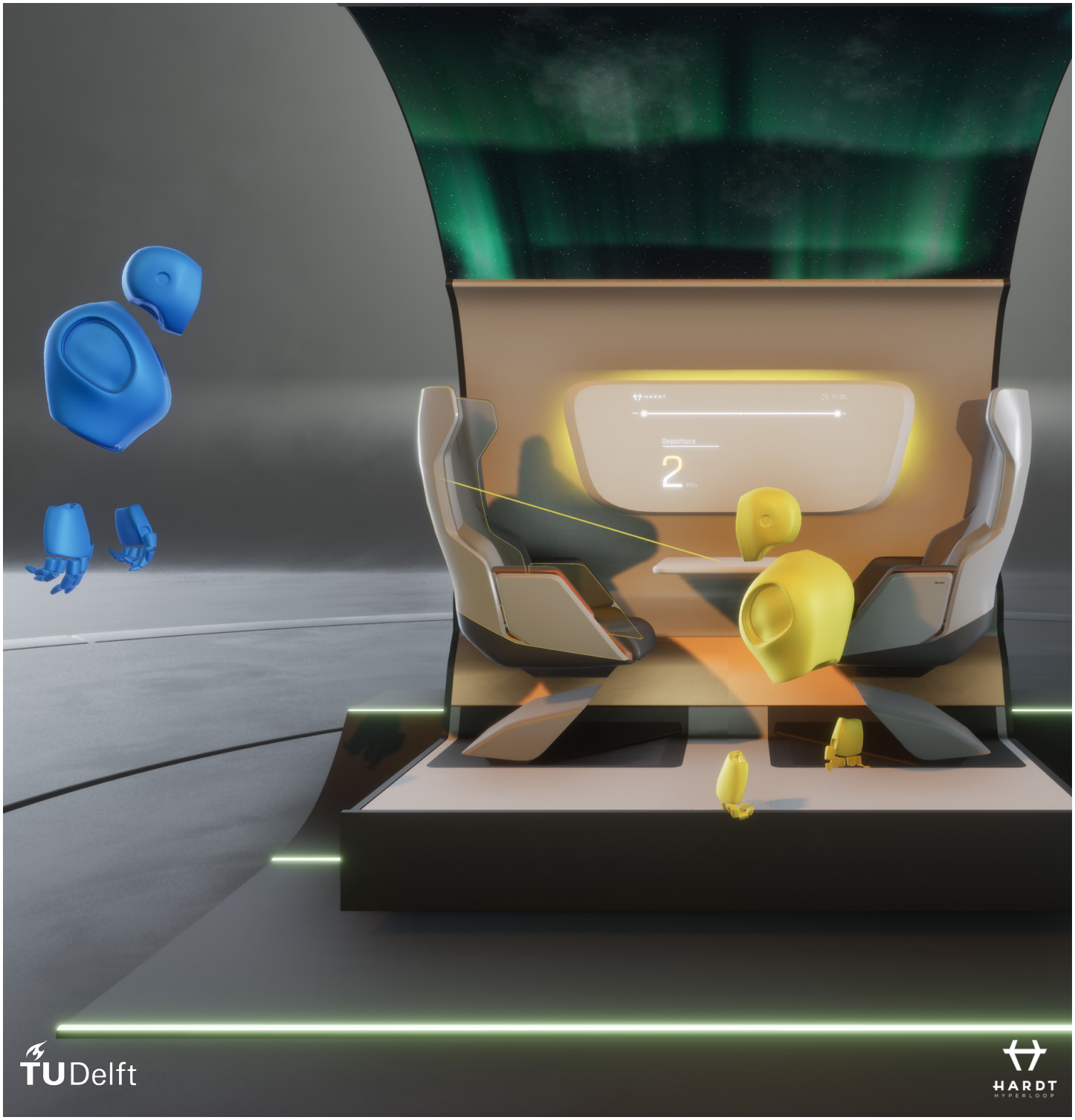
Hardt Digital Lab:

Virtual Reality Design Review tool for Hyperloop Development



Master Thesis

José Manuel Rodríguez Díaz
Student number: 4711459

VR Communication Tool José Manuel Rodríguez Díaz

Hardt Digital Lab:
Virtual Reality Design Review tool for
Hyperloop Development

Msc. Integrated Product Design
Faculty of Industrial Design
Engineering
University of Technology of Delft
Delft University of Technology
www.tudelft.nl/ide/

Supervisory Team

Chair
Doris Aschenbrenner
Sustainable Design Engineering
Industrial Design Engineering Delft
University of Technology

Mentor
Jan Willem Hoftijzer
Human-Centered Design
Industrial Design Engineering Delft
University of Technology

Company Mentor
José Eduardo Sánchez Pérez
Head of Design
Hardt Hyperloop

VR Communication Tool José Manuel Rodríguez Díaz

AKNOWLEDGMENTS

When I came to Delft as an erasmus, I did not think that I would have done a project with these characteristics. Meeting people with different stories inspired me on how everybody can have a place in the difficult market that sooner or later I will have to face. It has been a long journey, but my mindset has evolved so much that sometimes I cannot recognise myself.

I want to thank TU Delft for the opportunity given to take this Masters and the network that I was able to make.

To **Doris** and **Jan Willem** for your knowledge, patience and understanding during these hard times.

To all members from Hardt Hyperloop for the internship and the graduation project, specially **José**, because you are an inspiration for me even though sometimes I want to spike you like D.K. does.

To **Dicky**, because you are one of those teachers everybody should meet.

To my parents, **Jose Antonio** and **Nieves**, because they have been supporting me during the whole journey.

To **Elena**, for supporting me in the darkest parts of this project.

To **Marina**, for being that lighthouse each time I have been lost.

To the Game crew: **Rubén, Cristian** and **Fabio.**

To every kid who supports gaming and they continue supporting Epic Games. VR is the future and this is thanks to you too.

And lastly, to **Antonio** and **Tjark.** Thanks to help me see the world with different eyes.

EXECUTIVE SUMMARY

Due to the increase in flight demand and pollution impact that it has, the idea of the hyperloop concept has gained relevance in our society. Even though the hyperloop concept is still in a conceptual phase, there are already several companies working on it. Here in the Netherlands, Hardt Hyperloop is developing its vision. The hyperloop is a new mode of transportation that requires a lot of public-private collaboration from diverse sectors, generating an ecosystem.

Hardt is a very technical focus company that has problems communicating its vision concerning the hyperloop. Without a good communication strategy between Hardt and the stakeholders, the hyperloop ecosystem will not reach its full potential. Good communication is required internally between members, but also externally with the stakeholders.

Due to COVID-19, Hardt is facing how to keep alive the ecosystem with a working-from-home situation. Remote meetings are not as engaging as face-to-face meetings. Onboarding new stakeholders through virtual conferences, instead of visits to the Head Quarters, was not effective at all. The communication through text with other stakeholders who were already part of the ecosystem was not fluent. Hardt with the pandemic situation started to have difficulties reaching their milestones. This could affect the development of the hyperloop.

Currently, the video conference tools used are obsolete (Teams and Zoom). As an alternative, a virtual environment where to showcase virtual prototypes was proposed. The concept is called Hardt Digital Lab. It is a multi-user review platform that can be accessed from the web browser, avoiding installations for those who want to participate in the design process. The platform can be accessed with PC and smartphone. Virtual Reality is also a possibility but cannot be used through the web browser. Communication with interactive visualizations improves significantly.

A prototype was developed with Unreal Engine 4 to prove this concept. The project was evaluated by Hardt members with positive feedback. Even though they considered the environment to had simple but effective functions, they thought it could have promising features in the future. The main concern was to adapt the environment visualization to the workflow of the company.

VR Communication Tool José Manuel Rodríguez Díaz

CONTENT

1. Context

The next chapter describes Hardt's communication collaboration with stakeholders involved. Later on, it is explained what Hardt forms and who participates in the Hyperloop ecosystem. Finally, the challenge is presented together with the methodology that the designer will approach the problem described previously, defining how the report is structured.

CONTEXT

1.1 Problem

Transportation and pollution are big concerns nowadays. The environmental impact of aviation is huge. However, our society is already looking for sustainable alternatives. Hardt Hyperloop is a Dutch start-up based in Delft that aims to fully develop a new form of transportation which is fast, sustainable, and safe called “Hyperloop”.

This engineering solution is highly complex and requires a large investment. The solution cannot be built by only one company; therefore, public-private collaboration is needed. Up until now, many companies have shown interest in Hardt’s vision about the Hyperloop, resulting in successful collaborations that became an ecosystem, which Hardt leads.

One of the main concerns that Hardt has is the way their products are communicated to stakeholders. Nowadays, Hardt is making use of traditional rendering techniques for images and videos. Hardt also showcases physical prototypes to stakeholders when they visit the office. In this way, they can understand the technology, which happens to be one of the most effective communication strategies. Ongoing communication about the stage of the project is key to keep stakeholders in the loop and engaged with Hardt’s vision. Here is where most of engineering companies happen to have problems sharing ideas.

Figure 1: Mars Geuze, Co-Founder at Hardt, presenting the Low Speed Test Facility to a potential investor.

Now that the pandemic has forced greater use of remote work, along with online platforms, we can see that Hardt is having troubles onboarding new stakeholders. Moreover, keeping conversations with key partners to meet the ecosystem objectives is more difficult with the solutions available. The overuse of emails and videoconference meetings with Zoom, Teams and Skype are losing human face-to-face interactions. Presenting prototypes at Hardt’s HQ on a regular basis is no longer an option Hardt must be prepared for future pandemics that limit physical social interactions. In addition, moving prototypes from one location to another requires a lot of resources and costs, so it is not a viable option. Hardt should consider a new communication strategy to reach out to potential investors from different places around the world. Just as Hard’s vision of the hyperloop “No Boundaries, No Limitations”.

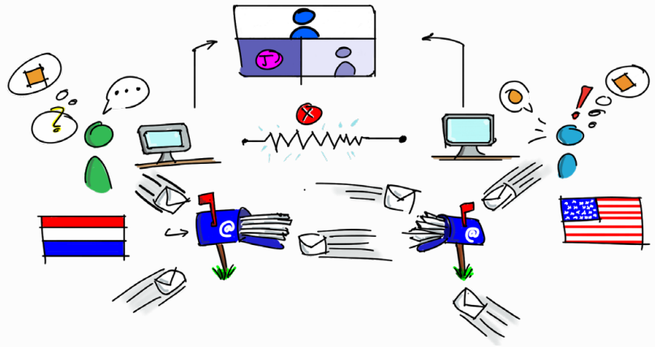


Figure 2: Frustration due to working from home - image from Pexels.com

1.2 Background

What is the Hyperloop?

With passengers sitting in pods, traveling at airline speed through sealed tubes using electric propulsion and magnetic levitation, the Hyperloop is the fastest way to cross the surface of the earth. With a multidisciplinary team and the ecosystem around it, Hardt will try to fit this transportation system into the market. Hard is developing two main products; “Cargoloop” and “Hyperloop”. With these two products, Hardt aims to improve the mobility of people and goods with a zero-emission impact. You can find more information about Hyperloop technology in Appendix B.

What is Hardt?

Hardt B.V is a dutch start-up based in Delft, from where all the operations and design work take place related to Hyperloop. Hardt B.V works with different stakeholders from all over the world and aims to have a global ecosystem. During its years of life, Hardt is carrying out an international initiative to ensure safety, connectivity, and compatibility across borders with countries like Spain, Poland, France and Italy while is driving a project around international standardisation cooperating with Hyper Poland (from Poland), TransPod (from Canada, with offices in Italy and France), and Zeleros Hyperloop (from Spain).

Hardt’s Ecosystem

Hardt as a company develops potential routes for passengers and cargo, but also develops the technology. To do so, they need to be in contact with public and private stakeholders. Within the public and the private sector, we can find two main groups that Hardt differentiates:

- **Implementation**
- **Technology**

Further in the report, stakeholders will be studied more in detail.

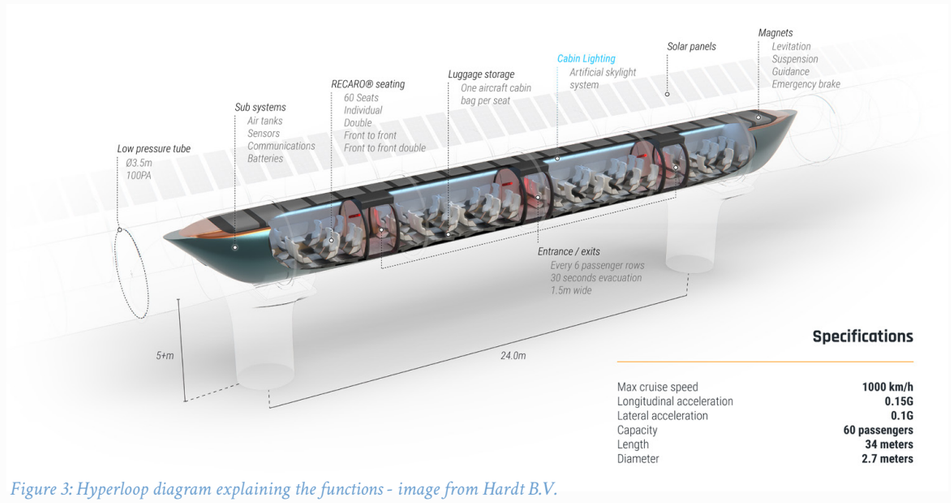


Figure 3: Hyperloop diagram explaining the functions - image from Hardt B.V.

VR Communication Tool José Manuel Rodríguez Díaz

Hardt also has a Business Development department within his team, as well as a Product Development department. The Business Department studies potential routes, looks for potential investors and studies public adoption. Whereas the Product Department studies how to integrate the different technologies that would make the Hyperloop a success.
There is ongoing communication between departments and external stakeholders to find out what the future goals of the ecosystem are and to complete them successfully. This communication aims to create bonds between the companies that commit them to the project, sharing a common vision and goal for the realization of this technology and how it can impact society.

Market Development

The Market Development goal is to build up relationships with external parties and involve them within the Hyperloop ecosystem. Its responsibility is to get the resources that Hardt needs, such as human-kind, knowledge, and cash, by studying route alternatives, and pilot studies of an envisioned global network.

Product Development

Its goal is to continuously validate technologies of the technology roadmap of the company, scaling the prototypes into several proofs of technology that will demonstrate to external parties the Technology Readiness of the company.

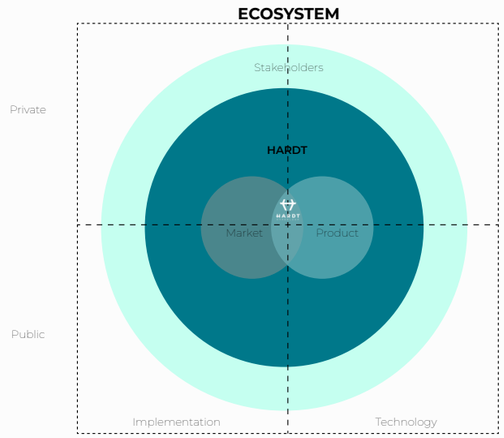


Figure 4: Diagram of the Ecosystem of Hardt Hyperloop

1.3 Challenge

1.3.1 Assignment

To provide **collaboration** and **communication** between the members involved of the hyperloop in **Hardt´s ecosystem**. Research will be carried out on **visual communication** trends, user needs, technological recent developments, resulting in a new communication strategy.

1.3.3 Description

This project explores the potential impact that interactive 3D rendering can have on stakeholder communication. Interactive 3D rendering refers, for example, to virtual reality applications, but does not restrict applications to Head-Mounted Displays. Sharing knowledge can increase team performance, predict behavior, ease communication, and distribute knowledge for hyperloop development.

Furthermore, I propose a communication strategy and develop a digital tool through which I can evaluate my findings by improving the grounding between stakeholders, bridging the knowledge gap between them. My expected contribution is to improve internal and external communication with all stakeholders involved in the Hyperloop ecosystem. This will result in boosting the design process, saving money and time. The aim is to achieve alignment on the design between stakeholders. And also to inform them of the stage of the project.

VR Communication Tool José Manuel Rodríguez Díaz

1.3.2 Goals of the Project

•Explore potential solutions of interactive visualizations for sharing understanding

•Improve internal and external communication within Hardt's ecosystem.

•Develop a Demo that can enhance the collaboration between stakeholders involved in the hyperloop ecosystem.

Cost - Effective

Time Saving

Collaborative

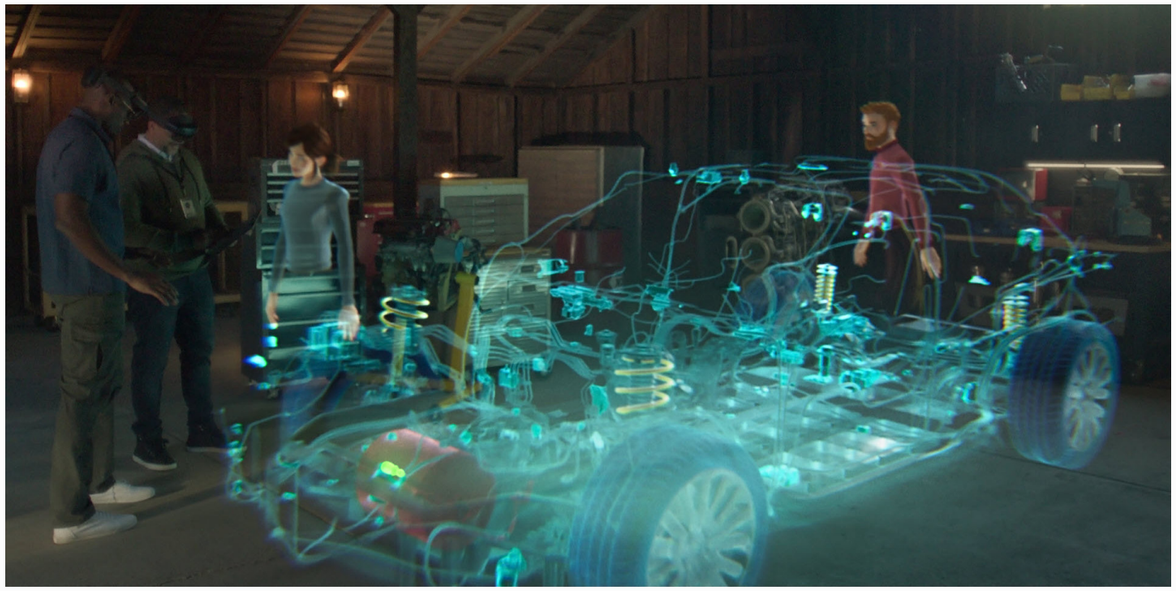


Figure 5: Microsoft Mesh concept of sharing virtual working spaces with the use of Augmented Reality - Property of Microsoft

1.4 Approach & Methodology

When starting a design process, I prefer to focus on three themes: People, Market and Technology. In this project, I divide the brief into these topics to define the research focus.

Two different methods are used to structure the project: the Double Diamond and the RITE Method.

Double Diamond

The Double Diamond is a method that conveys a design process(Twitter et al., 2015), exploring issues more widely or deeply (divergent thinking) and then taking focused action (convergent thinking). This method piqued my interest because of its first diamond, where it helps designers to research and analyze context and users. It also guides designers to come up with defined problem statements that can be of help to keep in mind and ideate having those principles in mind.

Unfortunately, the Double Diamond might not be sufficient for the development of the project. This is because the product or service that will result from this Thesis needs to validate recent technologies. . And the limitations within this context are unclear. Therefore, a second diamond is used to explore technologies. This will help to understand what can or can not be done. It will also help during the development of the prototype, which is used in the last phase of the project

R.I.T.E. Method

Once the prototype is established, the RITE method will be used The RITE method stands for Rapid Iterative Testing and Evaluation. This method, with a bigger approach to usability, defined by Michael Medlock et al (2007) aims to test and validate the usability of digital products. With this method, I will schedule participants to use my design, measure their behaviors and evaluate the errors and misunderstandings participants encounter during testing.

Lastly, the design that aims to solve collaboration and communication issues is evaluated compared to the existing way of communicating ideas and concepts. Desirability, usability and sharing knowledge are the drivers of the evaluation test.

In the figure 6 the diagram used during this project is defined. It highlights the merge between the different methods that are followed along the process.

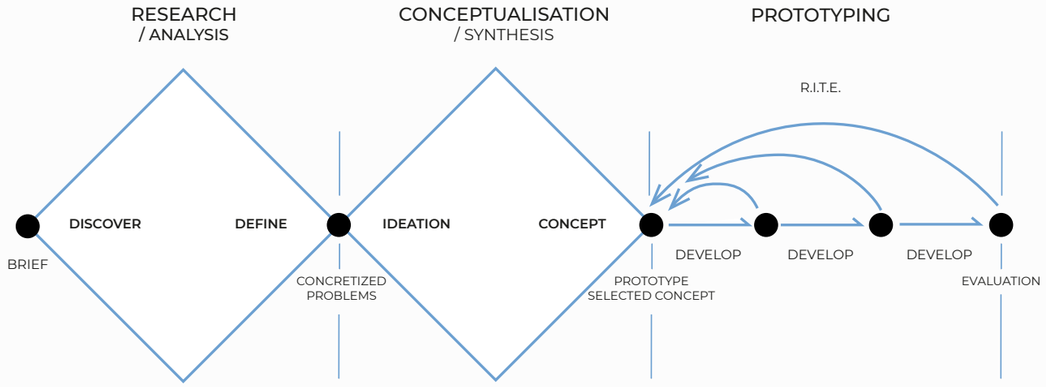


Figure 6: Diagram of the methodology that will be followed along the design process.

Below more details on how the documentation is structured can be found. According to the already mentioned combination of the two methodologies used:

Discover
At the beginning of the first diamond, divergent thinking helps to understand the problem in depth. Spending time with the people affected by the problem is required. So contextual analysis and interviews are conducted in this phase.

Define
Narrowing down the scope with the insights from the Discover phase helps to define the challenge. The outcome of this second part of the first diamond should be the red line to start diverging again.

Ideation
Together with the insights collected in the first diamond, different answers to the defined problem are explored.

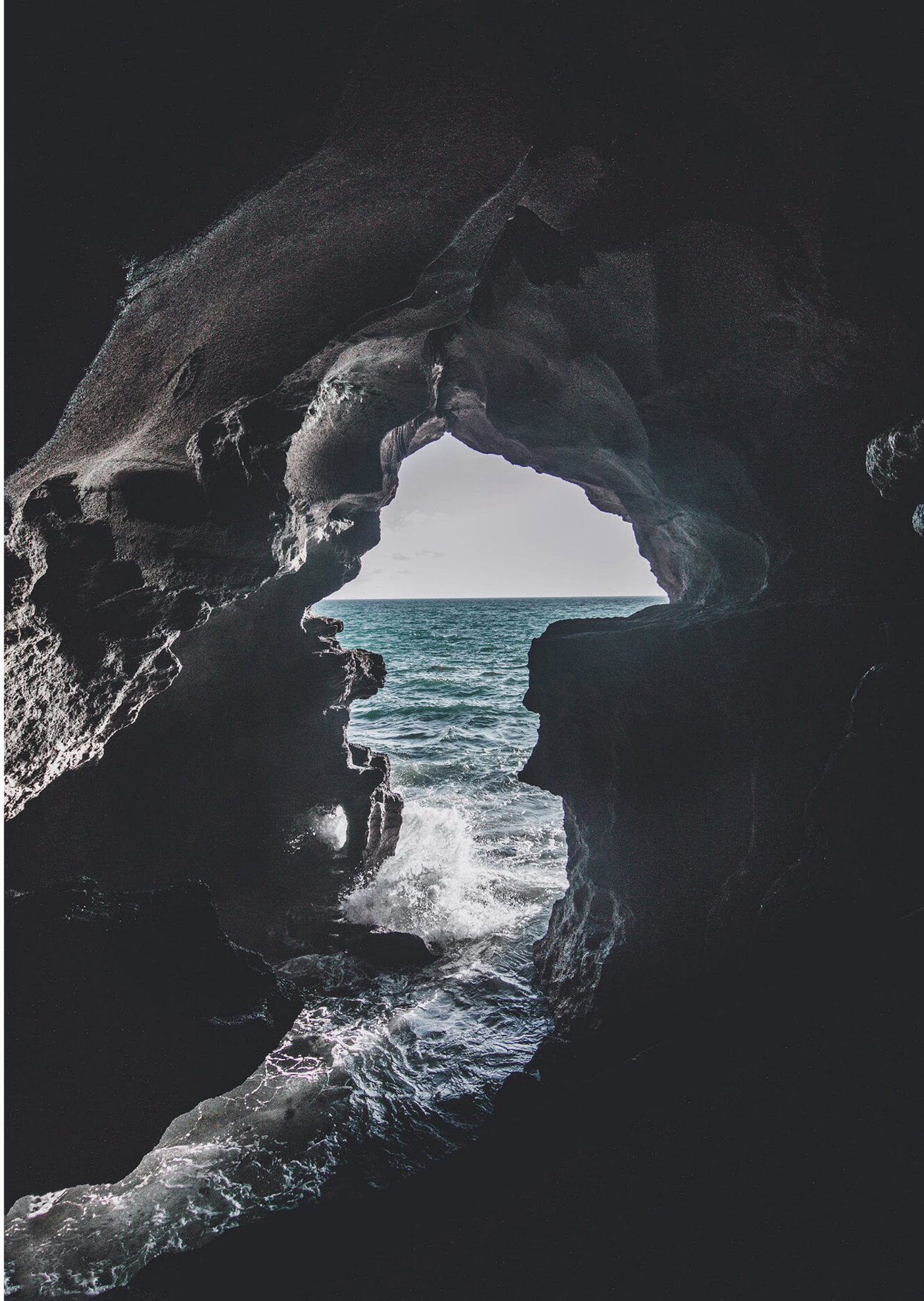
Conceptualization
Once the answers are presented, a chosen concept will be chosen to consequently develop a prototype with which it will be able to validate the hypothesis of improving how Hardt is communicating their ideas. The end of this chapter means also that the Double Diamond is finished.

Prototype
In this chapter the R.I.T.E. method is used to constantly improve the usability of the digital solution.

Evaluation
Validate if the design solution improves the current communication strategy of Hardt in a specific task.

2.
Discover

In this chapter, research on user needs, market and technology is described. An overview of the overall picture of the situation is sought. Insights on improvements are identified by analysing Hardt's current solutions and interactions with the various communication channels.



DISCOVER

2.1 Introduction

The first diamond is used to collect enough data, analyze the context where Hardt is involved. It also helps to discover the main barriers that slow down the productivity of certain areas of the company. Communication and coordination are key for any team that wants to boost their productivity, so these were the topics to go deep and broad, identifying what was not working properly.

Hardt is currently scaling up as a company. This requires effective communication and leadership with their partners. Therefore, it is essential to understand the way Hardt communicates. This serves as a starting point on how to facilitate onboarding new partners. And also keeping them in the loop without decreasing the productivity of the ecosystem. I had the opportunity of doing my internship at Hardt. This helped me to identify potential topics of observation.

Another important fact to take into account is the impact of COVID-19 in the working environment. The pandemic has forced a transition to digital solutions when it comes to remote collaboration. Thus, it is important to understand how COVID-19 is affecting Hardt in the way they engage with the stakeholders.

All my learnings can be found in at the end of the chapter, where I identify problems related to efficiency, coordination, understanding and technology. These problems are taken forward to the next phase of the project, where convergent thinking is used to narrow down the scope.

