treated confidentially, and in any report on the results of the Thesis project, the interviewee's identity will remain anonymous. This will be done by, if required by the participant, changing the partaker's name and disguising any details of the session that may reveal the identity or the identity of the people mentioned.

All original recordings will be retained by the researcher, to be accessible only by him and his Thesis Supervisor until the end of the Thesis project (autumn 2023).

Please feel free to contact the researcher (nicolas.robertsondeferrari@aalto.fi) to seek further clarification and information.

Signature of Participant______________________________________ Date____- __________2023

Background information

1. Please state your age?

- ☐ 23-26
- ☐ 26-32
- ☐ Over 32

2. What's your current area of occupation?

- ☐ Hard Consumer Goods
- ☐ Design Generalist - Industrial Design
- ☐ Interior and Spatial Design
- ☐ Manufacturing - Design for Manufaturing
- ☐ Product Management
- ☐ Research / Academia
- ☐ Others, please clarify:

____

3. Which tools do you usually use?

- ☐ Digital tools (Miro, Figma, etc)
- ☐ Physical prototyping tools
- ☐ 3D Modelling
- ☐ VR Sketching

4. What's your usual role on a design project?

- ☐ Concept Design
- ☐ Design for Manufacturing / CAD
- ☐ Design Lead
- ☐ UX
- ☐ Other, please specify:

____

Name of research participant ______________________

Interview questions

[INTERNAL]

- *Observe participants' reactions when during the process:*
  Gestural expressions, behavioural (step back, move closer), and comments.

[**INTERVIEW**]

A. **About interaction**

1. How would you describe your overall experience, have you had any similar experiences in VR before? Please describe it:

2. What worked well/poorly?

B. **About setup**

3. How did you feel during the fitout, setup and login process?
   Ask to describe the feeling

4. Why did you feel it this way? Is there any specific feature or challenge that you would like to point out?

5. On a scale of 1-5, how comfortable did you feel ? *[Likert Scale]*

C. **Wrap Up Questions**

6. Based on your recent and past experiences, do you find this or a similar tool could improve the exploratory aspect of the design process?

7. On a scale of 1-5, how likely would you include VR into your normal workflow? *[Likert Scale]*

8. Is there anything about the experience that we haven't discussed yet that you want to share with me?

9. Do you have any questions in mind?

Name of research participant ________________________________