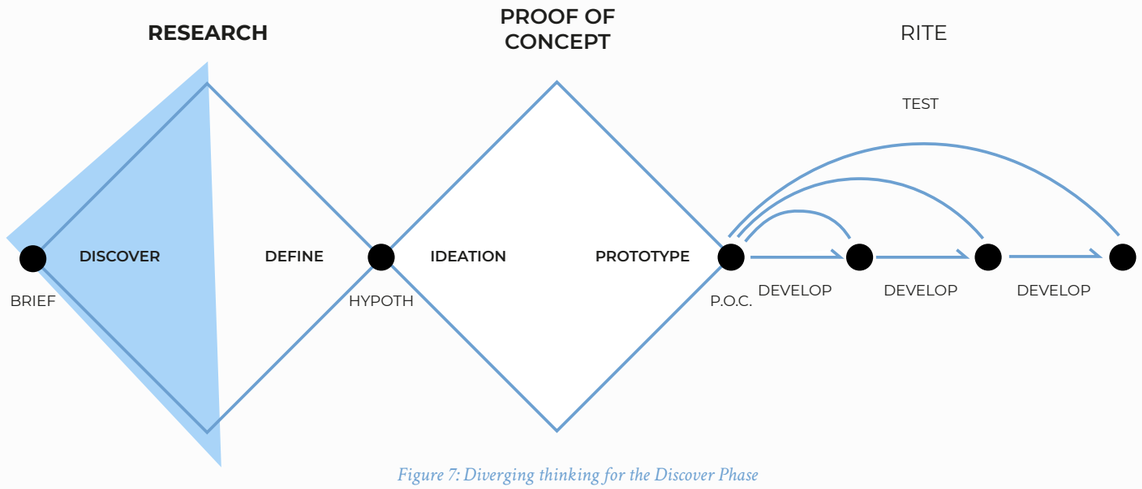


Figure 7: Diverging thinking for the Discover Phase

2.2 Goals of the Phase

- *Build General and specific knowledge about the communication between all the members of the Hyperloop ecosystem at Hardt.*
- *Meet relevant stakeholders who can influence positively in later parts of the project.*
- *Identify the main barriers of communication within the ecosystem.*

2.3 Collect and Analysis

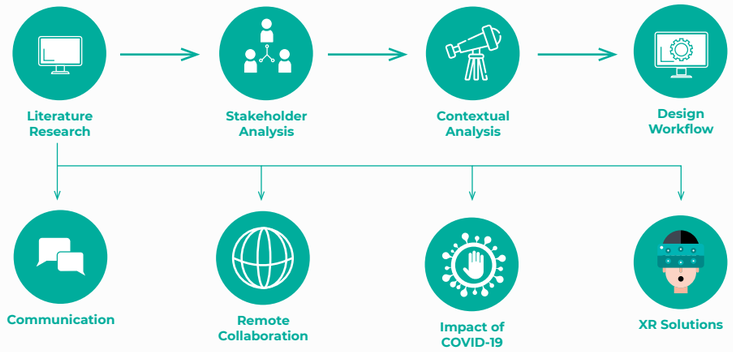


Figure 8: Diagram describing the research topics of the Discover phase

In the Discover phase, the goal is to help people understand the core problem. In order to shape a solution, it is important to know the situation of the people you are working for. In Figure 8 the research flow that is followed during the Discover phase can be found. The figure makes a distinction of users, market and technology. , making a distinction of Users, Market and Technology. The goal of the research is to identify user pain points. These pain points are used to broaden the scope through divergent thinking. This will provide a broad overview of the current situation.

2.3.1 Mental Models

The goal of this project is to boost communication and coordination within the Hyperloop ecosystem. If the design tries to improve how people are connected, it is impotant to know what creates these connections. The first thing needed to identify communication problems is to understand the basics.

Communication

Communication is best defined as the exchange of information and the expression of ideas, thoughts and feelings by using words and other methods.**(MISSING REFERENCE)** Relevant project information has to be communicated to all project stakeholders. To better understand communication, the concept of mental models will be introduced, which can help to get the basic elements of the communication process.

Mental Models

The use of mental models started in the 80's with the development of cognitive science by Johnson-Laird. Johnson-Laird (1980) proposed mental models as the basic structure of cognition, which he used to describe how people reason about the reference in terms of syllogistic reasoning.

A more recent definition would be that mental models in the design process are what the user believes about the system at hand (Nielsen, 2010).

Basically, mental models are essential to understand the basics of communication and i. It is a prime goal for designers to make the user interface communicate the system's basic nature well enough that users form reasonably accurate (and thus useful) mental models. (Nielsen, 2010).

In this project mental models help to better understand the process of communication between the stakeholders and the company. The goal is to help users to define accurate mental models that they can share with peers, boosting communication and coordination.

What makes a mental model good or well-conceptualized is how its representations are related to each other. It is not about the knowledge but the structure of them that matters the most when a mental model is represented. A good Mental Model will tend to categorize the knowledge we know and how it is organized (Klimoski and Mohammed 1994)

The main value of a Mental Model is the simplicity it has. If a mental model is accurately conceptualized, people will be able to act in unknown situations. If a mental model is inaccurate, people can lead to misinterpretations, performing an unestimated action.

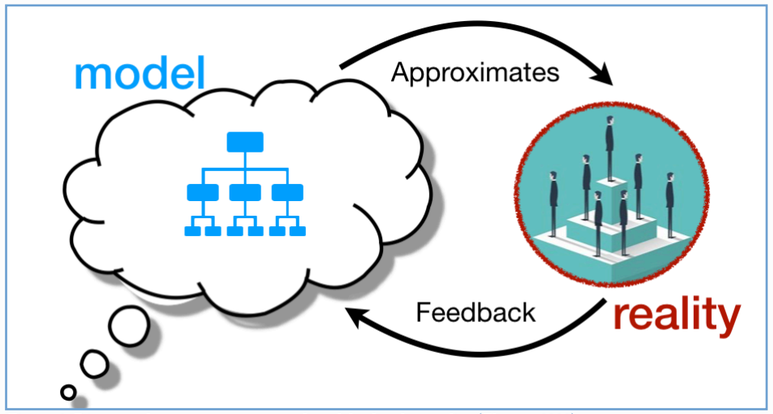


Figure 9: Diagram that represents a mental model related to reality (Flemm, 2020)

Types of Mental Models

Two types of mental models are established:

Task Models make reference to a person storing knowledge regarding a particular task. and is focused on how to do a task without considering the knowledge or fact necessary when performing that task.

Team Models are defined as team members' shared, organized understanding and mental representation of knowledge about key elements of the team's relevant environment (Cannon-Bowers et al. 1993; Klimoski and Mohammed 1994)). Team Models include the information we have about the team members like their abilities, responding roles, and responsibilities, and also explain how to interact with the different members of the team.

Common Grounding

When two people from different backgrounds interact, they need to update their common ground. This process is called the "grounding process", in which the entities try to reach a mutual belief on the situation and the objects. This is especially important if those two people need to work together. In order to coordinate their tasks, they need to actualize their mutual knowledge constantly.

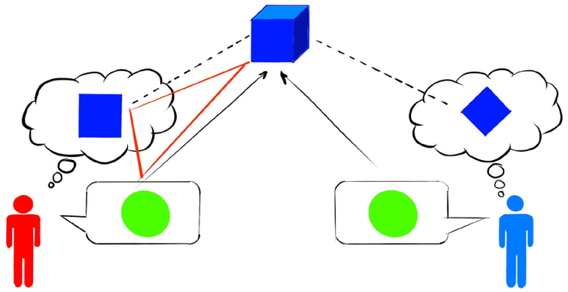


Figure 10: Diagram of the visualization of common ground. Aschenbrenner (2017)

2.3.2 Stakeholders

Once Communication is understood, which is the exchange of information between two users, the next step is to identify who is involved in these communications. Hardt's business model aspires to create local ecosystems, all over the globe, realizing hyperloop routes into a connecting network. In all ecosystems, Hardt achieves milestones in a cost-effective and time-effective way by leveraging the partner's expertise and work. In return, Hardt's system creates context and inspiration for all involved companies and prepositions partners for subsequent hyperloop projects.

Identifying the profile of companies and the people who make decisions there, that would fit or are already part of the ecosystem is key to understand the needs or find out the barriers of communication.

Hyperloop Ecosystem

There are 13 different sectors regarding the hyperloop ecosystem. According to Hardt "All can benefit from different stages in the process from concept studies and financing up until the use and maintenance of a hyperloop route as part of a network"(Partner and Ecosystem Strategy, 2020). Each of them can contribute to the impact, giving benefits in the short term and in the long term. Those 13 ecosystems are displayed in Table 1:

Figure 11: Businessman shaking hands - Pexels.com

1. Contractors	**8. Technology developers**
2. Suppliers	**9. Users**
3. Consultants	**10. NGO's**
4. Financers	**11. Research Institutes and Academic Sector**
5. Asset Developers	**12. Operators and rail authorities**
6. Governments	**13. Digital Service Providers**
7. Transport Hubs	

Table 1: Stakeholder map from Hardt

Stakeholder Mapping

After the research with regards to the stakeholder analysis, Hardt has two dimensions when it comes to map the stakeholders involved in the hyperloop development from external parties, as you can see in the diagram in the figure 12. Those two dimensions are:

- **Public-Private**
- **Implementation-Technology**

Stakeholders have diverse interests in the Hyperloop to become a reality. Some technology stakeholders see a new industry being created, and they want to take part since the beginning as they see it as a great opportunity for their business together with the knowledge that they already have.

Implementation stakeholders can have either public or private interests. Public Stakeholders such as the government would like to invest in the Hyperloop because they believe in a transition into sustainable mobility, together with an economic growth once this technology is implemented. Whereas companies like PostNL, could also have interests in a partnership with Hyperloop because of the Cargoloop product. Cargoloop can be a sustainable solution for e-commerce and its growing high demand.

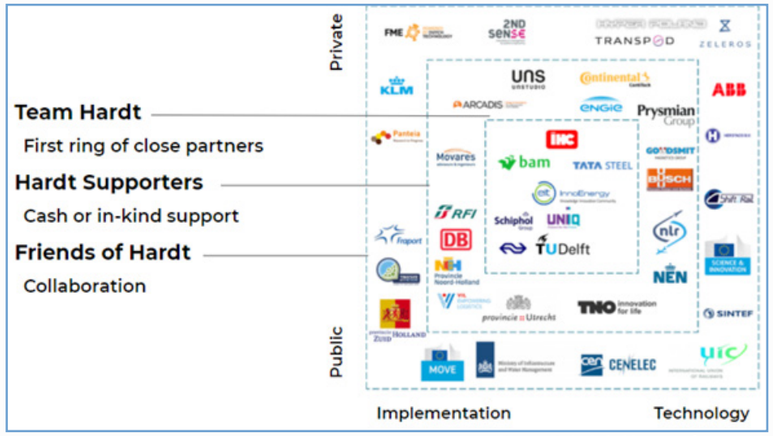


Figure 12: Stakeholder map from Hardt

Insights

After analyzing the stakeholder map, even though it has two dimensions the key difference between the backgrounds of the users who participate in the conversations is how friendly they are with technology on a daily basis. Companies related to technology development have more experience with engineering and 3D software than the implementation stakeholders, such as members of the government. The public and the private dimension does not make such a difference when it comes to sharing knowledge, but the grounding process and the adoption of digital solutions will always be easier with members who have a technical background. With this assumption, users can be identified as **Tech** and **Non-Tech** users.

Figure 13: Businessman (Non-Tech) and Engineer (Tech)

2.3.3 Communication issues within the Ecosystem

One of the most efficient techniques to collect information related to communication within the company was conversational interviews. The researcher had several informal conversations with members of the company, so they could give their opinions. The fact that the researcher was an intern before the start of the Graduation Project, and Hardt members already knew, made it easy to speak about this topic, which can be uncomfortable to sometimes say what is not working related to communication between colleagues.

Meeting with visual content

To identify the pain points, together with the interviews, the Journey Mapping (Gibbons, 2018) workshop with a Business Developers inside Hardt about the Communication with External partners and colleague Engineers.

The most important interview was carried out with the Project Manager in charge of the feasibility of the Cargoloop Holland project. See Appendix C for notes and structure of the interview. His main duties were to establish connections between internal and external members of the company for knowledge sharing, and carrying out workshops with members of the ecosystem.

He described the importance of visual content for the grounding process as it is shown in figure 14 related to a meeting with an implementation stakeholder in June 2020. After the presentation of all the technical details of the cargoloop by the co-founders of the company, the main question they had was:

"Great, but how will the packages be loaded and unloaded?"

The videos that were showing the cargoloop in use were key to confirm a shared understanding between both sides. Having a shared context awareness can help building relationships and social networks (Bosch-Sijtsema & Haapamäki, 2014).

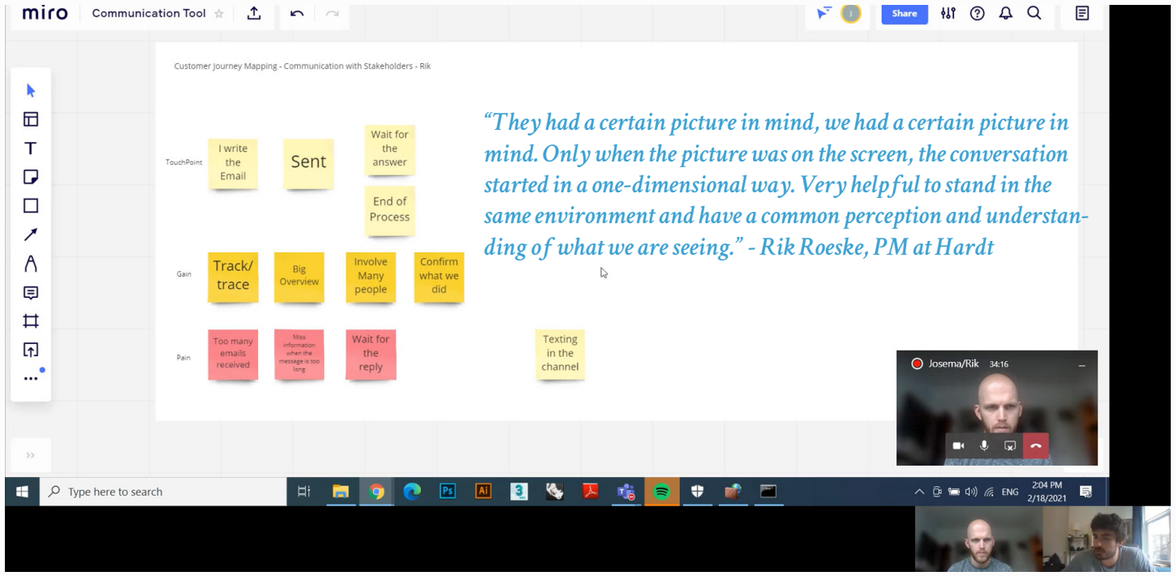


Figure 14: Informal Journey Map regarding the communication within Hardt

Insights

Once the interviews were done, Isome statements that can help to shape the design were pointed out. By analysing the pains and gains of the communication with stakeholders through the interviews, insights were drawn.

Update the right People

"Not everybody is acquainted from the newest direction" (Roeske, 2021)

Shared mental models are important for highly coordinated actions between different team members (Badke-Schaub et al., 2007). Keeping the right members aware of the changes that affect their tasks will improve coordination between the different team members.

"Things change pretty fast and not everybody is acquainted" (Roeske, 2021)

Traceability

In order to manage a network, traceability is something valuable. This is a feature that emails have, and in case that we use a new way of communication, tracing the information must be kept.

Misinformation in emails

"An innovative company should have time to discuss and agree" (Roeske, 2021)

Platforms like email are used to speak with many people, and it might be the case that information can be lost among others. The information must be easily accessed in the design.

Black or White

It is quite common to ask Yes or No questions to avoid misunderstandings, as a way to clarify if the information was clear enough.

Involvement

"When there is something I want to know, I ask through email involving different Hardt members, because I do not really know who knows about my issues" (Sanchez, 2021)

Sometimes people want to involve as many people as possible in a conversation to reach out quickly to the intended users.

Big overview

Emails have a nice feature, and it is that you can detail a big overview of the situation to who you are sending the message to. This helps to put into context or remind better of a previous message.

Share Context awareness

Experiencing visually the same context with the stakeholder can help a lot to understand the other or have a common perception.

2.3.4 Walkthrough - Contextual Analysis

Prototypes Presentation

The hyperloop is a complex project that most of the time is seen as a futuristic solution far from reality. Hardt's strategy to convince investors is by proving the technology with prototypes and showing them what the company is capable of doing. Due to the fact that the hyperloop has a long roadmap, Hardt needs to onboard new partners that share their vision and keep them engaged with the project. One of the most effective ways of onboarding new stakeholders was conducting visits to the facilities in Delft, as can be seen in figure 16, to explain the technologies developed and proving that the hyperloop is closer to reality than most people's thoughts.

At the end of the first month of my internship, coronavirus kicked in. As we all know, covid-19 has transformed the way of living or communicating, among others. Suddenly we were forced to work from home and carry out the transition to a digital environment using the working tools that we already had from Microsoft, such as Teams or Sharepoint.
It was obvious that due to the circumstances, we could not handle more visits, thus we lost one of the most important strategies to onboarding processes. The company still arranged some remote visits through videoconference, as you can see in figure 16, but they are not as effective as physical ones.
As part of the research, the User Observations method from the Delft Design Guide (2020) was followed. Analyzing how Hardt members were presenting the prototypes was the task observed, trying to find out what was useful in the communication with stakeholders that could be translated to a different medium suitable to the current and future contexts.

How might we keep this approach to stakeholders without being blocked by Covid-19?

Does Hardt have any digital representation providing the same information?

If it does, how does it communicate?

Figure 15: Mars, Co-fouunder of Hardt, presenting the LSTF - Property of Hardt

Figure 16 Videoconference presenting the LSTF - Property of Hardt

Figure 17: Hardt engineer explaining the functionalities of the LSTF

Visit to the Facilities

While arranging the visit to the facilities with the engineer, I could realize about the costs needed to make it happen. The walkthrough, even though it would have been explained in around 1 hour, in reality, was costing approximately 4 hours, for the engineer to perform the visit properly. These costs happen due to the transport needed to Hardt HQ and also the facilities from TU Delft, and the availability of the engineer to schedule a physical meeting with the stakeholder, who also has to come to Delft, making it even more difficult. In figure 19 the whole journey from the engineer is mapped.
The visit was recorded and I followed all the safety rules provided by the Engineer. The engineer started to explain the 3 main features that were proved which were:

-Magnetism
-Propulsion
-Switch

More details about the visit can be found in Appendix D. The technology explanation was very complex, but after the interaction with the engineer, several facts helped with the learning process.

Use of gestures
The importance of body language to understand certain mechanisms (Jackson & Fagan, 2000).

Use of Analogies
The engineer was constantly using analogies of daily cases to understand some units, for example. (The energy consumption is less than what the water cooker needs)

Persistence of Communication
In case there was something that I did not understand, it was possible to ask again until the information was clear (Jackson & Fagan, 2000).

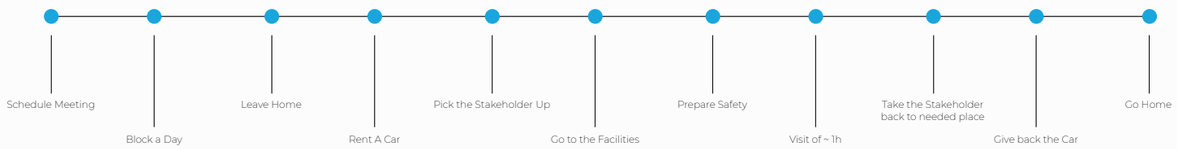


Figure 18: Diagram of steps needed to present physically the prototype

Digital Presentation

Once the visit was done, I was taken back home. I decided to check a video from Hardt, related to the Grand Reveal done in July 2019, that explains the LSTF's functionalities, which can be seen in the above figure, and compare it with my recent experience. Screenshots of the video can be found in Appendix E.

The video was trying to emphasize the views of interest by highlighting certain parts of the prototype, with the use of arrows explaining the mechanisms and cinematics of parts of the product. The problem with the video is that is a linear experience without interaction. He can only go back in the video in case he has any doubts, but it can be watched as many times as the user wants.

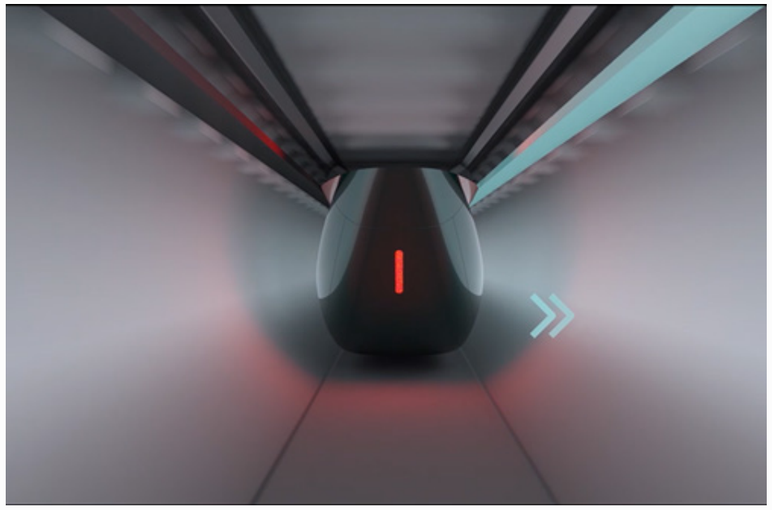


Figure 19: Render explaining the funtionalities of the LSTF - Property of Hardt

Insights

After analysing the process to showcase the prototypes, I could point out certain topics that can influence the future design solution.

Face-2-Face

Physical meetings have additional costs in terms of time and money, but they work pretty well for exceptional situations. It creates trust and engagement with the project.

Gestures

The use of gestures, and body language, helps to understand the technical solutions.

Analogies

Analogies from daily products or situations help to understand the solutions

Personal approach

Not everybody learns at the same pace. People hide when they do not understand.

Presence

Being there makes it more believable and gives contextual awareness.

2.3.4 Analysis of the Design Workflow

As part of the internal communication, the researcher analyzed how products were designed in Hardt. For this case, the Cabin-1 prototype was analyzed, which is the most advanced physical product that Hardt has developed in terms of Passenger Experience.

The Cabin-1 is a great example because it merges internal and external communications. Engineers, project leaders, and designers had to be in contact with the three stakeholders that took part in the creation of this prototype. The stakeholders were Recaro, for the chair design, Continental, providing sustainable materials, and Accenture Interactive, whose goal was to showcase their experience in extended reality as a way to communicate ideas and concepts.

For the development of the product, face-2-face meetings and remote collaboration participated in the process. This project was also developed before the pandemic, so Face-2-face Meetings with colleagues in Hardt were very easy to implement. The collaboration with the external stakeholders has always been remote.

Face-2-face meetings vs Remote Meetings

Face-2-face Meetings are expensive (travel expenses, time-consuming, inflexible) but they are more effective than Remote Meetings when it comes to making decisions. In the room, ideas are explained in a more clear way and there is a different mood around the meeting that might improve the goals of the parties involved.

Remote meetings are cheap and straightforward but they can lead to misunderstandings, communication, isolation, and it can hence conflict between individual team members (Jackson & Fagan, 2000). The benefit of remote collaboration is that it can work asynchronously (not at the same time) like it would happen when 2 users use email, taking their time to answer properly. ("Benefits of Working in an Office vs. Remote Work," 2020). Down below you can find a chart comparison between the costs and benefits from office and remote work. ("Benefits of Working in an Office vs. Remote Work," 2020)

OFFICE WORK		REMOTE	
Benefits	**Costs**	**Benefits**	**Costs**
✓ Improve work-life balance	✗ Increased Overheads	✓ Reduced Commuting	✗ Software Upgrades
✓ In-person collaboration	✗ Reduced productivity	✓ Improved Mental Health	✗ Cultural Barriers
✓ Improved team morale	✗ Market Competitiveness	✓ Employee Retention	✗ Formal meetings vs Casual conversations
		✓ Wider Talent Pools	✗ Hardware Expenses

Figure 20: Chart comparison between Office work and Remote work ("Benefits of Working in an Office vs. Remote Work," 2020)

Figure 21: Head of Design commenting on design proposals

Visual Mental Models

In order to achieve a common understanding between the members involved, Hardt has been using visual representations to explain the ideas. It is key for any design team to transmit the attributes of the design to continue with progress. Up until now, Hardt has used images and videos to establish a common ground.

Out of this project, form study was part of the design process. The Head of Design, Jose, and one engineer were key to understanding the luggage compartment. Conversations were discussed by both watching the 3D model in the 3D software and sketching on a piece of paper to discuss alternatives. They pointed out that the work had to be done separately, because of the software incompatibilities from the design team and the engineering.

Unfortunately, the conversations with Recaro, the ones in charge of the chair design and manufacturing, were also done by using different software that caused several incompatibilities too. As an alternative, the design team and Recaro team were using screenshots from the CAD software, commenting on it, showing different perspectives, and sending it through email to discuss alternatives.

Sketch

Sketching on top of the design is a very effective solution due to its several advantages. Sketching is rapidly made, and it doesn't need to be complete, accurate, or consistent in terms of detailing or truth to scale (Goldschmidt, 2007). Designers use sketching as a way of communicating with each other, but also as a way to communicate with yourself as an individual. It is commonly used during the early stages of the design process and can avoid future concept issues. Down below in figure 24 you can find a 3D model provided by Recaro, with sketches and comments on top done with Photoshop realized by the design team of Hardt as feedback. Even though 2D sketches are very useful, not everything that we see in 2D is translated properly to 3D. This might lead to the Recaro team and design team understanding something that might be wrong for both, turning out to be an inaccurate mental model. Consequently, that is why sketching is not very useful when it comes to ergonomics. This is also why we develop prototypes to validate our concepts.

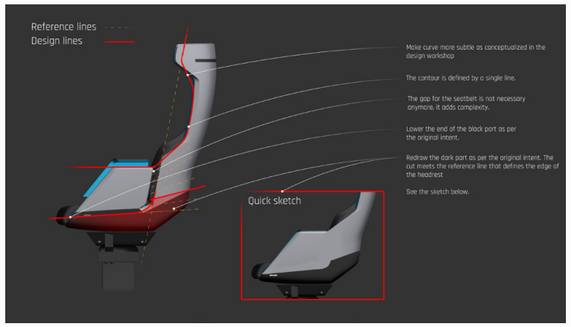


Figure 22: Sketch on top of the screenshot - Property of Hardt/Recaro

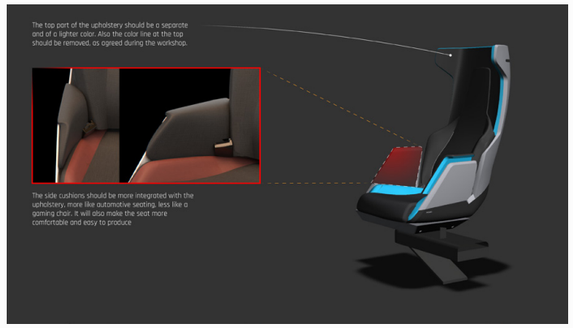


Figure 23: Different points of view - Property of Hardt/Recaro

Insights

After analyzing the workflow between the members, it was apparent that the design discussions, especially with Recaro, lead to skeptical decisions during the process. Recaro had a lot of experience, but some decisions were not comfortable to make, even though everybody was very happy with the end result once they stepped into the manufacturing. Some insights discovered during the analysis are shown in the following section:

Sketch

It is a great tool, and an intuitive way of communicating, especially in the early stages. It would be nice to keep this simple, and as a freeway of expression during discussions. Figure 20 showcases a communication between a teacher and a student, from the scientific paper "To see eye to eye" (Goldschmidt, 2007) where the teacher sketches over the drawing of the student providing alternatives to the first idea. This kind of interaction happens as a team booster, maximizing the knowledge increase of the student, and improving his skills. (Goldschmidt, 2007)

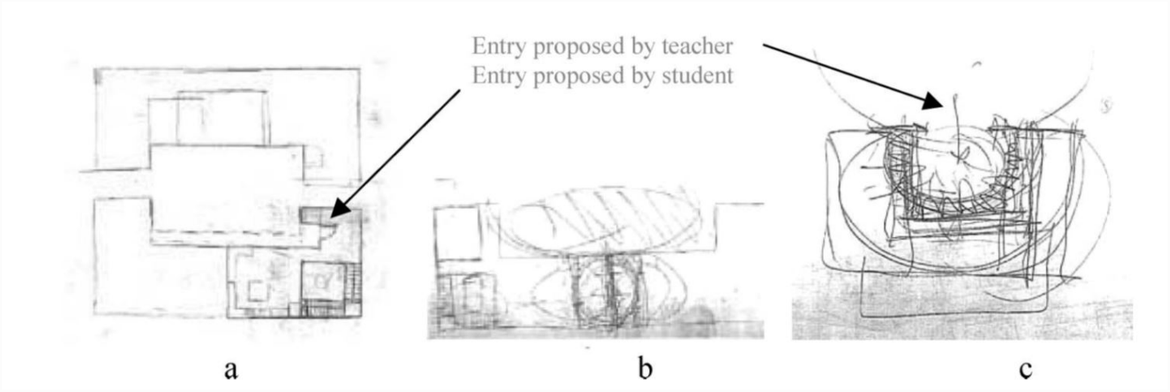


Figure 24: Conversation between a student and a teacher (Goldschmidt, 2007)

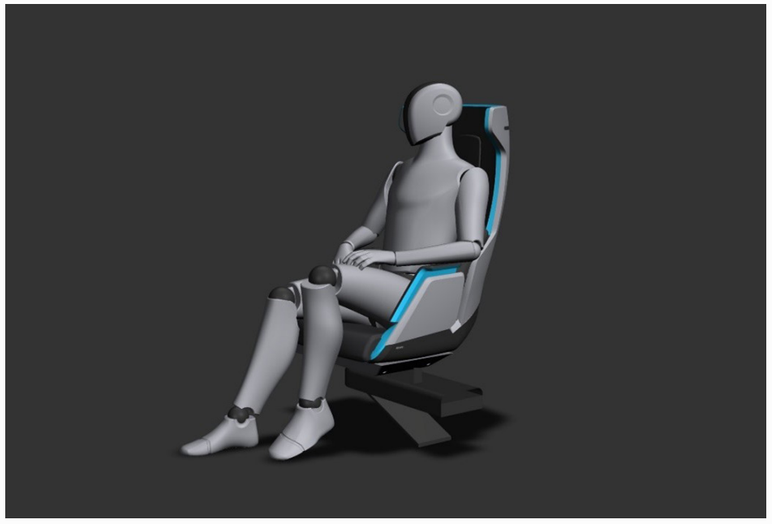


Figure 25: Ergonomical study with dummy - Property of Hardt/Recaro

2D to 3D

It is difficult to turn 2D designs into 3D with accuracy. There must be a way to validate the accuracy of these visual mental models. In terms of ergonomics, sketching in 2D is a tool that can give the designer an idea, but it does not provide enough information. That is why Recaro uses a dummy in the 3D models, as you can see in figure 25, but they are the only ones who have access to it.

Virtual vs Physical

A new survey, from FlexJobs and Mental Health America (MHA) taken last month reported that 75% of workers have experienced burnout, and the 40% of those polled said it was a direct result of the coronavirus pandemic. (Mendoza, 2020). After seeing the benefits of virtual meetings in terms of time and cost, but paying attention to the costs of making too much use out of it, it is time to bridge the gap between these two ways of conferencing. I created a priority matrix that you can check in order to identify opportunities. I compare costs with engagement, and Virtual meetings can have a good balance, thus an opportunity.

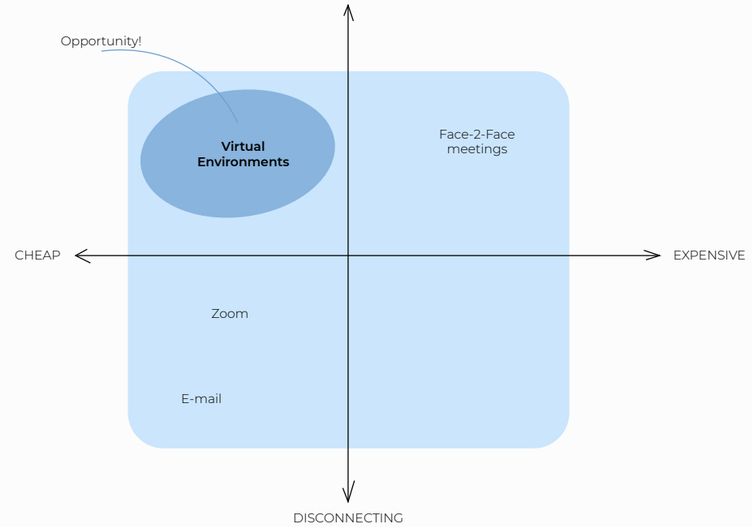


Figure 26: Matrix for opportunity finding - 2x2 Prioritization Method

2.3.6 Post-pandemic Vision

2.3.6.1 Context

After researching how people were designing and communicating inside Hardt, we have to accept that the pandemic has changed the working environment and how people relate to each other. This remote situation is not going to last forever, but it is important to know what will be kept in the future.

Working Habits

COVID-19 pandemic has forced many companies to adapt to digital solutions, especially for non-essential workers (Boston, 2020). There is an increase in happiness due to less commute, companies have invested in equipment like laptops and expanded Virtual Private Networks (VPNs), and big firms have learned how to coordinate work from home (Boston, 2020).

Not everybody has the same type of job, being able to do it from home. Sales or relationship management, which has historically been viewed as requiring face-to-face interaction, may need to evolve given changing health guidelines and customer preferences, as well as travel for non-essential purposes (PricewaterhouseCoopers, n.d.). We can see this happening on the difficulties Hardt is having problems to onboard new investors presenting the prototypes, as we saw in the walkthrough analysis.

Companies are already thinking about the end of full-time remote working, considering that workers should be some days at the office. According to Ana Botin, president of Bank Santander "Even in banking, we need to be together to create" (Así será la vuelta a la oficina de las grandes empresas españolas, 2021). It is a reality that working habits have shifted. McKinsey Global Institute says 20-25% of workers in advanced economies could work remotely 3+ days a week on a long-term basis. Hardt must adapt to this new hybrid reality.

Remote working is not considered the perfect solution for future working habits. Remote work is actually increasing the number of burnouts. Even though the pandemic has been a break from office and commute, over two-thirds of workers are experiencing burnout symptoms while working from home. This can be due to the need for a break from technology and work (Fox, 2020).

Figure 27: McKinsey graph about office demand after pandemic (McKinsey, 2020)

Remote Collaboration

Since the pandemic kicked in, we are having online meetings more than ever before. Videoconferencing as a solution for this situation, but it does not always meet the working requirements. Ovum found out that 30% of sales professionals think that the online tools that are used nowadays make sales even more difficult, instead of helping (The 10 Most Common Video Conferencing Problems Explained, n.d.).

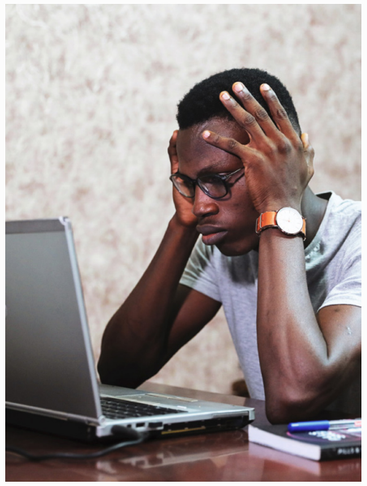


Figure 28: Image of a worker stressed by constant virtual meetings - Pexels.com

When it comes to sharing information, employees are turning into cloud-based solutions such as Sharepoint, Dropbox and Drive. Collaborative editing documents are rising like Google Docs, and regarding communication tools, solutions like Skype, Zoom or Teams are regularly used.

According to Zimmerman (2020) "With the SARS-CoV-2 pandemic stopping in-person meetings and conferences, videoconferences are the new norm. But video calls are old technology. Soon, conferences and meetings will be held in 3D, using VR headsets."

In the SWOT analysis from Ecorys (2021), which can be found in appendix G, it is mentioned Extended Reality (XR) solutions are considered an opportunity because old working structures are being deteriorated due to COVID-19.

After three decades of improvement in technology related to collaborative mixed reality, it looks like we are stepping into a moment where the applications of this technology can face real-world problems possible (Ens et al., 2019).

Virtual reality is already reaching a maturity level, as you can see in figure 29, which describes the Gartner Hype Cycle. This cycle links the expectation of the public and market of new and emerging technologies with the level of maturation (Ecorys, 2021). COVID-19 has created the perfect conditions to demonstrate how this technology can be resilient to pandemics due to travel restrictions. The XR industry is growing tremendously, and it is expected to grow even more due to three different factors: A global expanding XR market and industry, the solutions offered by XR and lastly, political priorities and policies. More information in detail can be found in Appendix F.

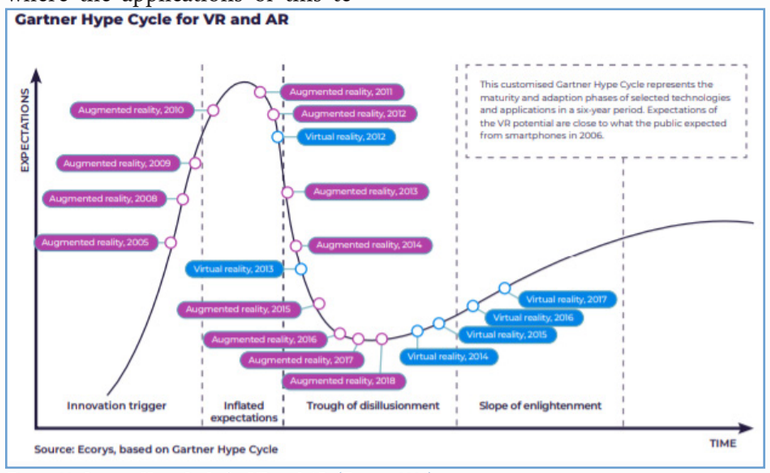


Figure 29: Gartner Hype Cycle for VR and AR. (Ecorys, 2021)

Different alternatives for virtual reality meetings have appeared recently, as you can see in Appendix G. From my own experience, I know Gravity Sketch which is a VR software where creators can 3D sketch and review designs of CAD models remotely in true scale. Even though it can also be used on the iPad, the biggest potential is on the VR headset, limiting the users to this specific hardware.

On the other hand, we have Spatial, which is a cross-platform app for virtual meetings. It can put in the same meeting smartphones, PC, VR, and AR glasses, with the possibility to present concepts and even do Agile workshops using post-its, images and dashboards. This software is great for users who have no experience with virtual environments, because of the accesibility with different devices. Spatial has also access to Drive, being an environment where you not only use it as a communication tool, but for sharing information. Moreover, the use of XR solutions can save costs in terms of time and travel expenses (Epic Games, 2020). More information on remote collaboration can be found in appendix H.

Lastly, conducting activities remotely will reduce Co2 emissions due to less travel and materials used, contributing these solutions not only to save costs, but also as an environmental friendly application. In appendix H you can find more information related to XR as an environmental friendly solution. More XR solutions with positive sustainable effects will appear as a critical mass of users is reached (Ecorys, 2021).

Figure 30: Designing with Gravity Sketch at MMID Studio

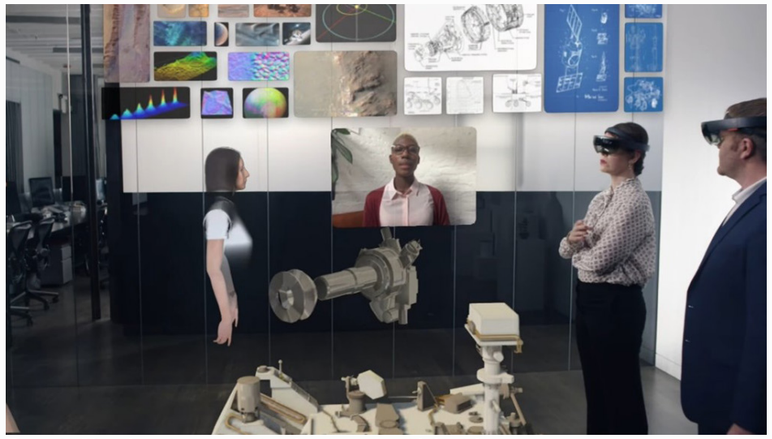


Figure 31: Virtual meeting using a virtual environment with Spatial

2.3.6.2 Technological Opportunities

What is XR?

From the previous section, it could be seen the potential of XR as a communication tool. XR covers three main technologies, which are Augmented Reality, Mixed Reality, and Virtual Reality. VR is easy to recognize because once you have put on the Headset the whole environment is digital. However, there is still an ongoing debate trying to differentiate AR from MR. To better understand which technology can provide a better solution to the current problems, it is necessary to identify how they work, which devices are needed, and what are the current limitations:

Virtual Reality (VR):

Consists of a fully digital and immersive environment with 3D interactivity.

Complete flexibility, true immersion, an endless number of virtual scenarios and experiences can be created. (Varjo, 2021)

Isolated experience, detaching the user from real surroundings and colleagues. (Varjo, 2021)

Augmented Reality (AR):

Overlays a digital information layer in the real environment.

Portable, wireless, lower cost, enables interacting with reality around you. Great for portraying simple content like information overlay. (Varjo, 2021)

Holographic, unrealistic augmentations, narrow field of view, no immersion, and limited enterprise applications. (Varjo, 2021)

Mixed Reality (MR):

Is a mix between AR and VR. Mixed Reality adds interactable virtual objects to the information overlaid to the real world. The main difference with Augmented Reality is that virtual objects can understand and react to the real world.

An immersive environment that matches reality, suitable for any simulations that need to reflect real scenarios. Mixed reality provides complete flexibility of the virtual world with the reliability of the real world. (Varjo, 2021)

Higher price, larger headsets compared to AR glasses, tethered. (Varjo, 2021)

These three technologies are always developed with game engines. A game engine is a software-development environment used to design and develop video games (“Game Engine,” 2021). The most common game engines in the market are Unreal Engine, and Unity. So basically, an interactive application developed for VR, AR or MR, are developed with the exact same technology as video games. This means that VR, AR and MR are developed with the same principles and logic, but what makes the difference is the output or device where the interactive visualization will be displayed. Therefore, PC can also be an output for interactive visualization and can be considered virtual reality.

XR with Design

Once XR is understood, finding the potential in the design process is a must. Three aspects are studied which are collaboration, visualization and product design.

Interactive Visualizations

Interactive Visualization is a technology that enables data exploration thanks to the manipulation of chart images, color, brightness, size, shape, and motion of visual objects (Mirko, 2020). Thanks to programming, we can set an array of options that will enable users to analyze data by interacting with a visual representation of it. (Mirko, 2020). Interactive visualizations have been around for some time already. They were commonly used in video games, and now, thanks to the graphics improvement, we can start finding applications in different areas where high-quality visuals can determine useful information for professionals.

Within Game Engine, we can find a game renderer, which is the one rendering 2D or 3D images. Game renderers work in real-time, not like offline render engines like V-ray or Keyshot. This is because Game Engines make use of the graphics processing unit (GPU), and it has evolved recently a lot. However, Keyshot or V-Ray creates stunning visuals by using the CPU, which takes more time. We are now in a moment where it is difficult to differentiate a render from CPU and one from GPU, especially if the users seeing the visuals are not used to working with visualizations. Therefore, we could consider the use of render engines, like Keyshot, a waste of time, especially when we have the skills to use GPU renderings, like Blender, Unity or Unreal Engine 4, both based on motion capture. For a still image, a CPU render can take 8 hours, whereas a Game Engine can take 0.1s. This difference in a still image is huge, but considering that this way of rendering is also used for high-quality videos, a 3 minutes video can take up to 37 days, whereas real-time rendering can be dropped to only 10 minutes. (Mirko, 2020).

Figure 32: Comparison between CPU (Most 3D renders) and Real-time rendering (Unity) (Mirko, 2020)

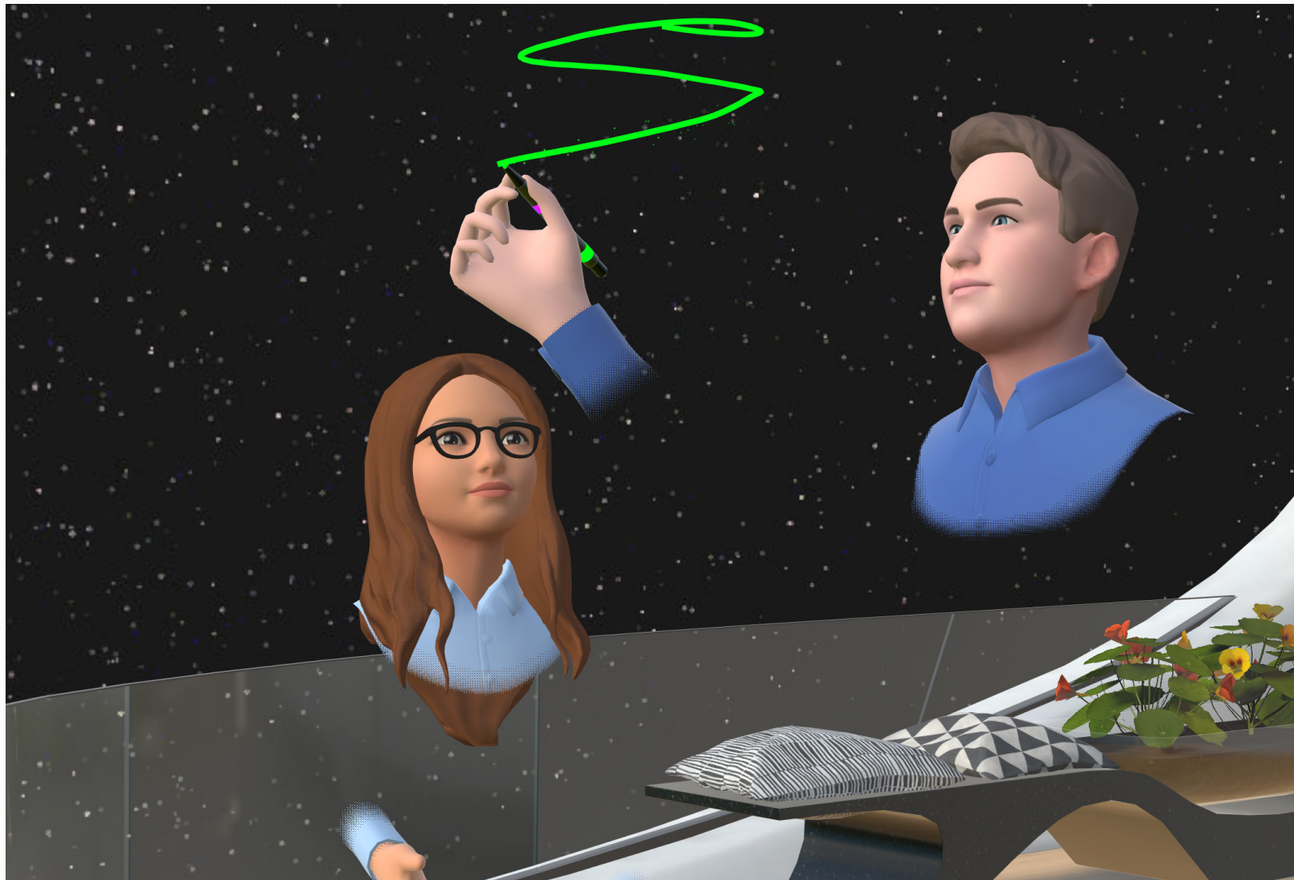
Building Networks and Memories with XR

When working in a team, lack of face-to-face interaction can lead to misunderstandings and feelings of isolation, which can hence conflicts between team members(Bosch-Sijtsema & Haapamäki, 2014). This misconnection between the members of a team can create innacurate team models (Badke-Schaub et al., 2007).

Virtual environments (VEs) can offer exploration capabilities by modifying the content of the environment in a collaborative way, when sharing a context with somebody else using avatars. These capabilities are seen as benefitial for virtual team coordination, creation of trust and shared knowledge (Bosch-Sijtsema & Haapamäki, 2014).

Research proves that social networks can happen when making use of avatars that share a working place (Bosch-Sijtsema & Haapamäki, 2014), being a potential alternative to how we build relationships through platforms like Microsoft Teams. Moreover, VEs can provide a level of immersion and presence, that will help users to remember the information shared better. This happens because humans tend to reconstruct their memories in 3D, called spatial understanding (Bowman & McMahan, 2007).

Figure 33: Virtual meeting - Courtesy of MeetinVR



XR in Transport Industry

Game Engines have evolved drastically in the last years, as we saw before in the visualization section. The implementation of this technology for complex products can improve the product life cycle in different areas, leaving the current production production outdated. Forward-thinking companies from the automotive industry are already making use of this technology in different parts of their pipeline (Epic Games, 2020):

Concepting: Concept artists are using interactive tools to explore and iterate on ideas instantly.

Design: Designers are collaboratively tweaking and refining designs in real-time.

Engineering: Engineers are testing engineering scenarios more cost-efficient in real-time environments.

Marketing: Marketing teams are creating product content personalized for each customer.

Figure 34: GranStudio Digiphy prototype

Figure 35: Virtual meeting in the same car - Courtesy of GranStudio

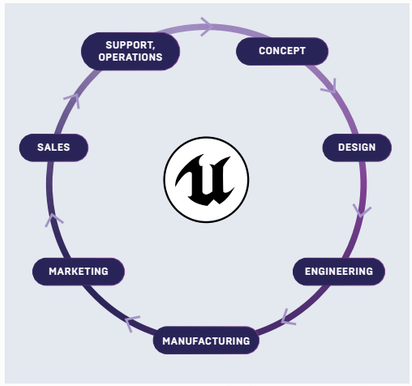


Figure 36: Automotive Product Cycle with Unreal Engine - (Epic Games,2020)

When implementing concepts in a virtual environment developed with a game engine, people can already find and fix ergonomics and manufacturing errors when it is still easy and inexpensive(Varjo, 2021). These concepts can turn into real-scale virtual prototypes, where designers and engineers can validate forms, shapes and behavior of users with fewer materials and a reduction in the production of a prototype. In Appendix I, a description of the prototype of the Cabin-1 can be found, explaining the costs required for its development. The content can also be shared with interactive visualizations with XR solutions (Varjo, 2021). With interactivity, people will understand by themselves the knowledge that others want to share with them when they have their own autonomy in the virtual environment (Jackson & Fagan, 2000).

The potential of game engines is the different interaction options that it provides, from 2D screen solutions for marketing purposes, to 3D representations like virtual reality for engineering validation (Epic Games, 2020). Virtual and mixed reality makes sharing a design with non-designers much easier, enabling key stakeholders to become involved earlier in the design process (Varjo,2021). The product cycles are shorter thanks to the fast feedback from key stakeholders, improving decision-making. Companies like Siemens are already using virtual reality to meet customer needs. Volvo has developed a configurator that can be used from home, to avoid traveling to physical places where to check their products. Other hyperloop companies are using virtual reality to showcase their station concepts, so they validate the public adoption. More information about interactive visualizations in transport design can be found in Appendix J.

Figure 37: Siemens using Virtual Reality to meet customer desires

Figure 38: Volvo online configurator

2.3.7 Conclusions

During the Discover phase, I gained a broad understanding of how Hardt's ecosystem works, the problems that need to be tackled, the current communication challenges, and the pains and gains from technology solutions used during this pandemic.

Research on communication gave me an understanding of the importance of effective knowledge sharing. Sharing mental models visually can help to create a common belief, being called the "grounding process". Visual communication is proved to be effective, and this can happen with the use of images, videos and sketching. In a team is important to know who needs to know what to have an effective performance.

After learning the basics of communication, understanding who was taking part in the conversations was important. It turns out that even there are many stakeholders involved in Hardt's ecosystem, users can be easily categorized into two types for the design purpose: Tech friendly users, and non-tech-friendly users. The reason we differentiate in these two categories is for the grounding process related to the hyperloop system, and how used they are on using complex digital platforms.

Hardt's communication channels are internal and external. For the external communications, interviews were carried out, where it was highlighted the fact that current channels like emails and videoconferences are inefficient, slow and can create misunderstandings. Moreover, a walkthrough through the prototypes was recorded to understand how new stakeholders were onboarded was analyzed before the pandemic kicked in. Body gestures, shared context environment and simple analogies turned out to be effective when trying to create a common belief on how hyperloop's technology is closer to reality than what people might think.

With regards to internal communications, Hardt has been working since the beginning in a hybrid way using remote and face-to-face meetings with members of the company and external parties. 3D files incompatibility between different parties makes content sharing inefficient, but regular face-to-face meetings too, leaving a potential gap for virtual environments as a productive way of meeting and content sharing.

Remote and hybrid communication is the new norm since the pandemic started, creating a big impact on the number of business trips, making it more difficult to engage new investors with the project due to fewer visits to the facilities of Hardt. A forced change to digital tools for collaboration has happened in most companies, but there are common issues using these platforms such as Zoom that happen to build networks harder than we used to. Extended reality has the potential to be a digital solution to this misconnection between stakeholders, reducing travel costs and saving time, while still being able to build relationships environmentally friendly.

All the insights from the Discover phase try to describe the present situation broadening the scope. In the next chapter, convergent thinking will be used to define future situations using these insights as a starting point.

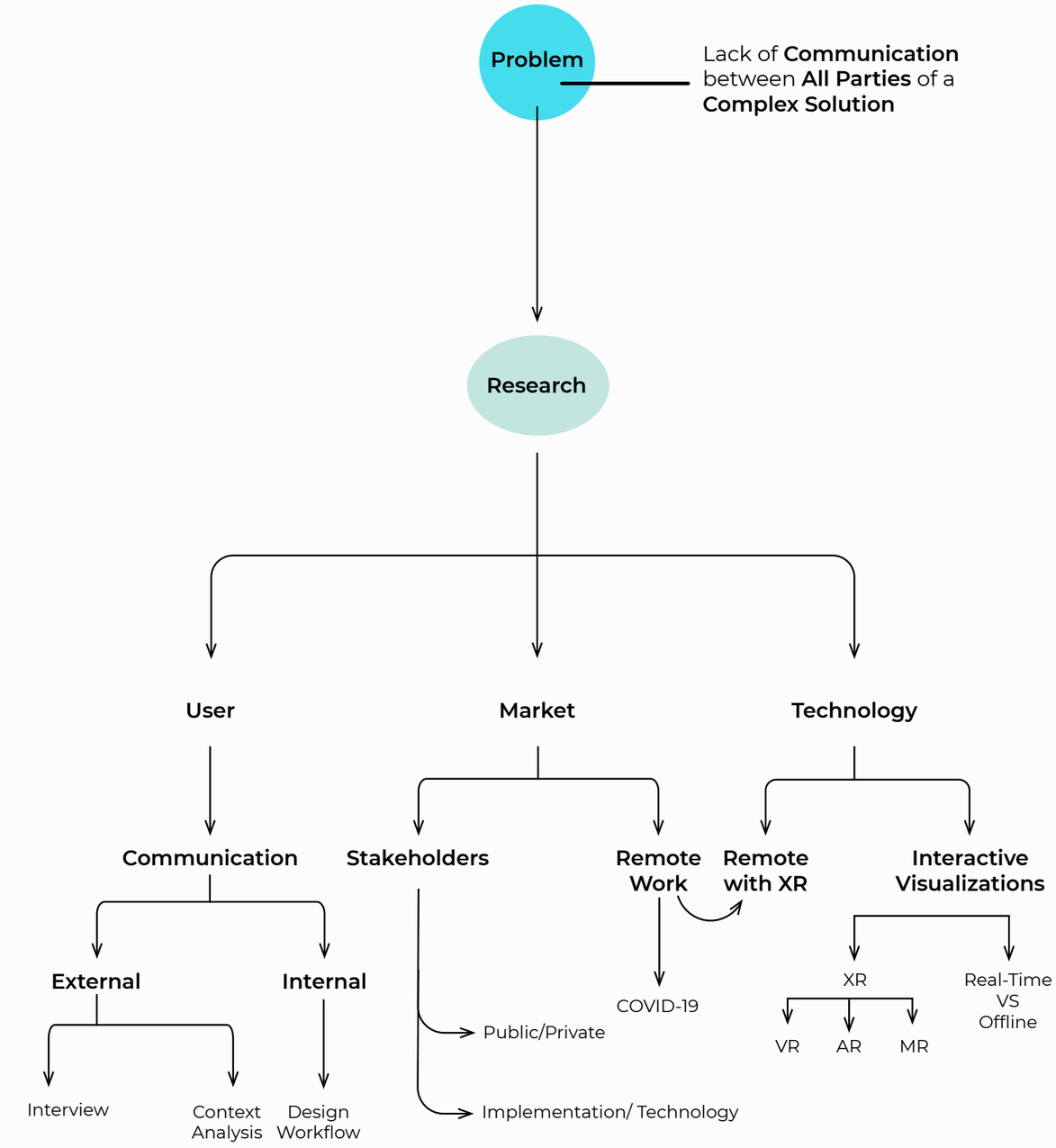


Figure 39: Diagram explaining research fields studied

3. Define

For the Define chapter, design methods will be used to synthesize the information gathered in the previous Discover Chapter. By putting into context the insights collected up until now, it will be possible to frame the design space, therefore it will be doable to define problem statements in order to finalize the chapter.

DEFINE

3.1 Introduction

Once the first phase is over, the Define phase starts to converge the first diamond to narrow down the possible directions of the design based on the selected problems. During the Discover Phase, I wanted to acquire a broad knowledge regarding the topic, but it is time to concretize ideas by defining them into simple and understandable statements that I can tackle with enough arguments.

As it can be seen in figure 40, the process during this phase of the project is to synthesize who participates in the different communication configurations; how would this configuration work with digital solutions; what would be the desired situation, and what are the current limitations. The end goal of the Define Phase is to define the problem as concretely as possible. This way, solutions, considering the requirements, may be provided throughout the project.

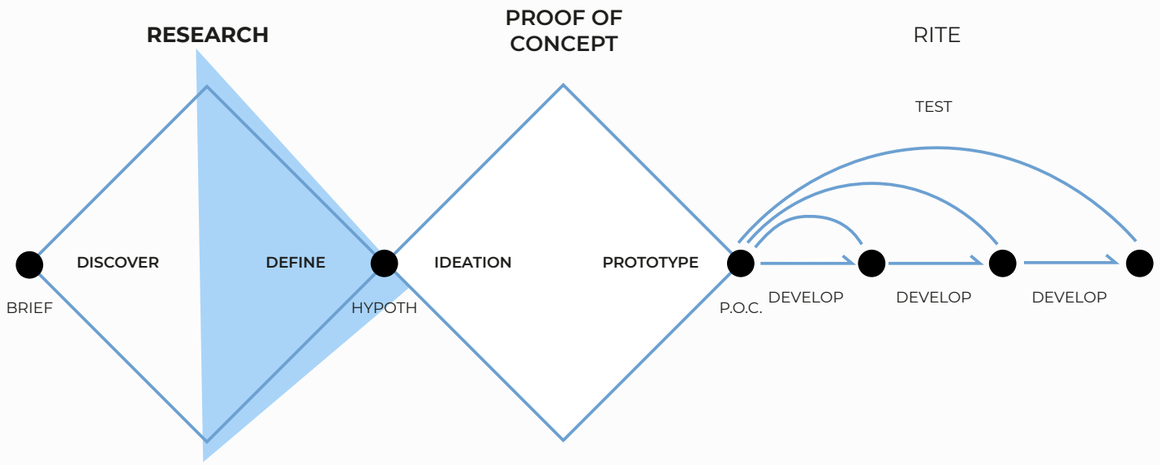


Figure 40: Converging thinking for the Define Phase

3.2 Goals of the Phase

- *Identify the situations with potential improvement within communication.*
- *Formulate problem statements that will be useful for the development of the project.*

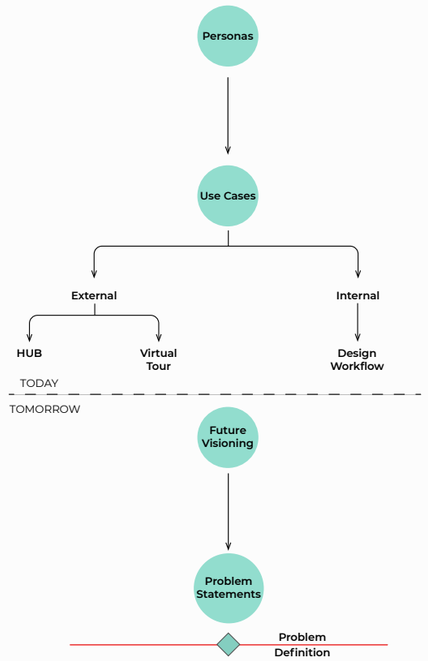


Figure 41: Define flow describing the methods used

3.3 Collect and Analysis

Most of the time, when a designer is working on the research phase, he may find out different problems. There may always be a need to tackle all of them, but designers must be realistic and use their skills to identify potential areas that can be solved within the timeframe provided. At this stage the convergent thinking within the research starts, and the designer has full control of the situation and strengthens with arguments the decisions that are made.

3.3.1 Persona

The different roles participate in every conversation, having an impact at different levels in the development of Hardt's projects. Communication should go seamlessly from product development to external parties, and bidirectional so the feedback provided by everyone involved can help to make decisions faster and better.

Communication with the whole Ecosystem has 5 main user profiles. These users are:

- **Hardt Engineers**
- **Hardt Business Developers**
- **Hardt Product Designers**
- **Implementation Stakeholders**
- **Technology Stakeholders**

From internal communication, we know that engineers and business developers have to update their knowledge constantly. Engineers must communicate the state of the technology developed within the company, and business developers must communicate the desirability of the project from the investor's perspective, as well as developing potential routes for the hyperloop. The Product Design Engineer ś goal is to bridge the communication between the engineering and the market, working as a hybrid profile.

Regarding external communication, business developers are the ones in charge to keep in contact with the implementation stakeholders, while engineers are in touch with the technology stakeholders. Defining some Personas would help to keep in mind who this design is for, having a reference from the end-users. These personas are imaginary representations, so they could be scaled up to future partners that want to join the project.

Name: Marcus
Role: Project Lead
Age: 32
Languages: Dutch, and English
Work Experience: Logistics Manager
Interests: Social Activities and fitness

Goals: Align all stakeholders within the Hyperloop Ecosystem. He is the one who must put in contact the right people and provide the useful information used inside the company to external parties.

Frustrations: He misses more conversations where people can discuss and agree on the new directions of the project.

Name: Connor
Role: Engineer
Age: 27
Languages: Dutch, and English
Work Experience: Engineer at Hardt (2 Years)
Interests: Cars and Extreme sports

Goals: He has the ambition to take part in a project that can change the mobility of the future. Become part of the impact in sustainable and efficient high-speed transportation.

Frustrations: He cannot handle properly when people do not understand the effort of his work.

Name: Juan
Role: Design Lead
Age: 35
Languages: English and Spanish
Work Experience: Design Engineer at Hardt (4 years)
Interests: Video games and sports

Goals: Bridge between engineers and business developers. Meet user needs within the technical boundaries. Responsible on how Hardt communicates the work to the exterior of the company.

Frustrations: Communicating engineers the importance of user-centered design.

Name: Barkin
Role: Implementation Stakeholder
Age: 53
Languages: Dutch, Turkish and English
Work Experience: Member of the Government (15 Years)
Interests: Reading, Networking and Golf

Goals: Contribute to improve society through politics. Takes part on big decissions from the government like infrastructure investment projects.

Frustrations: Not comfortable with complex technologies. Gets tired of slow communication due to bureaucracy inside his working environment.

Name: Geert
Role: Technology Stakeholder
Age: 45
Languages: Dutch and English
Work Experience: Structural Engineer (12 years)
Interests: Football and bars

Goals: Deliver designs and manufacturing of structures with optimization always in mind. Passionate about complex materials, and learning while working is part of his motivations.

Frustrations: Delays on projects. He has a very structured mind.

Figure 42: Personas Method

3.3.2 Use Cases

To help me put in context the conversations that normally take place in Hardt, the "Use Case method" (Affairs, 2013) was used to describe how users will perform certain tasks in fiction situations. This exercise helps to outline the user's point of view, and the system's behavior. During the description of the use case, the steps that each user will have to go through are written, starting with a user's goal, and ending up with the fulfilled goal.

With the use of this method, I will be able to explain how the different communication situations would work while I can brainstorm what could also go wrong, anticipating or highlighting barriers of communication within the system. Goals are enlisted and can define the complexity of the envisioned communication. Once all the functions are mapped, I will decide which ones can become a requirement.

Like it was said before during the development of the Personas, five main profiles are identified which led to three configurations of conversations for common grounding. These configurations were used to define three Use Cases that you can find the full representation in Appendix K. These are the three most common conversations taken from the research:

Conversation configurations:

1. **External Communication: Business Developer – Implementation Stakeholder**
2. **External Communication: Engineer – Stakeholders**
3. **Internal-External Communication: All members**

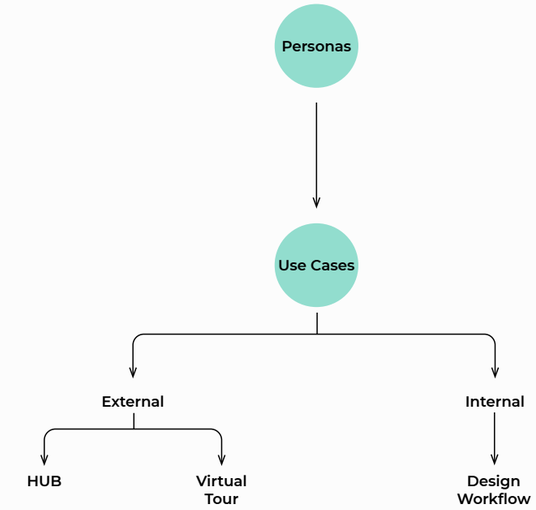


Figure 43: Diagram representing which Use Cases are studied

Hardt – PostNL Collaboration

One of Hardt's milestones to develop the hyperloop is to prove the technology in the cargo field. Hardt is aware of the growth of logistics, so the company is currently validating if hyperloop technology can bring value to this field. Hardt seeks partners and collaborates with others to develop business use cases. The knowledge gap between key players of logistics in the Netherlands and Hardt members regarding the hyperloop must be resolved. Putting everybody in the same context -in this case in the warehouse- would help dramatically, as Roeske (2021) mentioned from his experience with the stakeholders.

Business - Stakeholder

Use Case: Post NL, one of the potential stakeholders in the ecosystem with knowledge related to logistics, will have a virtual walkthrough of a digital warehouse, together with a market developer. They will check **how goods are transported** in the warehouse during the whole process.

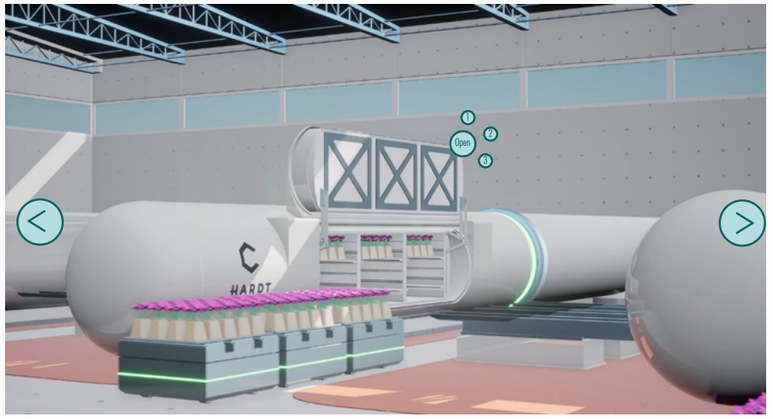


Figure 44: Interactive Visualization of a Hub with Cargoloop

Hardt Virtual Tour of the Facilities

The conversation would happen between an Implementation or Technology Stakeholder, and an Engineer from the company. Back in time, a way to show the tangibility of our projects it was the showcase of our different prototypes, such as the Low-Speed Test Facility. An Engineer would conduct in the past a tour through out the different systems and subsystems the prototype had, demonstrating our proof of technology. This has been done during the last year to engage with the investors proving we can build up the products that we envision and explaining the current roadmap that the company has in its mind. Hardt considers this tour to be honest outside the company, putting everybody to the ground saying at what stage of the project we are. The problem is that coronavirus has tackled this key factor that Hardt has, showing the first test facility from Europe.

Engineer - Stakeholder

Use Case: The conversation would happen between an Implementation or Technology Stakeholder, and an Engineer from the company. For this Use Case, a virtual tour through the Low-Speed Test Facility (LSTF) would be conducted, simulating how Hardt used to present the prototypes physically. The benefits of this tour is how stakeholders can explore the hyperloop technology by themselves without commuting to Delft.

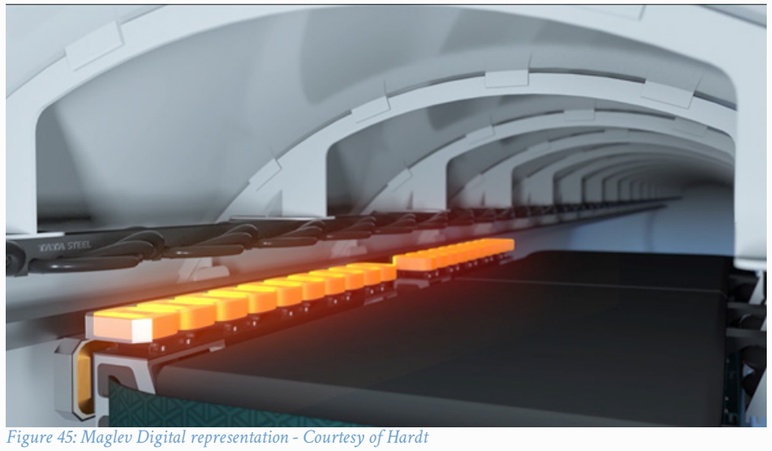


Figure 45: Maglev Digital representation - Courtesy of Hardt

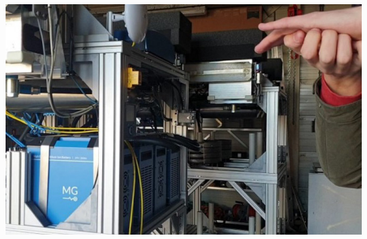


Figure 46: Explanation of the Magnetic Levitation using hand gestures

Hardt Cabin-1 Experience Prototype

The Cabin-1 is the most detailed prototype out of the physical products which Hardt has developed. As it is illustrated in the analysis of the Design Workflow (2.3.5), some of the communication channels are not fluent enough, therefore remote collaboration may be an option in a virtual environment.

From an internal perspective, members of different backgrounds from engineering and market development took part in the process. They all must have a common belief. From an external perspective, stakeholders such as Recaro, Continental and Accenture Interactive took part in providing their technology and knowledge.

Designer - Business Dev - Engineer - Stakeholders

Internal-External Communications

Use Case: This Use Case is focused on the development of the CABIN-1 prototype. From an internal perspective, an engineer, a designer, and a project manager from the market department have to communicate with each other.

With regards to external communication, Recaro would participate as a technology stakeholder, providing experience related to ergonomics, design and manufacturing, Continental as an expert in leather materials, and Accenture as a digital solutions expert.

In this use case, communications between the different stakeholders and Hardt members are explained with the use of a common virtual environment. Every user will be able to interact with the environment according to their roles, adapting the functionalities to their needs.

Figure 47: Cabin-1 image - courtesy of Hardt B.V.

Figure 48: Communication Diagram wit External Parties

Conclusions

The “Use Case scenario” helped to put into context a potential technology like interactive visualizations. Going through brainwriting was helpful to ideate possible flaws. After doing these three Use Cases, some common insights can be highlighted.

Usability

With regards to users who are non-technical like business developers and implementation stakeholders, they can feel overwhelmed with a complex 3D software. Their low experience with 3D software can lead to confusion and rejection of using the platform. Options must be simple and powerful, so they can feel part of the design process.

Coordination

Empowering other members of the ecosystem with certain skills can create more commitment with the project, also the team performance improves (Badke-Schaub et al., 2007).

Accesibility

Installation of apps can be tedious and a waste of time, especially if those are done remotely.

3.3.3 Future Visioning

Once the Personas were developed, the Future Visioning method (Delft, 2020) was taken into account to build up a future scenario where I could define the desires of the different users, and figure out which are the current limitations in terms of behavior and technology.

Together with this method, I could visually demonstrate the future interactions, but also keep the ones from the past, such as gestures and building networks.

Hereby, I present my vision of a remote meeting between a designer and an investor from New York using virtual reality. This meeting is happening considering that both users have a VR Headset, and it is working through the internet, which is fast enough to work on different devices at the same time, avoiding installations.

Right now virtual reality headsets are not spread enough in the market, and they also require a lot of GPU computing that the current internet is not strong enough to make it work. Stadia is a good example of the future of GPU through the cloud (Cloud Rendering), but it is not there yet.

Conclusions

For this project, it was necessary to adapt the current interactive visualizations to the hardware that common users usually have. Another question to consider is how these interactions can be kept when avoiding installations and making it more fluid to the users onboarding into the virtual environment.

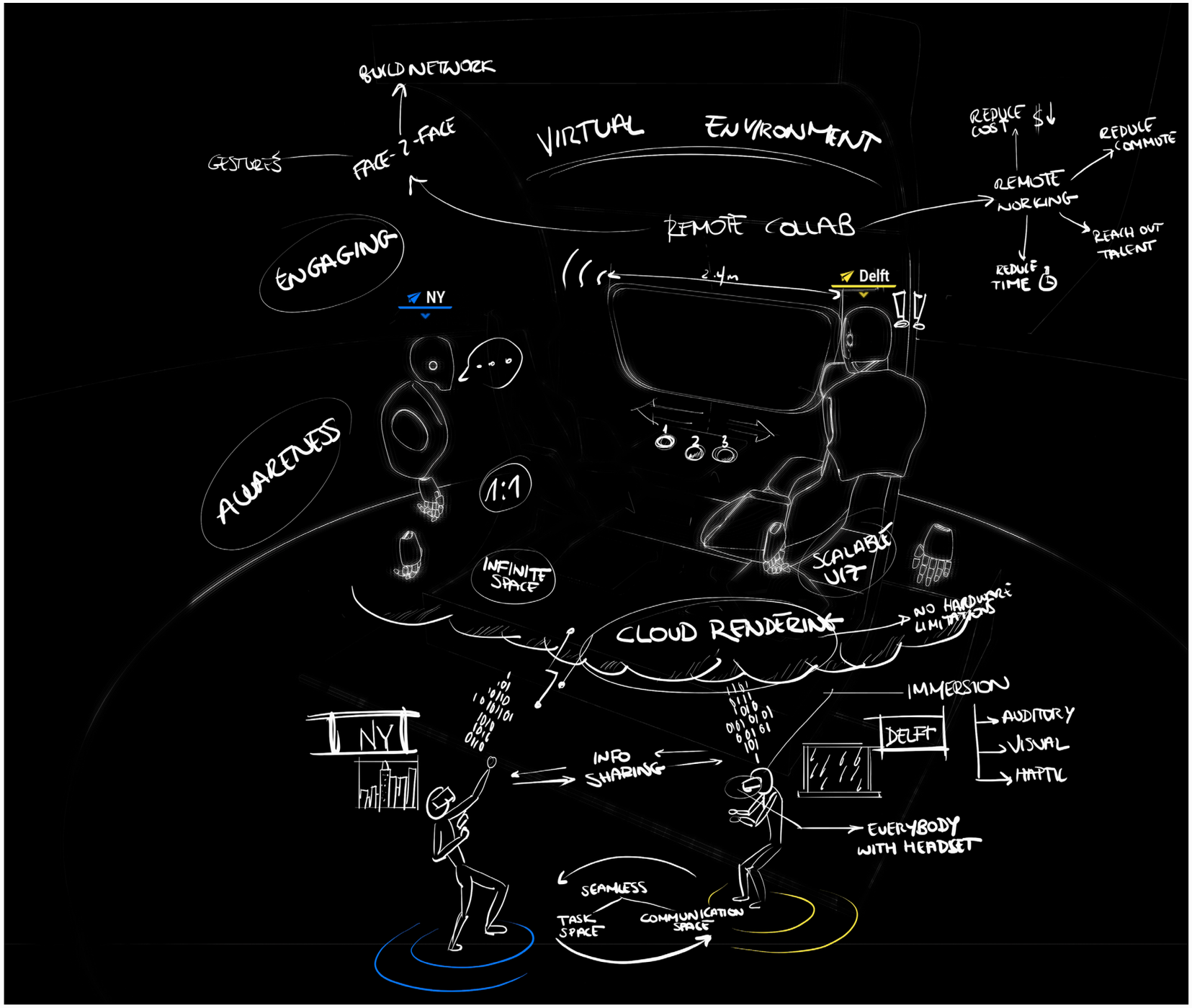


Figure 49: Future Visioning sketch

3.3.4 Concretising Problems

After identifying and concreting information during all the research design process, especially based on the selected functions from the Use Case method and Future Visioning together with insights, the problem statement method was used to enlist the issues from communication within Hardt that can be tackled with design. Mindmaps were created to understand the connection of the insights that end up defining the following problem statements.

Alignment:

Put together everybody's thoughts about the stage of the project, creating engagement and making everybody feel like they all have a say in the development.

There is a disconnection between certain stakeholders and Hardt in the hyperloop ecosystem when it comes to the stage of the project, or when it comes to understanding the technology during the onboarding process. "Different backgrounds must convey a shared belief" (Lee, 2001). Moreover, due to the pandemic and social distance, it is more complicated to build networks than before the pandemic. For example, regular visits to Hardt's facilities are not allowed, and those were really engaging. Therefore, there is a need to set common goals in the ecosystem during these tough times.

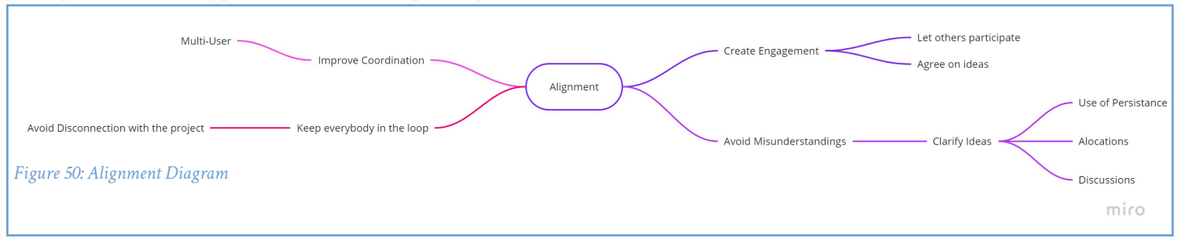


Figure 50: Alignment Diagram

Understand:

Facilitate the understanding of designs and assemblies to engineers, saving in costs and time to prototype and validate the decisions before moving to the next step of the process.

Physical prototypes can help a lot understand an idea once you see it on the true scale, but the throwback is that those prototypes can be very expensive and time-consuming to develop. Interactive dynamic systems can be great to transfer knowledge (Greenwald & Maes, n.d. In order to understand certain assemblies or designs without prototyping, more effective mental model representations than the current technical drawings must be explored, such as interactive design visualization systems (IDVS) that can eliminate mechanical and manufacturing problems (Lau et al., 2003) to set a common grounding between the members that take part in the conversation when it is still inexpensive to modify (Varjo, 2021).

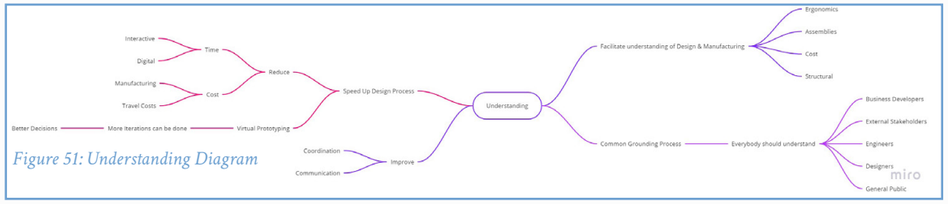


Figure 51: Understanding Diagram

Visualization for Involvement:

Provide 3D visual content to Non-Technical employees, involving them from an earlier stage, so there are no dependent members of Hardt to stop working on their task to attend to the non-technical worker's needs.

Currently, non-technical users do not have access to 3D visual content, due to expensive licenses and lack of knowledge. Providing a platform to involve them in the process is key for the success of the ecosystem, while also being able to take independent decisions(Varjo, 2021). This will liberate designers and engineers from spending time explaining concepts in certain situations, having more time to spend in decision-making.

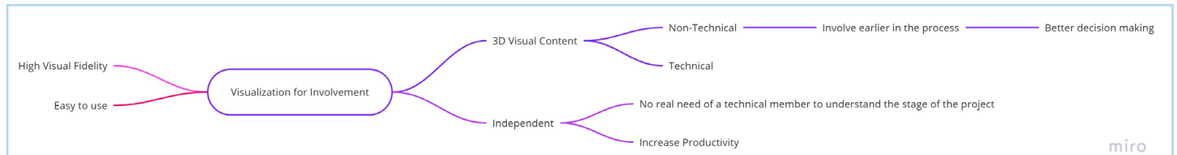


Figure 52: Visualization for Involvement Diagram

Accesibility:

Enable all the information in the same working space, so everybody can give feedback, engaging all parties, no matter where you are or the device that you have, avoiding different channels of communication.

Out of the future visioning conclusions regarding the software and hardware limitations of technology, accessibility is one of the main priorities of the design challenge. Stakeholders must not feel excluded by not having the required hardware, Hardt has to adapt to stakeholders resources like their hardware. One of the biggest concerns from the team Hardt is the amount of missed information through the email (Roeske, 2021). An alternative to these channels of communication must be found.

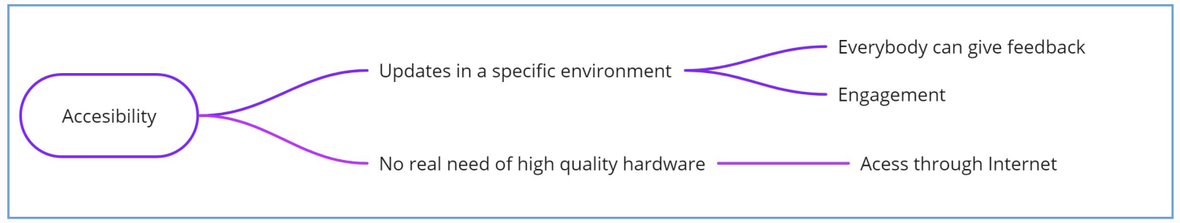


Figure 53: Accesibility Diagram

3.4 Conclusions

Research can be done endlessly, so in order to continue having the project under control, it was necessary to filter and cluster the information gathered. During the Define phase, I used several methods to generate insights out of the information discovered during the Discover phase such as Personas, Use Case method, and Future Visioning to end up creating insights that could help me define Problem Statements.

Together with the Personas and the Use Case method, it was mapped how the users in the three most recurrent communications within the ecosystem will perform in fictional situations using a digital solution. Thanks to this fictional situation, it was possible to brainstorm what could go wrong using a digital platform, and then turn functions into future requirements. These are common functions brainstormed in the three Use Cases that could possibly become part of a future list of requirements:

1. **Access to High-Fidelity visualizations.**

2. **Have the possibility to explore different design configurations.**

3. **Give the user the ability to explore different points of view.**

After developing the Future scenario, a solution exploration within the technical capabilities must be one of the priorities during future phases of the project. Three bottlenecks are identified that could possibly limit the feasibility of the project:

1. **No installation required:** Avoiding installations will facilitate the onboarding process with potential stakeholders, especially if the communication is fully done remotely.

2. **Multi-User capabilities:** Sharing a virtual environment provides engagement with the other users, and autonomy, being able to build a network (Bosch-Sijtsema & Haapamäki, 2014).

3. **Accessible for the platforms used by the stakeholders:** As we also know from research, a critical mass of users have not been reached yet (Ecorys, 2021), being necessary to provide connections to the platform from PC, smartphones, and early adopters of virtual reality.

The Define phase was a great way to cluster the big amount of information and settle design directions. With the convergent thinking, it was possible to narrow down the scope of the project turning insights into Problem Statements. Four Problems Statements were mapped, and that must be considered during the ideation phase as design requirements. These statements are:

1. **Alignment**
2. **Understanding**
3. **Visualization for Involvement**
4. **Accessibility**

The goal of the next chapter is to start ideating on how to improve the communications of Hardt having these statements in mind, and making use of interactive visualizations provided by XR solutions.

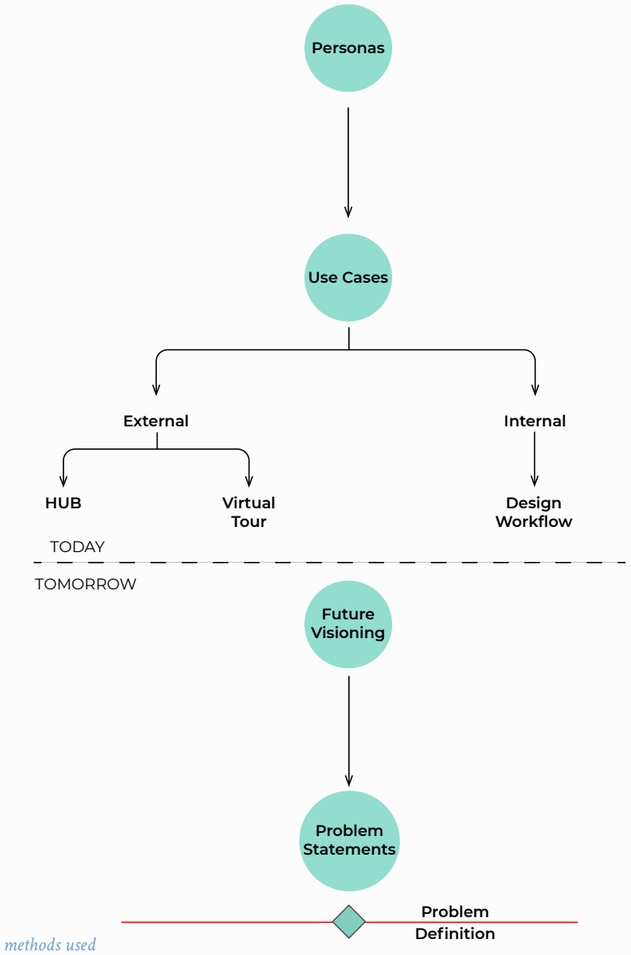


Figure 41: Define flow describing the methods used

4. Ideation

During the chapter 4, the ideation phase starts having in mind the statements developed in the previous chapter. Boundaries are settled by requirements, and the exploration of interactive visualization capabilities are brainstormed through the different contexts were Hardt participates.

IDEATION

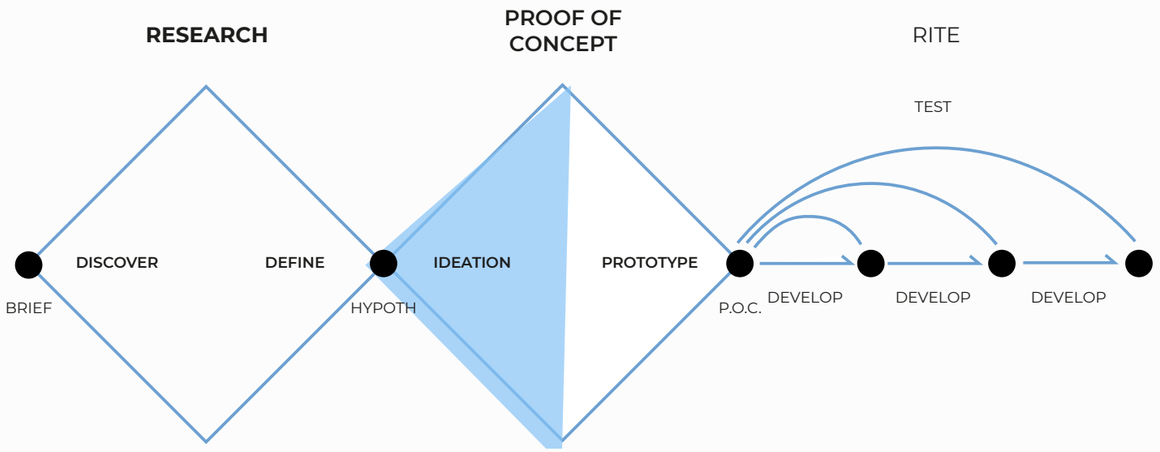
4.1 Introduction

The ideation phase starts once the research on the problem definition is finished. With the use of creativity, it is necessary to explore solutions of the encountered problems from the research. By limiting the design space with boundaries, a broad overview of the situation is seeked, taking into account the problem statements defined in the previous phase.

Up until now, research on interactive visualizations have demonstrated to be a potential solution for many communication issues. Virtual environments can empower users to do things remotely that could solve most of the current problems encountered due to the pandemic (Ecorys, 2021). Defining specific requirements will enable the exploration of possible interactions that can improve the communication of Hardt's ecosystem in various contexts.

Ideation can go endless, so deciding when to stop is needed. This exploration phase will end up by choosing a specific concept, that will be defined more in detail in the next chapter.

Figure 54: Challenge Approach Ideation phase diagram



4.2 Goals of the Phase

- *Limit the boundaries of the design space*
- *Explore functionalities for virtual environments*
- *Choose a concept to future develop*

4.3 Solution Exploration

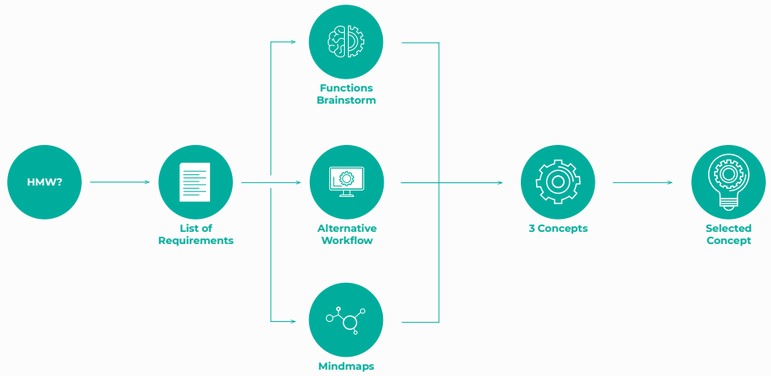


Figure 55: Ideation Diagram

The ideation process actually started with the Use Case exercises, in which possible conversations and their limitations due to digital solutions were put into context. Afterwards, a list of requirements was created in order to work with limitations and improve creativity. Then, the following aspects were done: Mindmaps, alternative diagram workflow and brainstorming exercises on the possible functions that may occur in virtual environments. Once the ideation was completed, three concepts were proposed. One of the concepts was chosen in order to continue towards a prototype phase, finishing in this way this section.

4.3.1 List of Requirements

To start ideating on how the communication could be improved, the WWWWWH method from the Delft Design Guide (2021) was used to ideate with How Might We? (HMW?) questions to figure out pain points and the integration of interactive visualizations in the future communication. This was done in the design workflow analysis (internal-external communication) and the walkthrough analysis (external communication). In Tables 2 and 3, the results can be seen.

WHO?	Designers, Engineers, and Partners	
WHAT?	Design a concept	
WHERE?	In Delft, but can be online	HMW Start validating decisions faster and better?
WHEN?	24/7	HMW keep the communication with different times if convenient? HMW track the conversations or sessions?
WHY?	Because there's a clear need to keep everyone with the same level of understanding about the concept.	
HOW?	Through screenshot Communication (2D Image) - File sharing issues	HMW improve the information shared? HMW Integrate the 3D files?

Table 2: Design workflow ideation with WWWWWH and HMW method

WHO?	Engineer - Tech, and Non-tech don't speak the same language	HMW make them understand what he says?
WHAT?	Present physical product. It cant be moved from there.	HMW move the prototypes to the stakeholders?
WHERE?	Delft HQ	HMW Start validating decisions faster and better?
WHEN?	When the meeting is finally arranged - It is difficult to arrange this kind of meeting.	HMW turn these meetings to be more flexible.
WHY?	To create engagement and trust. Bonds with stakeholders. We want to keep this.	HMW keep bonding?
HOW?	Physically.	HMW improve the current videoconference meetings from zoom?

Table 3: External Communication ideation with WWWWWH and HMW method

Taking into account the Problem Definition from the end of the first diamond, the technical requirements for the desired solution, and the questions that came out from Tables 2 and 3 from the HMW? questions, a List of Requirements was written, based on the method from the Delft Design Guide (2021). This List will help to set the boundaries of the design space. The results can be seen in table 4.

Engineering (E)

Involvement (I)

1. Accessible from desktops(Priority), scalable to other platforms(Wish) (A)

2. No installation required - Works with Internet (Easier to reach stakeholders to onboard) (A)

3. Give 3D visualization access to non-tech (Involve in the feedback) (I)

4. Adapt usability to the User-defined (Not everybody has the same expertise in 3D software) (I)

Technical (T)

Accessibility (A)

5. Interactive (Adapts to User needs) (T) (I)

6. Slight personalization (Wish) (I)

7. Validate Assemblies (Put together the 3D models from different (E)

8. Validate Ergonomics (Better than a static dummy) (E)

9. Fluid Performance (72 fps) (T)

Alignment (Al)

Understanding (U)

10. Ability to share ideas (Involve in the design process) (I)

11. Collaborative as an option (Adapts to time needs) (Al)

12. Track sessions (A)

13. Animations (U)

Table 4: List of Requirements

4.3.2 Alternative Workflow for Product Design & Development

As we know already, the involvement of stakeholders among the product development is one of the biggest interests of Hardt. Together with the research done in chapter 2 regarding the design workflow and the XR research, the SCAMPER method (Delft Design Guide, 2021) was used to improve how things are done at the moment. Results can be found in Appendix L. With all the insights, and using as an inspiration the new workflow proposed by Gravity Sketch in Appendix M, I mapped a diagram that explains the potential use of real-time rendering in a new workflow using virtual environments. In figure 57, is explained how this virtual environment can cover different hardware and software outputs, improving communication to tackle problems from the different deparments.

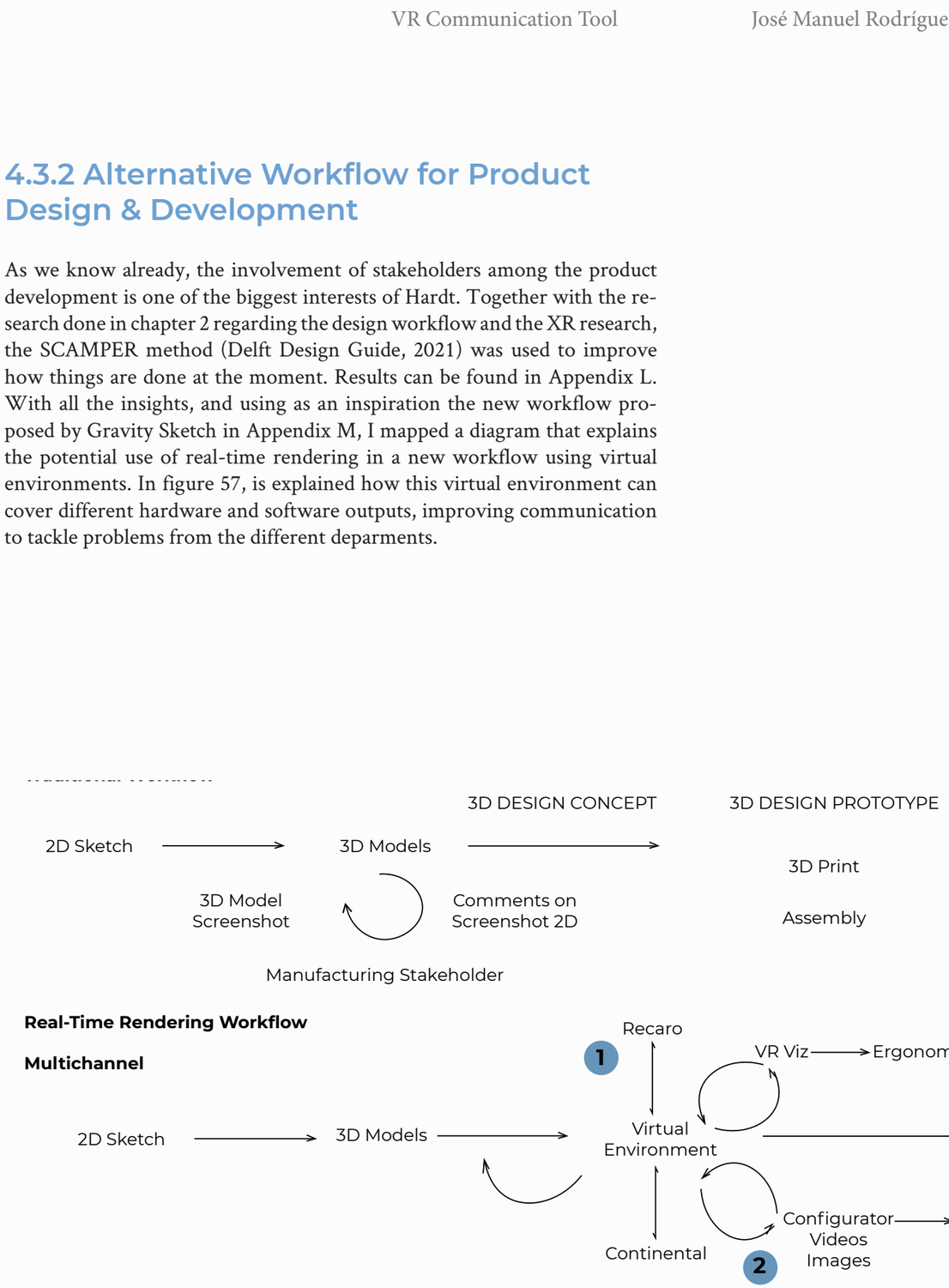
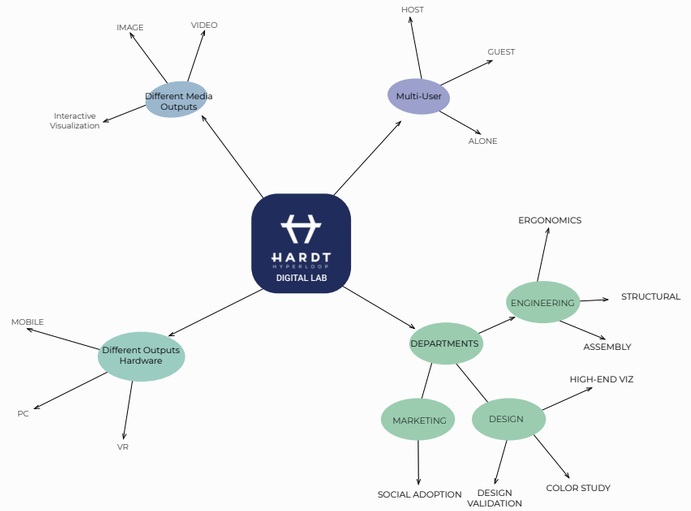


Figure 56: Comparison of Workflows with real-time rendering

Figure 57: Mindmap describing the functionalities and purposes from the scalable visualization



Solving existing pain points

Designer is dependant on availability of skills of other modellers (digital and manufacturing)

Communication between designer and design support team is too complicated.

High pressure on flexibility and cost efficiency.

Availability of experienced workers.

Goals of the New Collab Tool

Provide more space for designer creativity

Enable faster and easier team communication

Speed up the whole development process.

Cost-Saving. Fewer and faster design loops.

Figure 58: Chart Solving Existing Painpoints

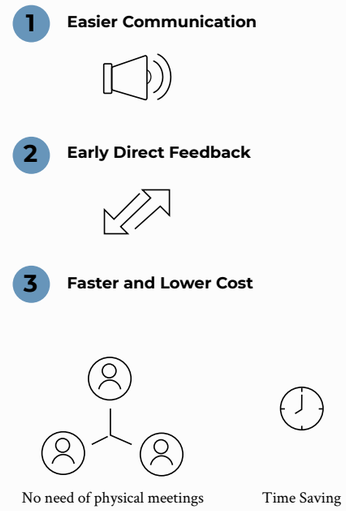


Figure 57: Comparison of Workflows with real-time rendering

4.3.4 Functionalities

There are already many VR apps used for communicating that can be a source of inspiration to the problems defined. Having in mind the VR app comparisons from Appendix N, I brainstormed on what would suit the communication tool. Gravity Sketch was used as a virtual environment to mock up interactive possibilities from other VR apps, using the dummies in context to brainstorm reactions and behavior. The following functions were brainstormed:

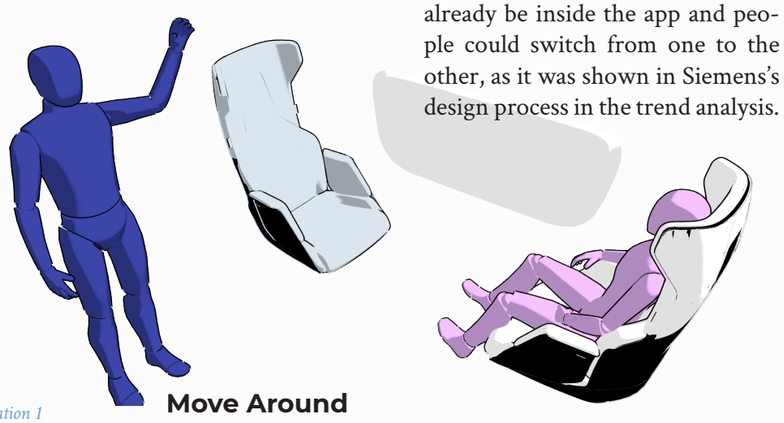


Figure 58: Gravity Sketch Exploration 1

3D Design Configurator
In order to involve stakeholders in the design process, 3D models can already be inside the app and people could switch from one to the other, as it was shown in Siemens's design process in the trend analysis.

Move Around
Endless space provides limitless exploration (Jackson & Fagan, 2000).

Sketch in 3D
As before, sketching is effective, but having 3D sketching can give a spatial understanding (Bowman & McMahan, 2007).

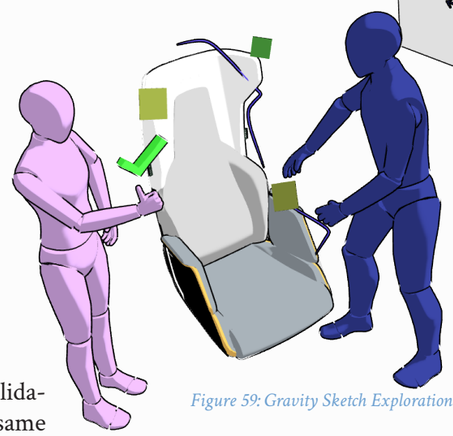


Figure 59: Gravity Sketch Exploration 2

Sketch in 2D
The sketch is one of the most effective ways of communicating due to its simplicity (Goldschmidt, 2007).

Post-It
Annotating specific parts of the design is one of the basic actions to represent mental models in design teams (Goldschmidt, 2007). This action can also be seen in the Spatial and Tvori. Gravity Sketch has 3D text available.

Confirmation
Black or white messages can validate that everybody shares the same knowledge, as we saw during the interviews (Roeske, 2021).

Voice Communication
Audio is essential through virtual reality. Thanks to the persistence of communication, people can be guided through the information inside the virtual environment (Bosch-Sijtsema & Haapamäki, 2014).

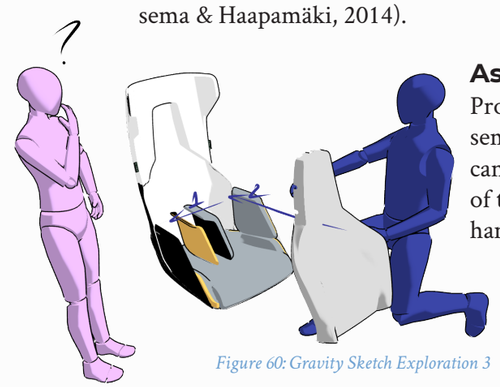


Figure 60: Gravity Sketch Exploration 3

Assembly
Provide exploration during an assembly in a virtual environment can provide a spatial understanding of the product (Bowman & McMahan, 2007).

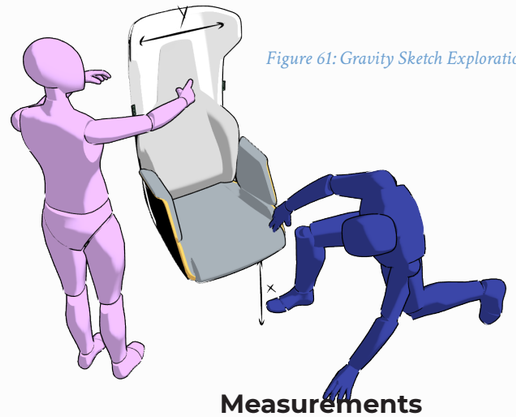
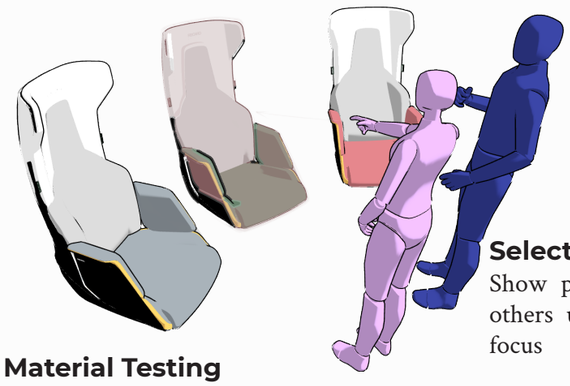


Figure 61: Gravity Sketch Exploration 4

Sketch in 2D
The sketch is one of the most effective ways of communicating due to its simplicity (Goldschmidt, 2007).

Figure 62: Gravity Sketch Exploration 5

Measurements
This feature is already part of the Unreal Engine template, and it essential to validate Assemblies (Epic Games, 2020).



Select
Show point of interest to make others understand where is your focus

Material Testing
Same as the 3D model configurator, materials can be switched from one to the other, fitting the customer ś expectations before the design is built (Müslüm Yakisan, 2018).

4.3.4 Concepts

Now that ideas have been developed in terms of functionalities and exploration within the different situations Hardt encounters communication issues, Three concepts will be presented. These three concepts are the continuation of the initial "Use Case" exercise, applying interactive visualizations as a potential digital solution, and deciding what is it possible to do inside the different virtual environments.

Interactive HUB

In this first concept, interactive visualization is used to explain the logistics solution that Hardt has in mind for potential stakeholders interested in the Cargoloop solution. Companies like PostNL, who play a key role in the logistics of the Netherlands are the target group to use this app. The goal of the concept is to gather early feedback from experts in the logistics field, at the same time they are involved in the process. The main functionalities for this Interactive visualization are the following:

Figure 63: Concept 1 - Virtual HUB

Functionalities:

- Demonstrate Loading/Unloading features.
- Configure the distribution of the tubes among the HUB.
- Interactive SDV (Self Driving Vehicles) routes.
- Showcase the entire logistics inside the HUB.
- Exploration of the HUB.
- For only one user.
- PC and Mobile

Users:

- Business Developers from Hardt
- Stakeholders with Logistics interest in the Cargoloop

Virtual Tour

The second concept presented is a multi-user solution to explore the technologies showcased in the Low-Speed Test Facility, which had a lot of success when Hardt was able to present the prototypes physically prior to COVID-19. The guest in the virtual environment will be able to test the technology in a safe way by themselves, improving their understanding of Magnetism, Electric Propulsion and Switch Lane. The goal of this concept is to continue onboarding future investors avoiding physical meetings. The main functionalities for this Interactive visualization are the following:

Figure 64: Concept 2 - Virtual Walkthrough

Functionalities:

- Explain technologies such as:
- Magnetism
- Propulsion
- Switch Lane
- Being guided by an expert among the virtual prototype.
- Provide autonomy to the future stakeholders through the prototype with safety.
- Multi-User.
- PC and Mobile.

Users:

- Engineers from Hardt
- All kind of stakeholders

VR Communication Tool José Manuel Rodríguez Díaz

Hardt Digital Lab

The third concept is more focused on product development. It is a virtual environment where different designs can be showcased and multiple users can join the environment to provide feedback on that. With this platform, the internal communication can be more fluent, involving business developers also in the design process, rather than only product development. Moreover, the platform can be used to communicate with external stakeholders such as Recaro and Continental to showcase the designs and check with their expertise their opinion. The main functionalities for this Interactive visualization are the following:

Functionalities:

- Showcase prototypes with the desired visual quality.
- Configure
    - 3D Models
    - Materials
- Validate
    - Ergonomics
    - Assemblies
    - Measurements
- Create Content out of the environment such as:
    - Still images
    - Videos
    - VR Visualization
- Review designs at different stages of the project.
- Multi-User capabilities

VR Communication Tool José Manuel Rodríguez Díaz

Figure 65: Concept 3 - Digital Design Review Platform

Users:

- Designers
- Engineers
- Business Developers
- Implementation Stakeholders
- Technology Stakeholders

4.3.5 Concept Selection

With the three clear concepts defined, it was the moment to choose a selected concept. In order to decide which was the concept selected to further develop, the Weighted Objectives method from the Delft Design Guide (2020) was taken into account for the decision making. This method consists of a chart where the designer chooses a number of attributes that are important for the project and distributes 100 points to those properties.

Once those attributes are distributed, each concept scores from 1 to 10, and the score multiplies with the weighted points. The total score gives the designer an overall performance of the concept for the chosen attributes. In Figure 66 you can find the distribution for this project and see that Concept 3 was the one that scored the highest.

Moreover, Concept 3 is the most complete concept especially because of the scalability and all the users that can involve, turning out to be a solution that can really keep many users engaged throughout the different levels of detail of a certain prototype.

		HUB		Virtual Tour		Design Review	
Properties	**Weight**	**Score**	**Total**	**Score**	**Total**	**Score**	**Total**
Scalability	15	6	90	2	30	10	30
Easy to Implement	15	4	60	9	135	5	135
Multi-User	10	0	0	10	100	10	100
Fluency	25	6	150	5	125	5	125
Desirability	25	8	200	6	150	8	150
Involves many users	10	5	50	10	100	10	100
Total Score	100	**Total Score**	550	**Total Score**	640	**Total Score**	**750**

Figure 66: Weighted Objectives chart

4.4 Conclusions

The ideation phase has been a process with the clear goal of exploring possibilities of interaction and communication through the use of virtual environments. As mentioned before, the functions brainstormed were explored inspired in other VR apps, and trying to meet the requirements of Hardt's three most common conversations with stakeholders, which are the onboarding introducing Hardt's proof of technology, the presentation of a warehouse showcasing the potential of the Cargoloop, and the conversations required for product development.

Virtual reality and real-time 3D rendering demonstrate a reduction in time, saving costs of manufacturing, involving more people, and being a sustainable solution, solving existing painpoints in Hardt's workflow.

After the development of the three concepts, the design review platform was the selected concept. Turns out to be the only concept that involves internal and external communication, allowing this project to develop some functionalities that in case Hardt wants to work on another concept in the future, the transition can be easier than it would be the other way around.

In the next chapter, the selected concept will be shown with more detail with regards to the hardware needed, the possibilities as a user inside the virtual environment and how the information is showcased. These details will allow to take a new step into prototyping, so the findings of the selected concept can be validated.

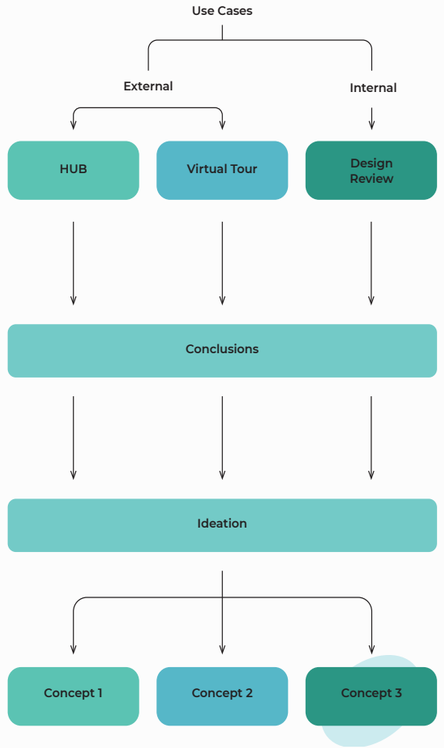


Figure 67: Diagram flow from Use Cases to selection concept

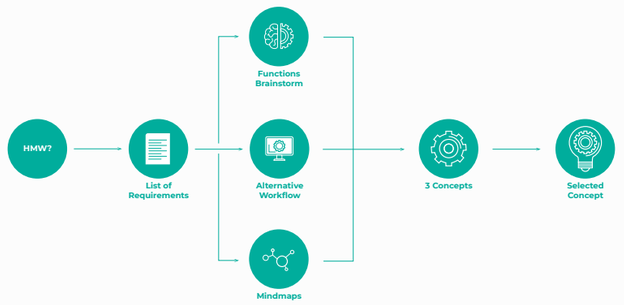
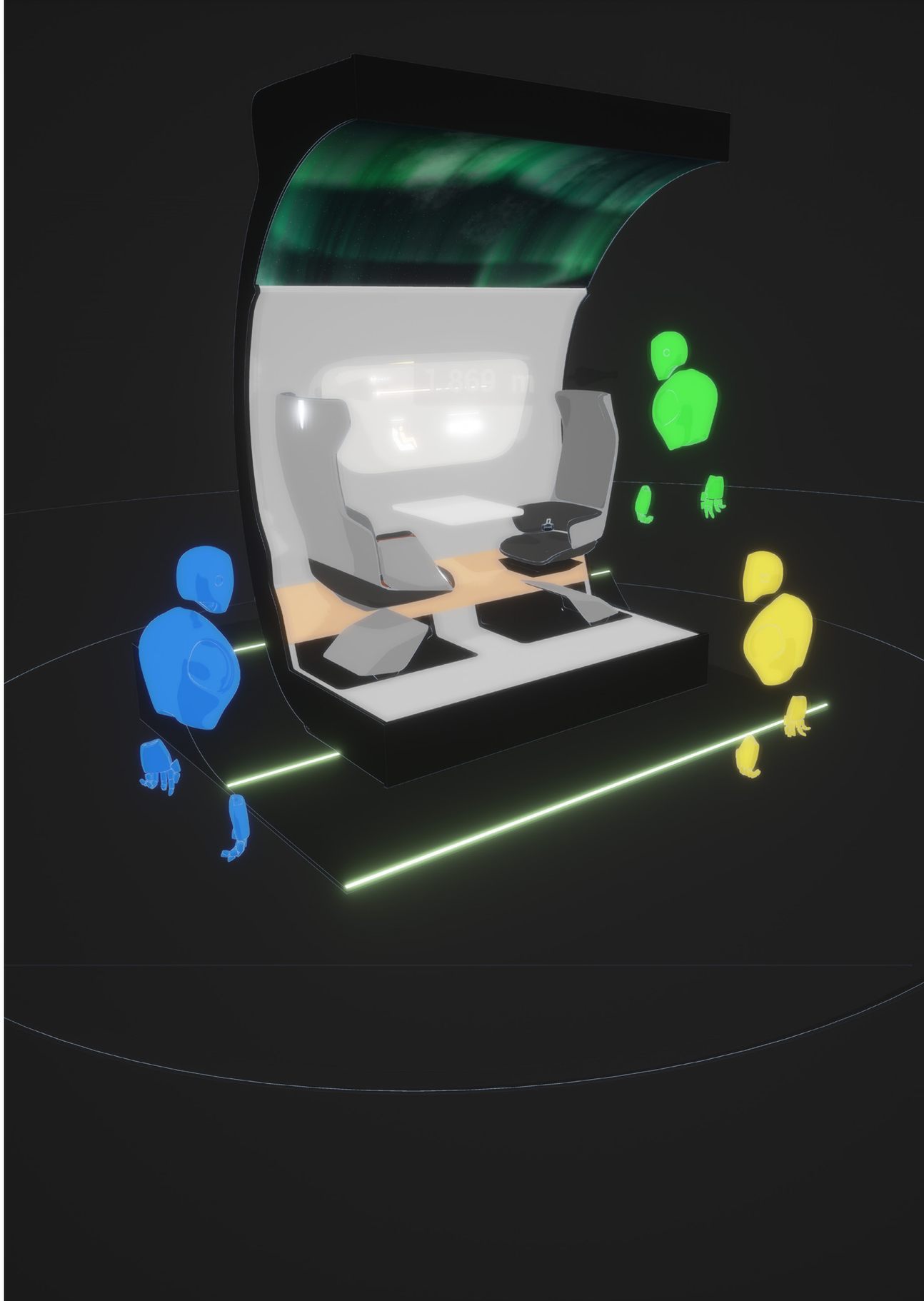


Figure 55: Ideation Diagram

5.
Concept

In the previous chapter, many ideas were generated, and together with the drivers of the problem statement, three concepts were presented. Out of these three concepts, a chosen one has been developed more in detail in the following chapter, collecting enough information to step on the prototyping

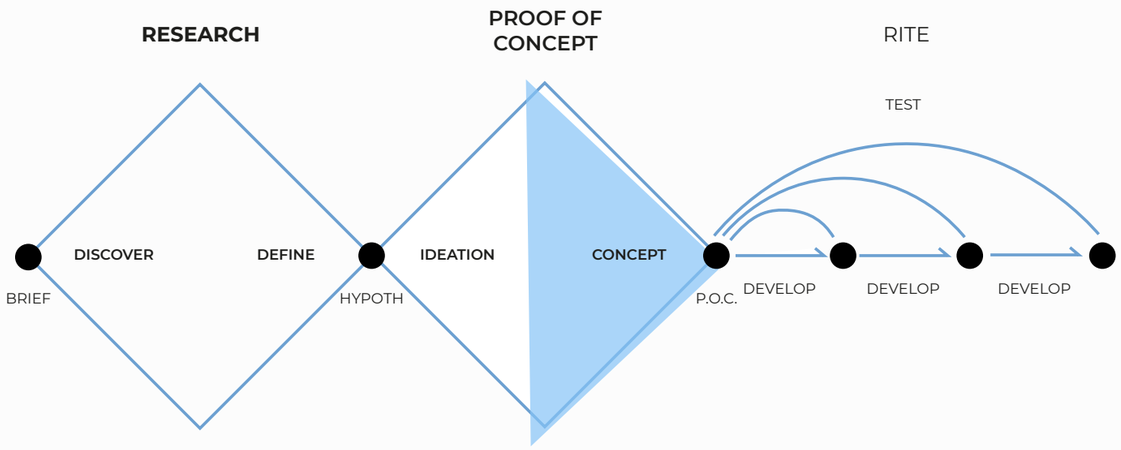


CONCEPT

5.1 Introduction

The Ideation phase from the previous chapter had as an end result in the selection of the Digital Design Review platform. Focusing on the problem of communication in the design and development of Hardt's products can have benefits for different departments within the company and ecosystem. The scalability provided by this concept in terms of media outputs (VR, images and videos), and providing solutions for the market and product department out of the same prototype is key to improve the constant knowledge updates required for such a complex product (Lee, 2001). This concept will involve the stakeholders earlier in the design process (Varjo, 2021), keeping an alignment in information sharing (Bekebrede et al., 2015).

The concept will be presented comparing the previous communication workflow, with the one envisioned using the interactive platform. By showcasing what can be displayed in the virtual environment, how can users interact with the content displayed, and which roles will have certain functionalities, the concept will be better understood. All the details will be taken into account for the future development of the prototype.



5.2 Goals of the Phase

- *Present the capabilities of Hardt Digital Lab*
- *Decide on whose roles will take part in the development and how.*

5.3 Conceptualization

The final deliverable of the project consists of the development of a platform with the use of Unreal Engine 4. Functions ideated in the previous chapter must be programmed based on visual scripting, called Blueprints. This is node-based programming, in which the nodes have the logic of the C++ language. The environment is also making use of high-quality visuals, thanks to a proper lighting environment and the use of Unreal Engine's shader material editor, which can only be handled with a VR-ready computer. Finally, once all the interactions are developed, the chapter will end to start with the usability prototyping phase.

Hardt Digital Lab:

Figure 68: Hardt Digital Lab logo

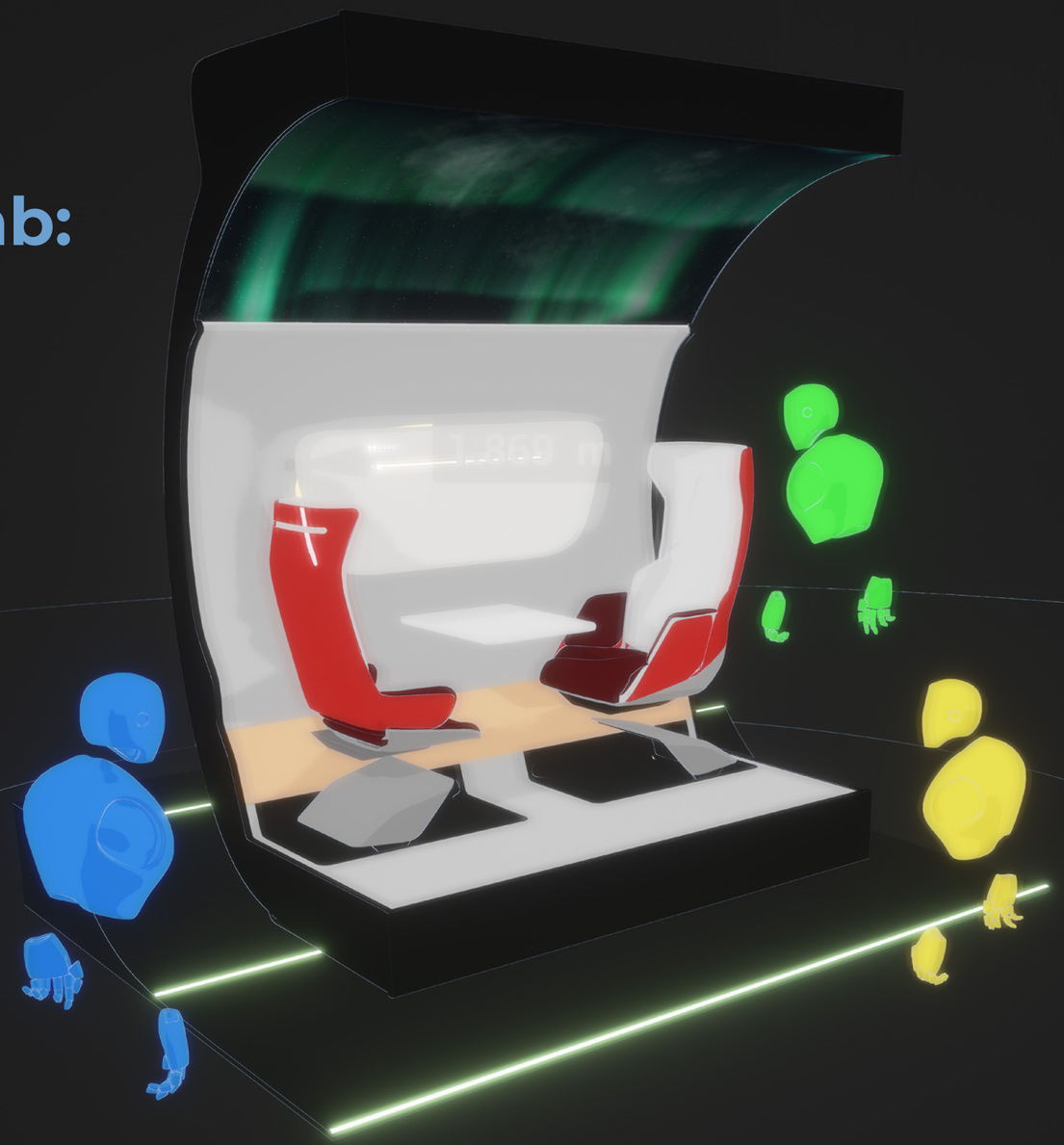


Figure 69: Concept Representation of the Digital Platform

"Digital platform that allows people from different backgrounds to be involved in the design process, no matter where you are, and which device you have.

Virtual Prototyping:

- Save Costs in Material.
- Faster design iterations.
- Find manufacturing errors without building the physical prototype.
- Avoid commuting for reviewing.
- Have all the possibilities in the same environment.
- Provide earlier feedback in the design process.

Figure 70: Cross-platform device representation

Multi-Platform

The platform has three different outputs when it is used as an internal app:

- PC
- Mobile
- VR (Not through web)

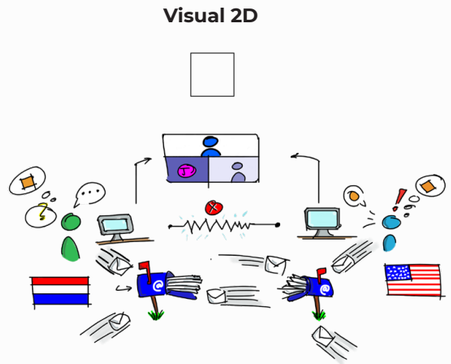
When we want to use it through the web, Pixel Streaming does not allow the use of VR. This means that only people who regularly go to the office can have acces to the VR features with the headset.

5.3.1 Virtual Reality Design Review Platform

As the research has shown related to the design workflow within Hardt, 2D images were shared through email when it comes to remote communication during the conceptualization process, even if it was necessary to look for explore different points of view.

With this Interactive Design Visualization System (IDVS), users can explore 3D images in a 2D screen or even a VR environment, being able to identify errors prior to being built. Different users can join at the same time, enabling synchronous communication and the benefits that it has (Greenwald & Maes, n.d.). This will help also to understand with interactions how things are assembled in a virtual environment because it is easier to understand the context with a 3D overview (Radkowski et al., n.d.).

High fidelity visuals can enable designers to decide better on materials, lighting, shape and form, speeding up the decision-making and saving crucial time for other tasks (Epic Games, 2020). This environment will constantly keep everybody in the loop with regard to the stage of the project. No installation is necessarily required, so the communication with external parties can be fluent. A more detailed overview of the functionalities of this platform is presented. In the description of the digital platform, we have to make a distinction between what we can see, what we can do, and how we will use it.



VS

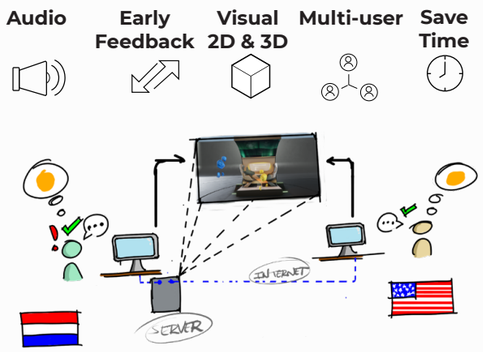


Figure 71: Problem definition of obsolete remote tools

Figure 72: Diagram representing the new tool

Figure 73: Woman using the platform - Metahuman provided by Epic Games

5.3.2 What can we SEE?

This platform aims to provide users the ability to showcase different virtual prototypes to discuss and give feedback about designs. In this virtual environment, we can display one or several virtural prototypes at the same time, so the designs can also provide context awa reness, helping users to take better decisions. For this specific case, the CABIN-1 was implemented in the virtual platform, more information about the CABIN-1 and the purpose of this prototype for social adoption can be found in Appendix N.

This product is already fully developed, but for future designs for the hyperloop, this digital twin of the CABIN-1 has some functionalities that can be implemented in a larger product.

- Light Control
  - Color
  - Intensity
- Display Videos and Sound
  - Infotainment Panel
  - Sky Screen
  - Explanatory videos
- High Quality Resolution

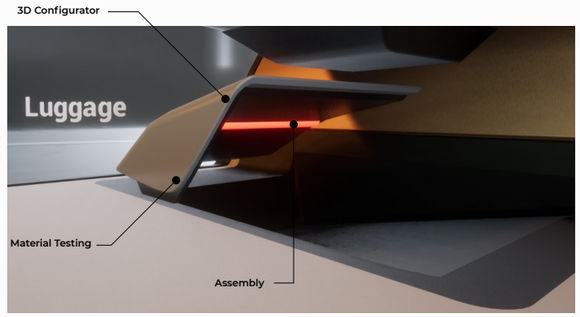


Figure 74: Luggage compartment options

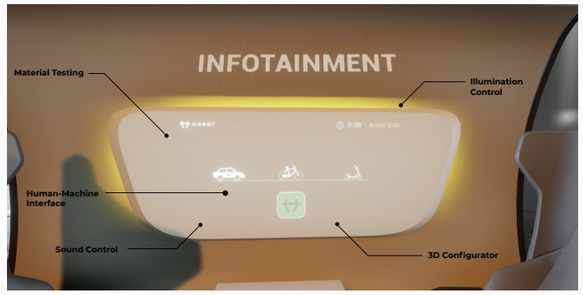


Figure 75: Infotainment options

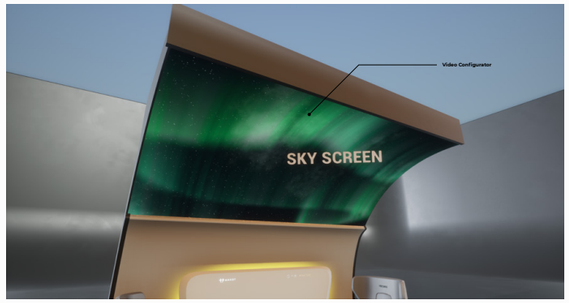


Figure 76: Sky screen video options

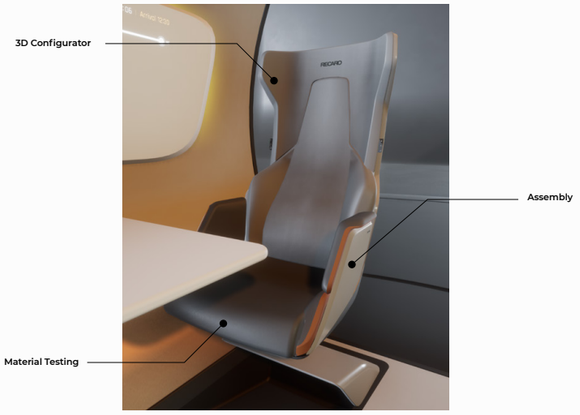


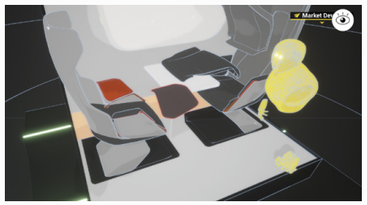
Figure 77: Chair options

5.3.3 What can we DO?:

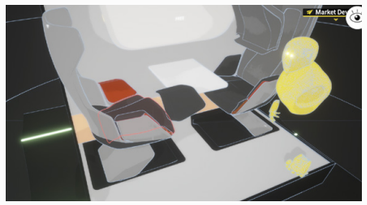
Step-by-step Assembly

Explain with animations an exploded view of a design. Later on, every component goes in order to its place step-by-step so people can comment on each part.

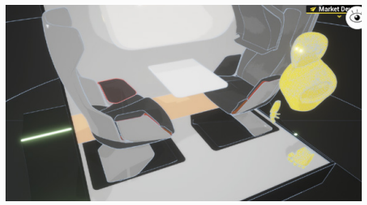
1.



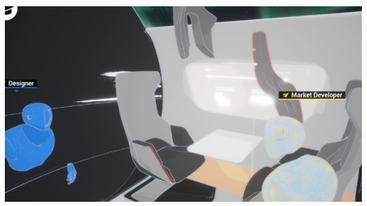
2.



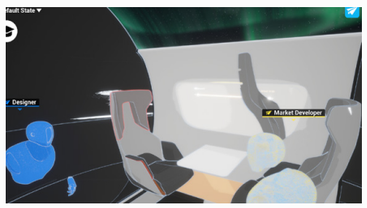
3.



4.



5.



6.

Figure 78: Assembly step-by-step explanation

Measure

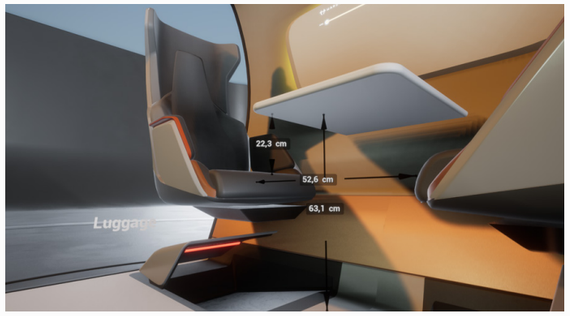


Figure 79: Measurement tool representation

Users can measure inside the environment. Ergonomics and future assemblies can be validated.

Change Design & Materials

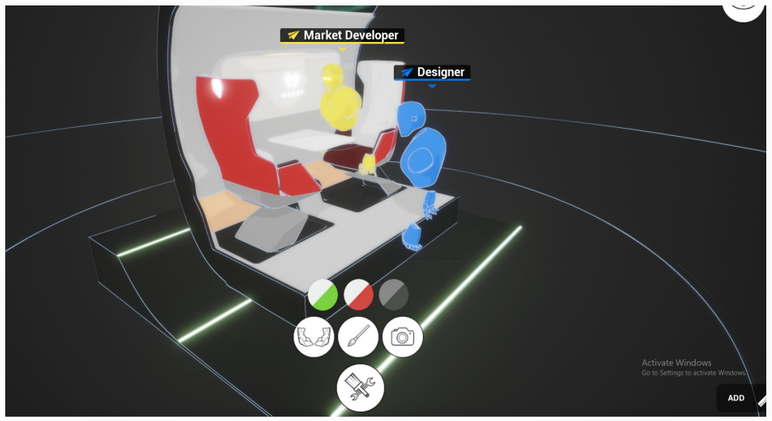
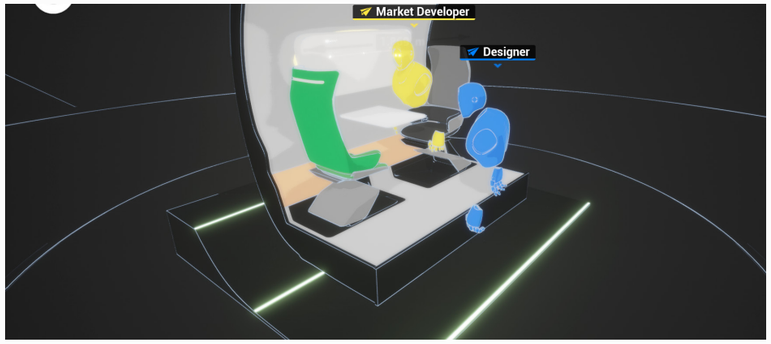


Figure 80: Design and materials configurator - 1

Users can explore different possibilities of 3D models and materials in the same environment with the configurator option.

Figure 81: Design and materials configurator - 2



Share Screen

1.

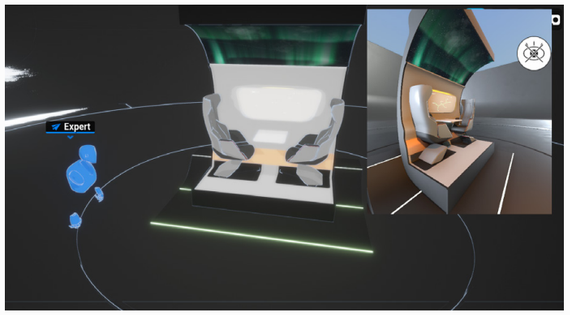


Figure 82: Share Screen

Ability to see the camera of other users in the environment. This enables someone to know what another person is speaking about.

Sketching in 3D

Freely sketch in the 3D space.

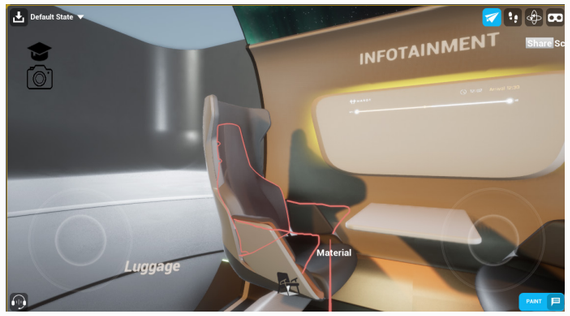


Figure 83: Sketch on top of the chair

Snapshot

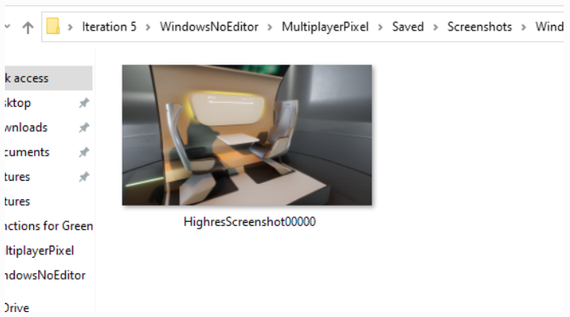


Figure 84: Render saved in an internal file.

Save Renders in a file. Pictures can be shared with others. Speaking with a visualizer will not be needed anymore. People can take their own pictures.

Digital Pointer

Figure 85: Digital pointer selecting part of the armrest

Select components from the environment. Color outline to know which part of the design somebody is speaking about.

Post-it

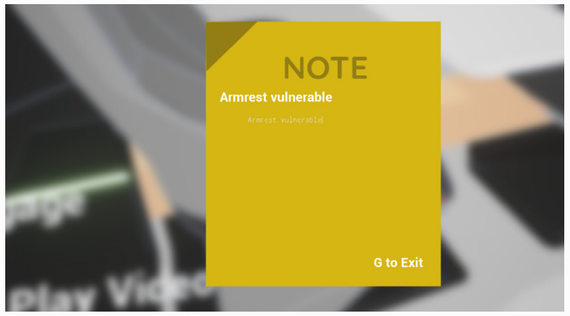


Figure 86: Writing a Post-It

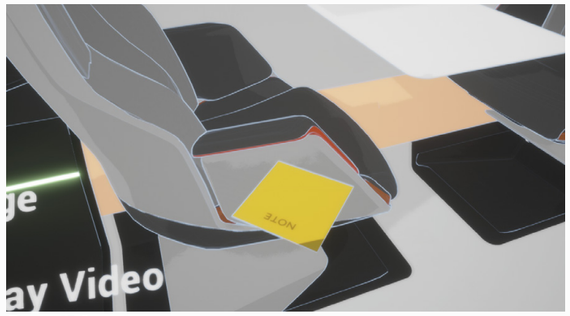


Figure 87: Leave Post-It floating

Ability to comment on designs. Leave a Post-it that others can read.

Whiteboard

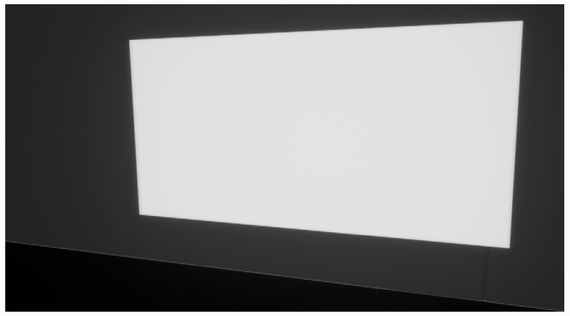


Figure 88: Whiteboard where to sketch

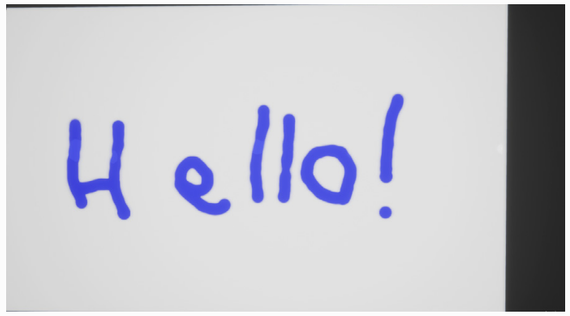


Figure 89: Hello written with the whiteboard tool

Sketch in 2D to express ideas

5.3.4 Roles

As we already know, based on the Personas method, different users involved in the communication take part in the design process with different roles and decisions. Limiting the decision availability to some of the stakeholders is key for the usability of the virtual environment, but also prior experience with 3D software can also influence the experience itself. Not all the functions described before are going to be for all the users, so a matrix mapping the functionalities was created to define who does what.

	Post-It	3D Config	Materials	Measures	Share Screen	Light	Move	Voice	Confirm	Sketch	3D Sketch	Assembly	Snapshot
Engineer	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓
Designer	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Market Dev	✓	✓	✓			✓	✓	✓	✓				✓
Technical Stakeholder	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓
Non-Technical Stakeholder	✓	✓	✓			✓	✓	✓	✓				✓

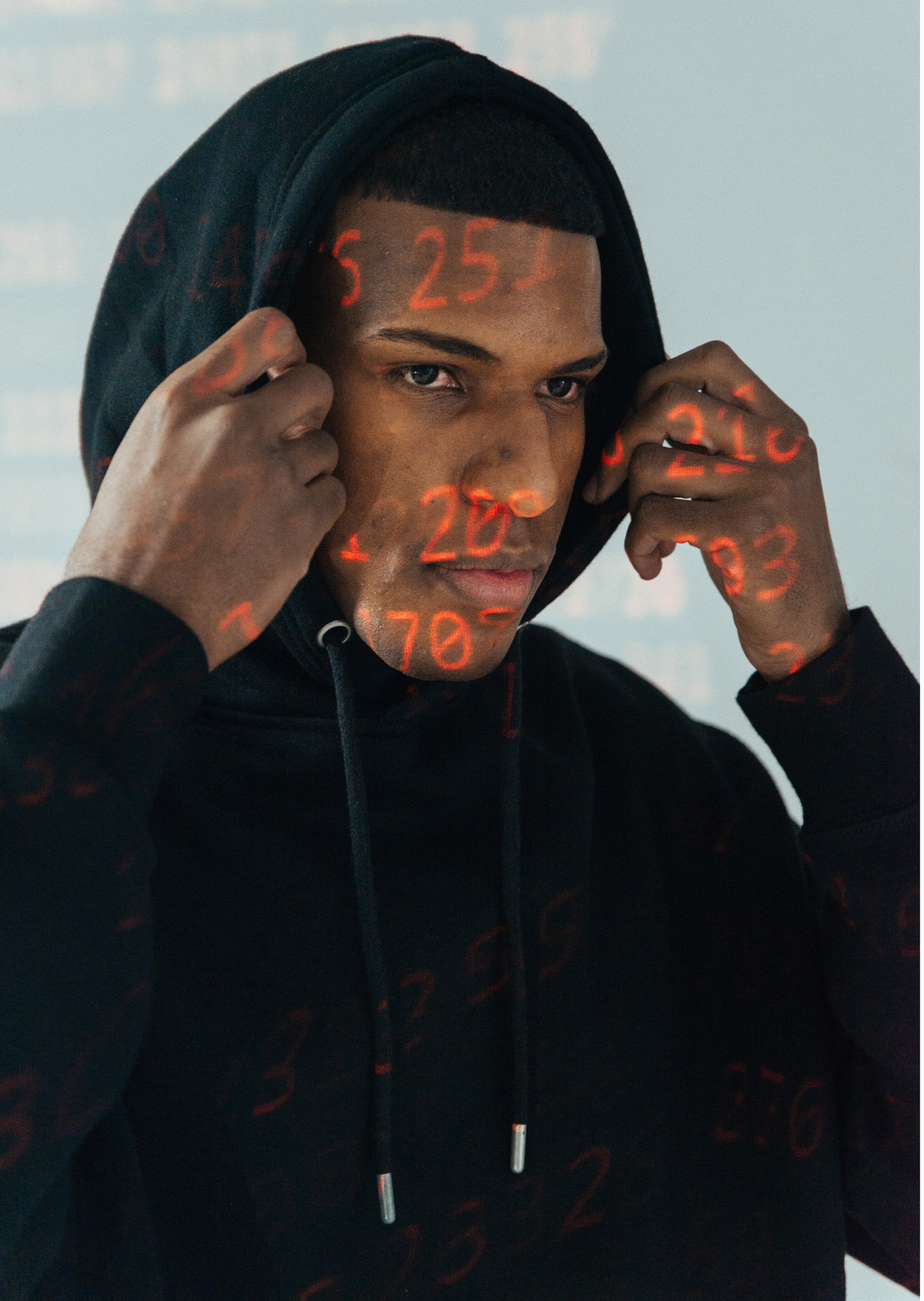
Figure 90: Chart explaining the functions available for each role

5.4. Conclusions

This chapter consists in the development of the concept, out of the ideation process from the previous chapter. The user interactions have been developed in Unreal Engine together with the environment preparation. The digital platform aims to be serving as a tool that improves the development of different prototypes that Hardt is interested in, having a lot of interactions that can be useful for the design process.

The environment has proved to be useful for different media representations like videos, images and 3D animations while using the tool. Many functions have been defined for being necessary in the concept, but not all of them can be tested within the timeframe of the project.

Different roles participate in different ways in the design process. From an engineering perspective, assemblies and manufacturing processes are validated using this tool, while business developers or implementation stakeholders are more aware of the aesthetics and user experience. Due to this fact, the continuation of the project into the prototyping phase will validate the usability of this tool from the perspective of implementation stakeholders. Implementation stakeholders are the chosen ones because Non-technical user's feedback is a priority nowadays. One of the main problems of communication in the ecosystem is how distant people can be from the realization of the hyperloop when they do not have engineering knowledge, so engaging them is part of the end goal. A number of functions from the chart will be selected to iterate the usability of a User Interface developed with Unreal Engine 4.



6. Prototype

During chapter 6, the concept selected from the previous chapter is prototyped. Using the Rapid Iterative Testing and Evaluating (RITE) method will help to improve the usability of the solution. A customer journey is presented and a discussion with regards to the results on the usability.

PROTOTYPE

6.1 Introduction

After completing both diamonds from the design approach taken in this project, the prototyping phase starts with the feasibility of the concept. The concept defined in the previous chapter explains the features that each member of Hardt's ecosystem can use in the virtual platform. In the prototype phase, we will only be covering the development of some features related to non-technical users. This will allow us to explore the usability of the User Interface with people with low experience with 3D software.

During this chapter, we will be covering certain aspects of the prototype which are:

1. **Integration of the 3D data inside the game engine**
2. **The implementation of the Multi-User capabilities**
3. **Using a workstation as a server to avoid installations**

These aspects are key to make the prototype work properly. Once those are covered, the RITE method from Medlock et al., (2007) will be used to iterate on the usability of the user interface. This chapter will finish with a fully iterated prototype that can be evaluated in the last chapter.

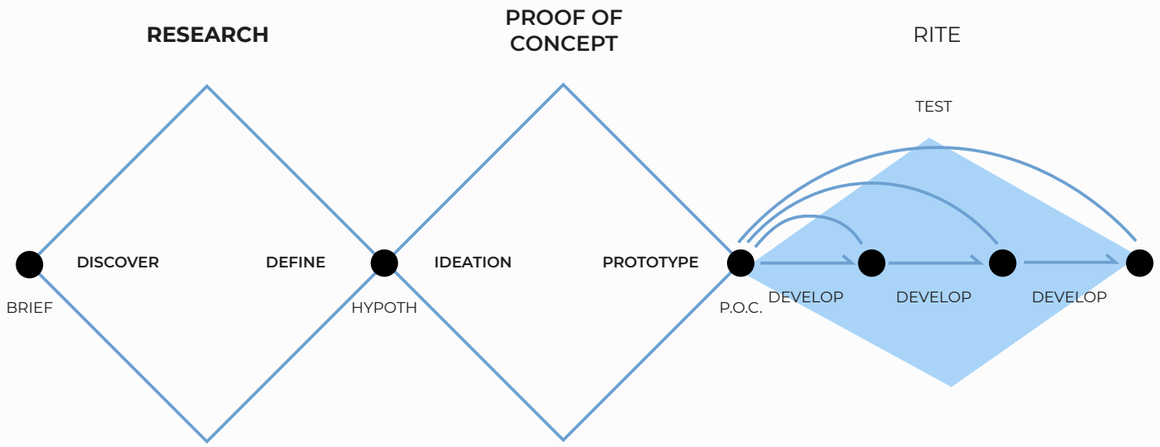


Figure 91: Approach diagram

6.2 Goals of the Phase

- *Explain the critical points of the prototype*
- *Evaluate usability with RITE method*
- *Present end result*

6.3 Prototype

The final deliverable of the project consists of the development of a platform with the use of Unreal Engine 4. Functions ideated in the previous chapter must be programmed based on visual scripting, called Blueprints. The environment is also making use of high-fidelity visuals, thanks to a proper lighting environment and the use of Unreal Engine's shader material editor, which can only be handled with a VR-ready computer. During this chapter, the process of 3D models inside the environment will be explained, starting with the Multi-User review template from Epic Games. Pixel Streaming, a plugin from Unreal Engine, will allow user testing avoiding the installation of the virtual platform. During the iteration and testing, the Minimal Viable Product (MVP) will reach a level enough to be ready to start the evaluation section with Hardt members, to finalise the project.

6.3.1 Proof of Tecnology

As it can be seen in the Concept chapter, there are four main features that the prototype must face technically to be succesful:

Cross-Platform
Multi-User
Seamless CAD Integration
Installation avoidance

With Unreal Engine 4, which is the selected game engine to develop this prototype, several technical solutions can be found to deal with these challenges.

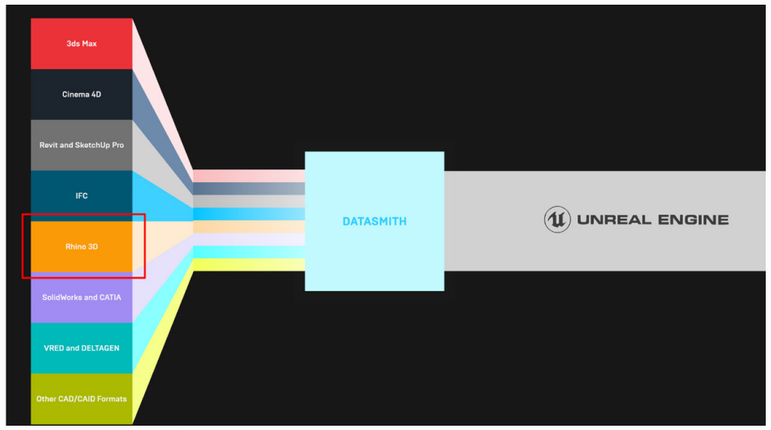


Figure 92: Datasmith integration of CAD into Unreal Engine 4

Datasmith

In order to avoid the tedious and time-consuming CAD integration workflow, Unreal Engine has developed the Datasmith plugin. This plugin can convert different 3D CAD files into game-ready 3D files(Datasmith Overview, n.d.). Rhinoceros, one of the most common 3D software used in Hardt, is also included in the list. This plugin allows to reimport, so several changes in the Rhino files can have instant updates in the Unreal Engine project.

Collab Viewer template

Unreal Engine, due to the increasing demand for multi-user solutions, has developed a template that allows developers to have a multiplayer with client-server technology (Collab Viewer Template, n.d.). In Figure 93 you can see a diagram explaining how the client-server architecture works. This template is already programmed in a way that could seamlessly change from PC, to mobile and to VR. This way hardware availability with this cross-platform feature is solved.

Pixel Streaming

The last challenge is installation avoidance. Pixel streaming is a plugin from Unreal Engine that allows users to connect to a server through the web browser. This feature allows the use of Unreal Engine applications with only an internet connection in your device (Pixel Streaming Overview, n.d.). The GPU required to use the application must be in the server. This is an example of the potential of cloud computing. For the prototyping of this project, a 3060 RTX is used. The server may be scaled up to a virtual machine like Amazon Web Server (AWS) for example, in case of limited GPU in a computer.

In Figure 95 you can see the integration of these three technical solutions in the same project.

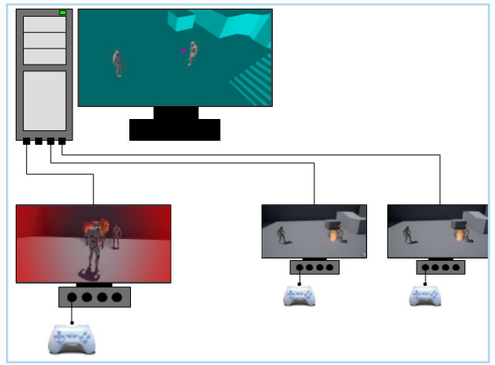


Figure 93: Client-Server architecture model

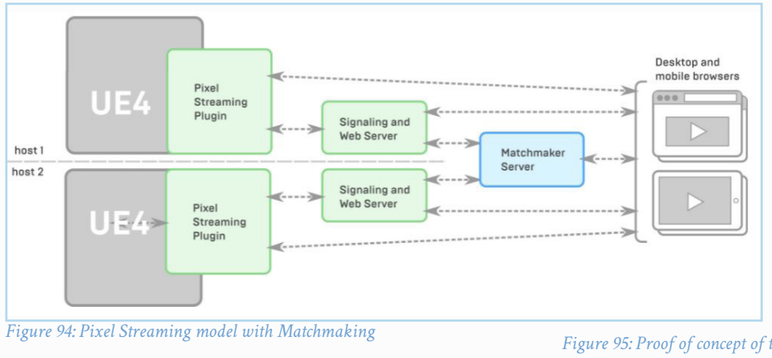
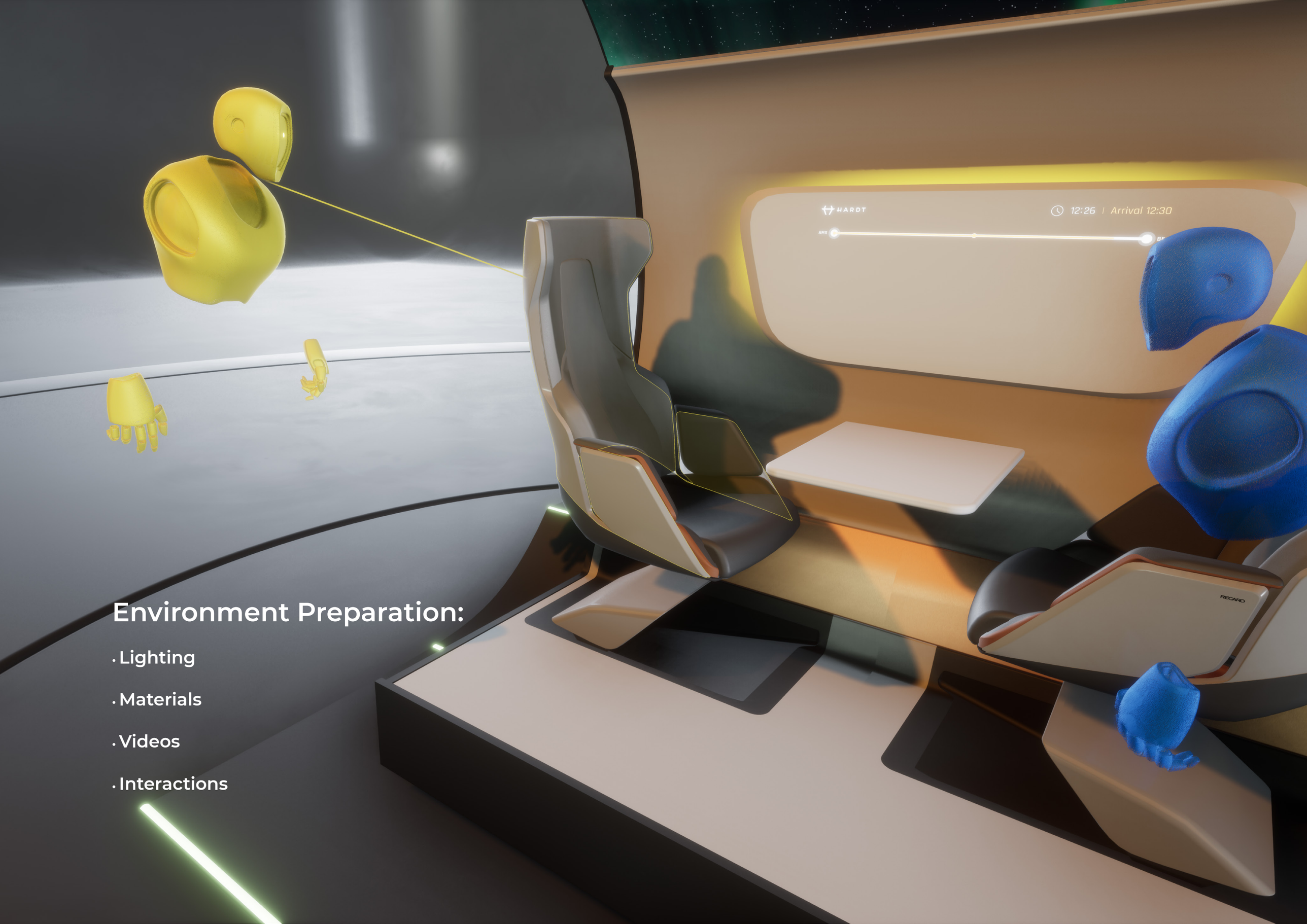


Figure 94: Pixel Streaming model with Matchmaking

Figure 95: Proof of concept of the Collab Viewer with PixelStreaming



Environment Preparation:

- Lighting
- Materials
- Videos
- Interactions

6.3.2 R.I.T.E Method

The Rapid Iterative Testing and Evaluating (RITE) method was created in 2002 at Microsoft Games Studios (Medlock et al., n.d.). With this method, a team of developers can iterate on a prototype, while continuously evaluating the performance.

Research Goals

There are two main goals while conducting the RITE method. The first one is to analyse and identificate concept flaws regarding the usability of the virtual platform. By conducting tests, errors and confusions from users will provide insights for future iterations, improving the User Interface.

Secondly, RITE method is used to evaluate whether or not there is a fluent communication about the design proposals between two users. Designers will be in constant communication with engineers and business developers, and this platform should allow everybody to have a say, ending up in a common understanding.

Participants

Even though there are multiple functions for multiple users in the concept, I will concentrate on those with a non-technical background to use this platform. Stakeholders with no 3D knowledge are among the priorities of Hardt to onboard in the ecosystem, so I will figure out which are the limited functions that these users can feel familiar with. Like this, Business developers from the company and Non-technical stakeholders can feel involved in the design process from an early stage.

Activities

Several research activities will be done in every iteration. With this platform I will put in context the participant, explaining to them what this virtual environment is about, and how he could take part in the decision making of our designs.

FAMILIARISATION

The participant will be asked to Host a session, and he or she will be able to explore the app for 5 minutes until they feel prepared to start the test. A second user, in this case the design expert, will also join the session, and can answer questions if there are any doubts. It is mainly thought to be a multi-user platform, simulating a real scenario, so guidance from the expert is expected.

USER EXPLANATION

Once the familiarisation phase is over, the participants will be asked to decide which is the configuration that they like the most. Consequently, make a render out of it, so the information can be traced and shared. The screen from the participant will be recorded for observation analysis. This test will be conducted online.

OBSERVING

As soon as the render is done, the expert will check if it has been saved correctly. The participant will have to answer several questions related to the usability of the demo. These questions can be seen in Appendix O. Moreover, the participant will go through a QUESI questionnaire in order to collect objective data. The questionnaire can be found in Appendix P.

Data Collection

According to Medlock et al (2002), performance is defined on how users can successfully complete tasks. From one iteration to the other, tasks can change significantly, so an objective and equal evaluation is needed. Performance then will be measured using the QUESI questionnaire.

Apart from the QUESI questionnaire, which can be found in Appendix O, we also have to take into account the usability questions from Appendix P, as a resume of the two conducted methods to collect data.

Data Analysis

Out of the 2 methods used, QUESI will provide the progress in terms of usability from every iteration. The usability questions from Appendix M will be used for making improvements from the prototype. The process can be followed in the next section of this chapter, “Most Viable Product”.

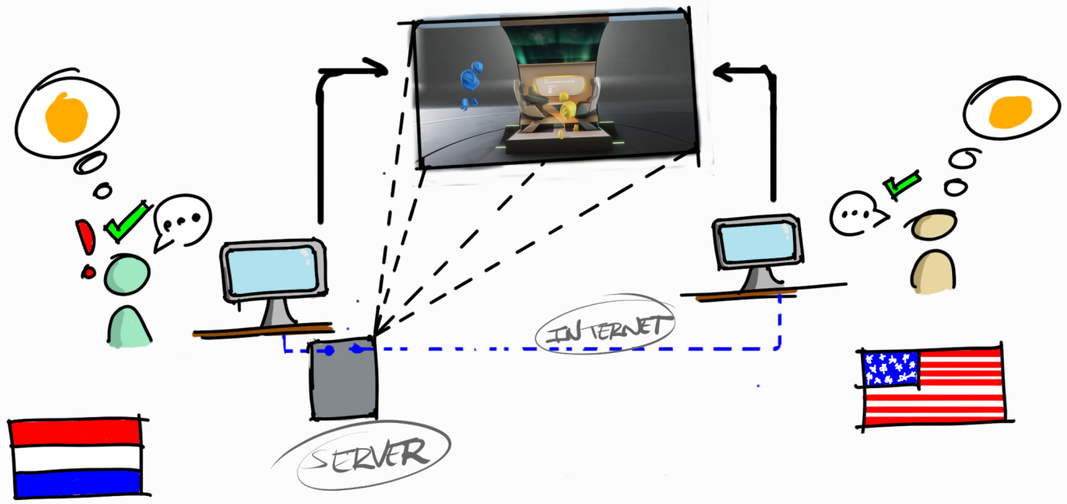


Figure 96: Setup of the Usability testing

Prototyping phase

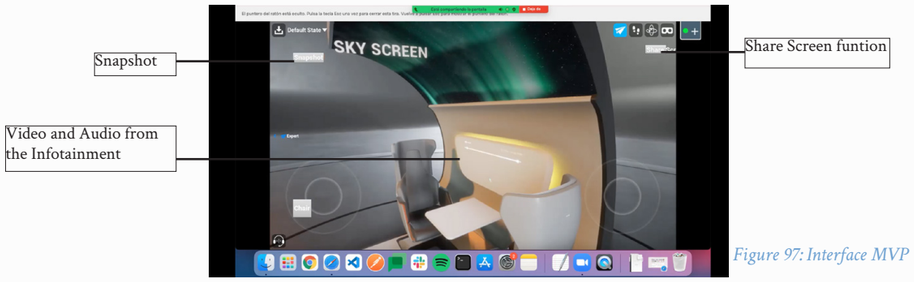


Figure 97: Interface MVP

Figure 98: Open Share Screen

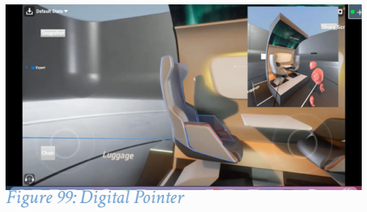


Figure 99: Digital Pointer

Figure 100: Select Design by click on D

Figure 101: Select Materials by click on M

Minimal Viable Prototype

The goal of the MVP is to achieve basic functionalities in the multi-user platform that can be tested. As we know already, from the virtual environment we can find different use cases, and also different roles in the process, so we will concentrate on the roles of Non-technical users, which are the ones who demand most of the visuals for their own benefit like presentations to stakeholders.

Functions Implemented

- Multi-User exploration and autonomy.
- Pixel Streaming function for sharing interactivity through web.
- Ability to share screen to the other user, for knowing the point of interest from the colleage.
- Ability to configure materials.
- Ability to configure designs.
- Digital Pointer to highlight different parts of a 3D model.
- Video and Audio on Infotainment and Sky Screen.
- Take snapshots for image sharing with people out of the virtual environment.

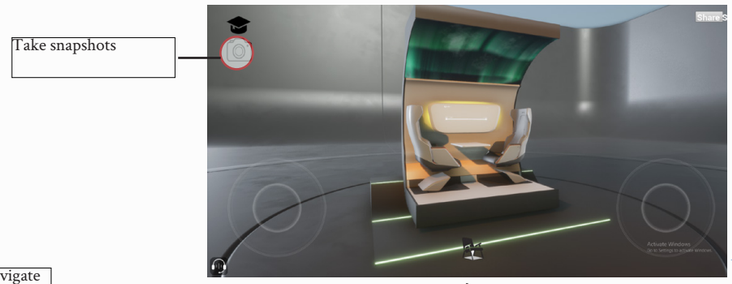
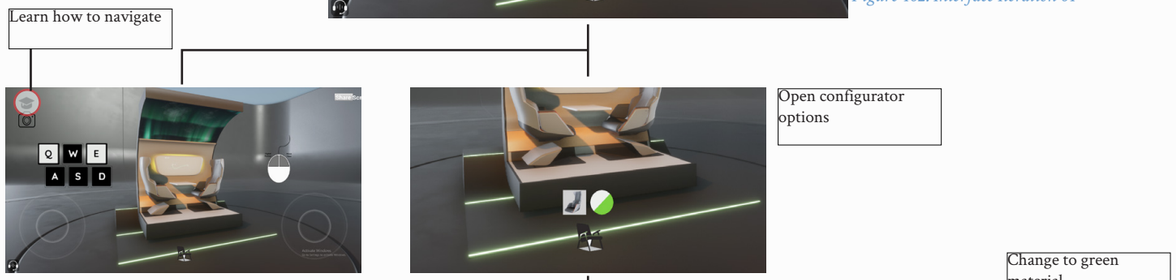


Figure 102: Interface Iteration 01



Iteration 1

Buttons with text were not understood by participant 1, therefore it was necessary to redesign the user interface to make it more visual by adding icons. In addition, participant 1 required information in order to select the different functions, especially the configurator function. Therefore, text labels indicating the last selected function were added. Participant 1 did not understand how to move the camera when navigating.

Afterwards, a simple tutorial of navigation was implemented.

Functions Implemented

- Snapshot icon
- Tutorial on how to navigate
- Chair icon button to configure designs and materials
- Updated icon of design and materials
- Text label to provide the user with knowledge on what was the last function selected

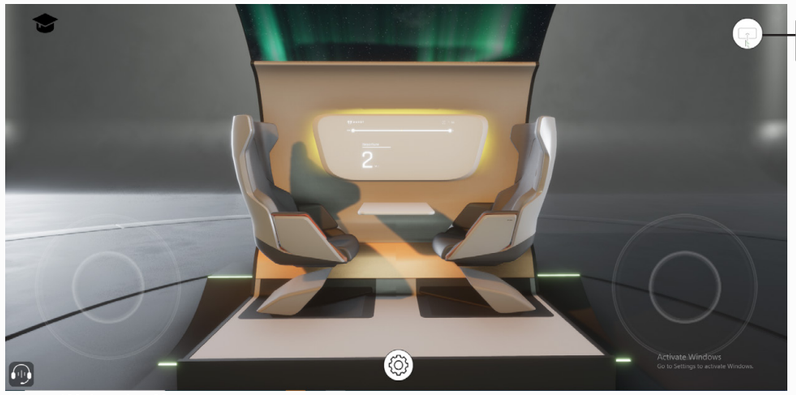
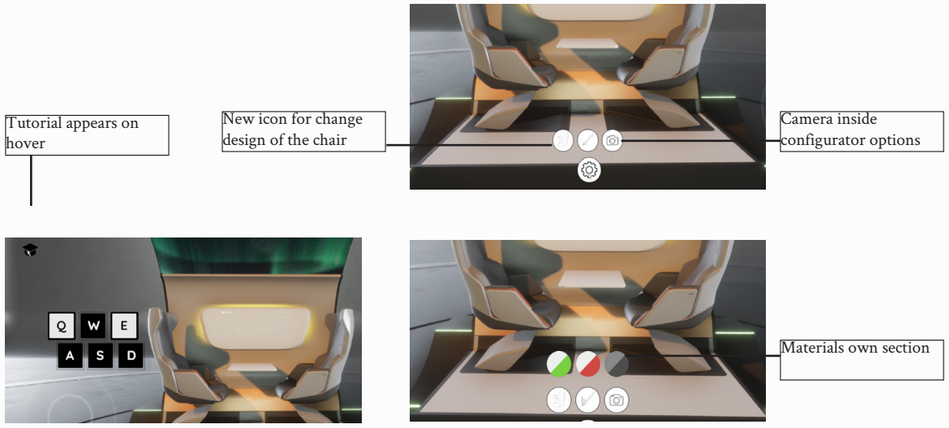


Figure 103: Iteration 02



Iteration 2

Participant 2 could not recognise some buttons on the screen. Once she noticed the buttons, she said that all the function icons should be located in the same area on the screen. Furthermore, she would have liked to have more options regarding the color of the chair, as there were only two options. It is important to say that participant 2 did not have a mouse and that made navigation more difficult.

Functions Implemented

- Tutorial appears at the beginning
- Text labels indicate the location of the buttons on the screen
- Improved visuals on the tutorial
- Modification of the configurator icon

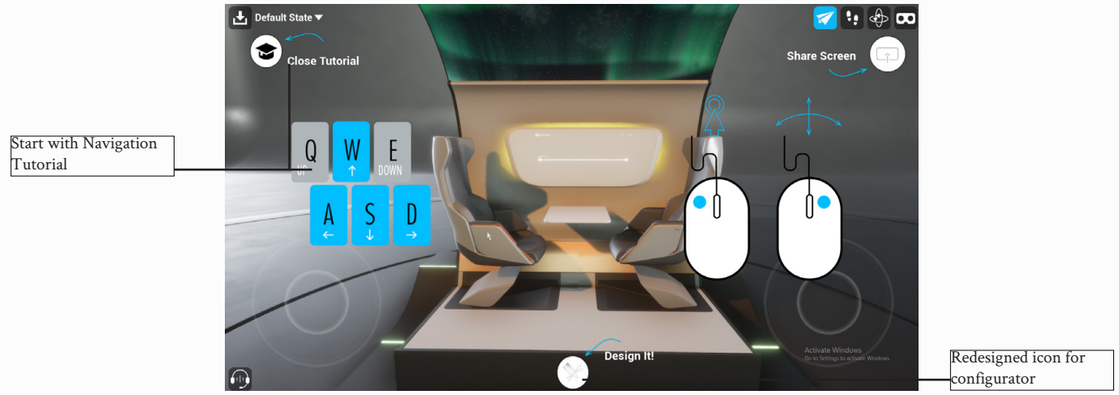


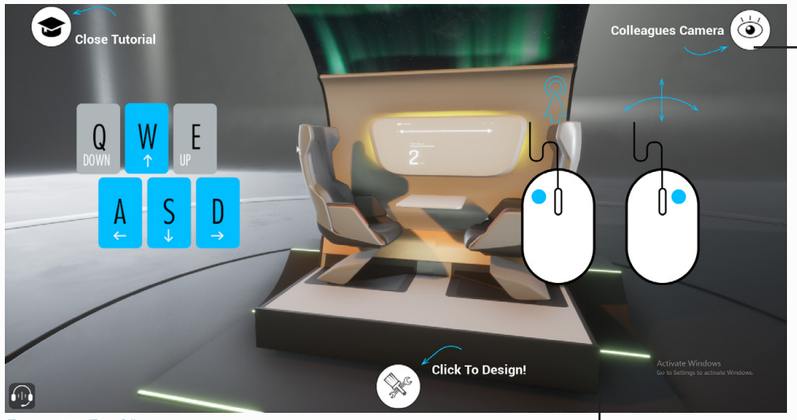
Figure 104: Iteration 03

Iteration 3

Participant 3 thought the information to start navigating was unclear, therefore the experience starts with a tutorial. Also, the configurator icon was not intuitive enough and it was modified to something more related to design and engineering.

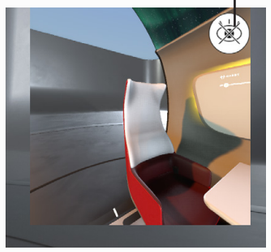
Functions Implemented

- Take snapshots for image sharing with people out of the virtual environment.
- Tutorial appears at the beginning.
- Text labels indicate the location of the buttons on the screen.
- Improved visuals on the tutorial.
- Modification of the configurator icon.



Icon as eye instead of sharing screen

Indicates how to close shared view



Thicker weighted line

Figure 105: Final Iteration

Control chairs independently and together

Shaded buttons on hover

Improved Line Weight

Final Prototype

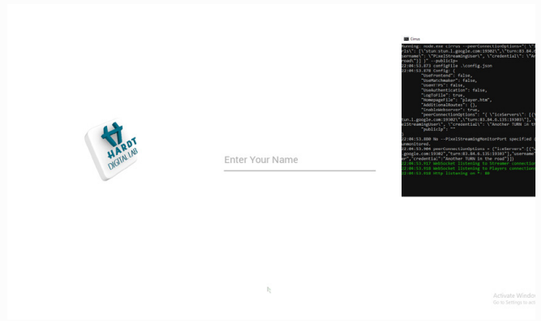
Participant 4 really liked the possibility of choosing one design. However, participant 3 suggested changing both chairs simultaneously to compare them. Sharing screen function was unclear. At this stage, both participant 4 and researcher realised that the aim of this function was to choose another user's view. Therefore, the icon for the sharing view became an eye. The touchpad function for mobile phones presented several issues when using it on the PC, and for that reason, it was removed.

Functions Implemented

- Improved line weight of the icons.
- Sharing screen icon turns into sharing view icon.
- Hover shaded effect on buttons to inform users the button being selected.
- Hover tooltip text to explain functions.
- More designs included on the environment.
- Better control of left and right chair when changing from one design to another.

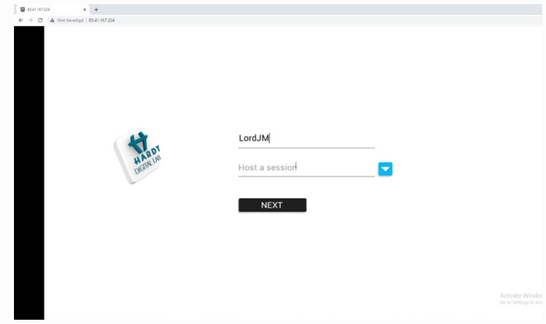
Customer Journey

1.



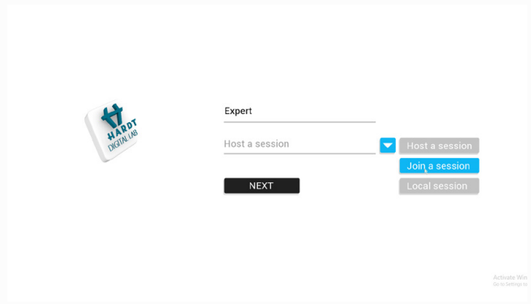
Run the server so the stakeholder can access the server.

2.



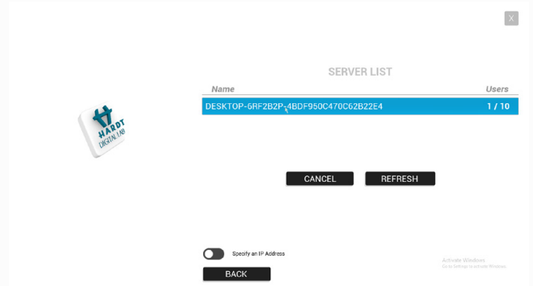
Run the server so the stakeholder can access the server.

3.



Expert opens another user so he can join the session.

4.

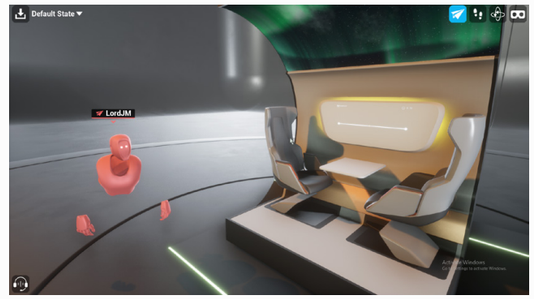


Expert joins the session hosted by the stakeholder.

5.

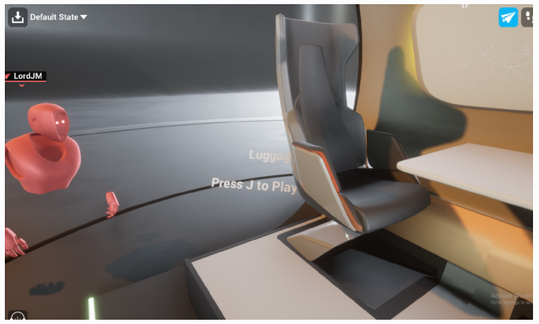
Stakeholder starts with tutorial on how to navigate and explore the UI.

6.



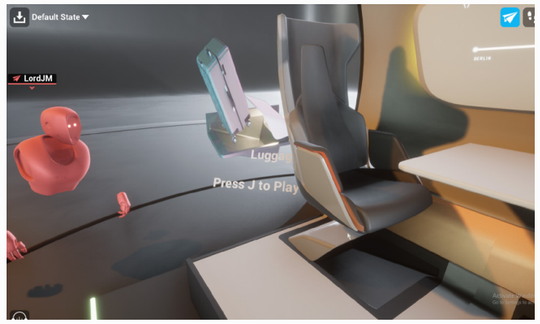
Expert view of the stakeholder.

7.



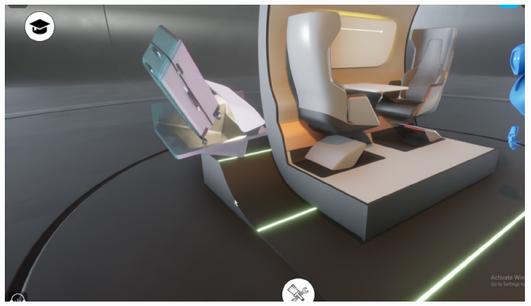
Approach products for specific information “Press J”

8.



Explains the functionality of the Luggage compartment with videos

9.



Floating 2D videos always face the users in the environment.

10.

Modify colors of the Infotainment Panel.

11.

Replicate the color so both users can know about the changes.

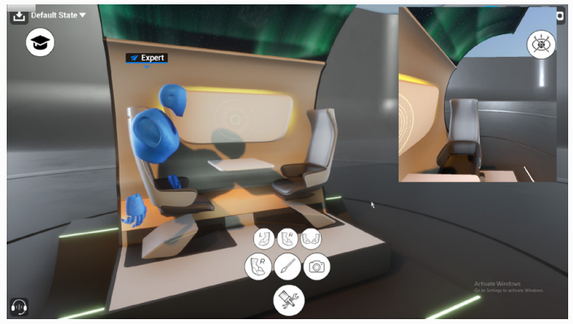
12.

All parameters can be modified

13.

Run the server so the stakeholder can access the server.

14.



Access the camera of other users to know what they are seeing.

15.

Make the screen bigger by clicking on the screen.

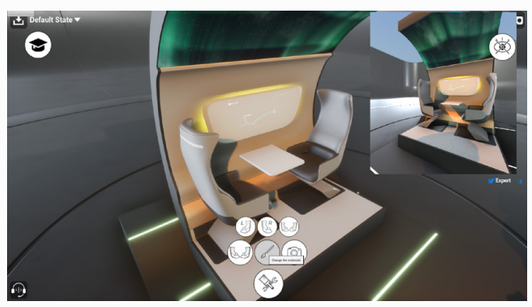
16.

Explore different designs.

17.

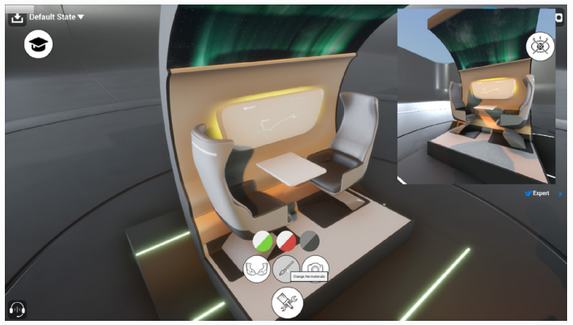
Chairs can be modified independently

18.



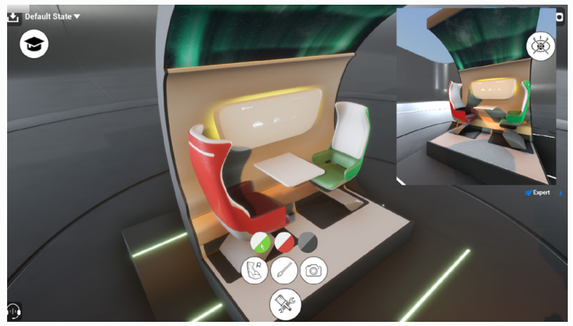
Chairs can be modified at the same time.

19.



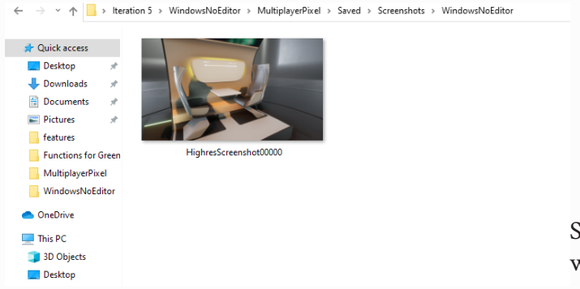
Open Materials Menu

20.



Apply different materials to the selected chair.

21.



Save Pictures in a separate folder with Snapshot function

Figure 106: Customer Journey

6.3.3 Results QUESI

A rising trend is identified in the average results of the QUESI Qualitative Questionnaire, see Figure 107. Despite the rising trend, there are some participants with better knowledge on video games that may have influenced the results. Participants have been trying a user interface and usually interfaces require more iterations due to bigger chances of missing information (Medlock et al., n.d.). but it is not possible to draw any conclusions from these few iterations. More iterations and results are required. The results are very distributed due to the participant's different profiles. In Figure 108, every question is plotted individually and combined with the qualitative feedback, there is an improvement in the user interface. Results from this test will be compared in the Concept Evaluation in the following chapter.

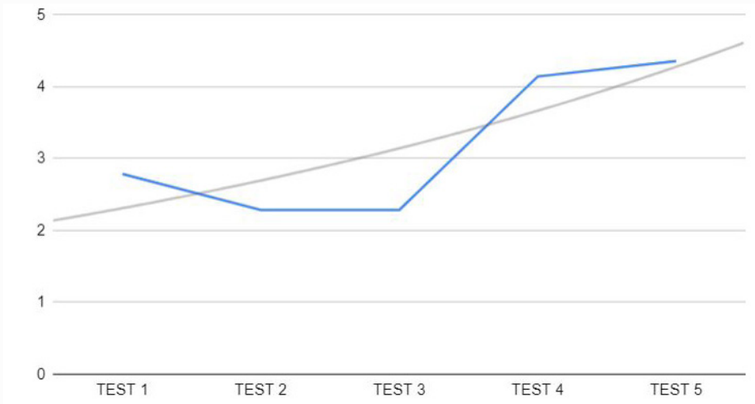


Figure 107: QUESI Qualitative results Score/ Participant

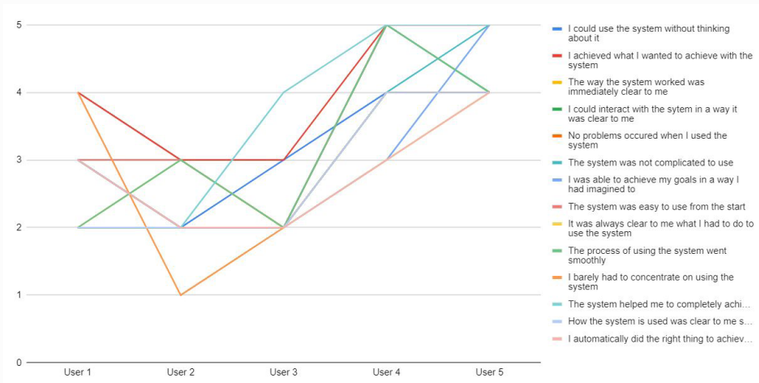


Figure 108: QUESI Individual results Score/ User

6.4. Conclusions

The Prototype Phase reached enough level to be fluent within the participants who tested the platform. The end result of the prototype can be forward to the next evaluation phase, where the concept validation would be at the core of the user testing. There are several certain factors to address with regards to this last prototype:

Multi-User functionality

Multiuser is one of the most important features of this project. Coding works properly with the client-server model. In fact, the multi-user feature cannot be tested with the current GPU (3060RTX). It would be interesting to keep investigating with a benchmark in order to know what the GPU required would be. Due to cybersecurity, the project should be used on a VPN that Hardt is able to control, because this technology with pixel streaming may leave the WiFi router in a vulnerable situation.

Improved Usability

Using the RITE method has improved the project's usability and this is apparent in the rising trend of the graph. See Figure 107. The QUESI qualitative Questionnaire was very helpful in order to look into the participants' thoughts. Qualitative feedback provided by participants was very important in order to improve the iterations and in fact, the project followed one direction based on the participants' recommendations. In spite of the last participant barely provided feedback to improve the project, the researcher found out that the project was reaching a bottle neck. This bottle neck is related to the digital pointer and it was too complex to code because it had been provided by the collab viewer template. However, the quantitative results show that if RITE continued, the results would as well. It is important to say that another usability questionnaire will be used in the Concept Evaluation Chapter.

Prototyping Recommendations

There are two main problems to deal with in order to continue prototyping this virtual environment.
Firstly, the platform must be introduced in the Amazon server ecosystem. On one hand, this would improve cybersecurity, because Amazon server has its own VPN; on the other hand, there are different GPU alternatives that can be adapted to the project's requirement, for example, the multiuser GPU requirements needed. However, this would have its limitations as one of the disadvantages is that the costs of the platform maintenance would increase.

The second problem that must be addressed is the amount of issues when coding due to keeping the digital pointer from the collab viewer template. The digital pointer of the template does not allow selecting parts from a Blueprint Actor and therefore it forces the use of static meshes in the Level Blueprint. In fact, coding in the level blueprint is inefficient because it cannot be migrated to new projects and it disrupts the workflow of Unreal Engine projects in Hardt. Participants wanted to have information on the thing they selected, which was one of the frequent recommendations. Keeping the digital pointer forced the participants to use the Level Blueprint. This did not allow a proper coding of the functions for the multiuser and did not meet the requirement of providing information to the participants, because there is no access to the components Blueprint Actor.

7. Evaluation

During chapter 7, the prototype will be evaluated with the current solutions that Hardt is working with. A comparison between traditional rendering with interactive visualization will be made to validate if the design solution is capable of sharing ideas easier, while also providing involvement in the project.

7.1 Introduction

This section consists of the description of the user testing phase, which starts once the prototyping development is done through the RITE method. The main objective of the user testing is to validate the concept and the usability of the application. This phase consists of the exploration of the virtual environment and of getting feedback on the value that it brings to the user. This way, it is possible to understand if the concept is interesting and attractive for the users.
In order to validate the concept, participants are given the freedom to explore the platform and understand the main concept. What is sought in this concept validation is the feedback focused on the value that the concept brings to the user.

7.2Participants

Six participants were invited to the test prototype in order to conduct the user test. Three of the participants did have 3D software experience, whereas the other three participants did not have it. Therefore, two perspectives are covered when validating the concept. On one hand, it provides insights on whether this concept would provide value in the design process to those users who are not used to participating in the design process; whereas, on the other hand, it provides insights on whether this concept would be used in the future as an alternative or in addition to the current ways of communicating ideas.

It is important to mention that all the participants work in Hardt, as the product developed is for Hardt and their opinion is necessary to know if they may be interested in using it in the future.

7.3 Guidelines and Procedure

The qualitative approach was the one selected for the user testing, due to the sample of participants available. As Hardt is a small company, it is important to go through deep thoughts regarding the prototype tested. Thanks to the qualitative approach it was possible to collect insights of the value and usability of the platform in order to validate the concept. (Qualitative Usability Testing to Validate Your Product Idea Fast, 2021).

In addition to the research,the short version of the Usability Experience Questionnaire was introduced in the interview. This questionnaire has 8 scales that cover the usability and user experience aspects from -3 to +3. The UEQ questionnaire could provide data to the researcher and once this data is introduced in a specific tool, it is possible to interpret the results regarding pragmatic and heuristic quality. These results are compared with the R.I.T.E. results from the previous chapter in order to gather more reliable data.

The setup of the user testing was similar to the R.I.T.E. prototyping method. The participant and the researcher met on a video call. The researcher activated the server, and the participant connected to the platform through the Google Chrome browser. An example of the setup during the user testing is shown in Figure 110. The structure of the guidelines and its goals can be seen in Figure 109.

VR Communication Tool José Manuel Rodríguez Díaz

Introduction

Introduce the researcher, the structure and goal of the session. (5 min)

Setting the participant on the scenario

Explain a story to set the participant into the context of the Virtual Environment platform. Guide the participant for the log-in.

The Prototype

Send the link to the participant so they can access the platform. Explain moderately how the prototype works together with the tutorial. (5 min)

Moderated Testing

Moderate Testing allows the participants to interact with the platform and guides them through the different functions of the Hardt Digital Lab. During the testing, the participants explain their thoughts, motivations and concerns (10 min)

Interview

Ask the participant several questions to evaluate the concept and the navigation of the application. Ask the participant to propose potential improvements. (20 min)

Wrap up

Thanks the participant and summarize conclusions. (20 min)

Figure 109: Structure of the Guidelines

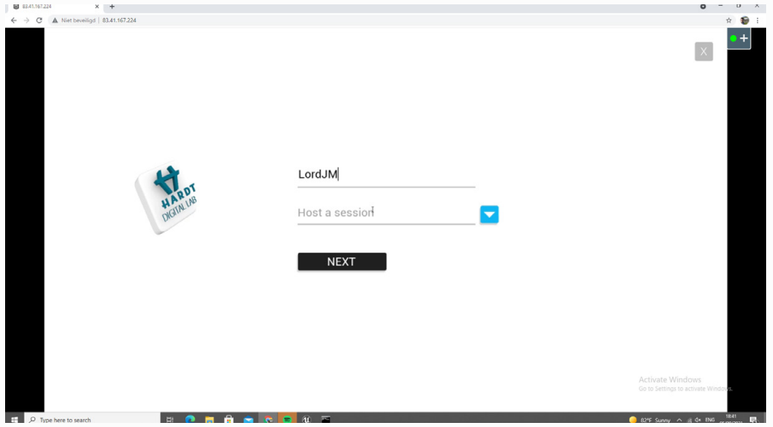


Figure 110: Onboarding on the platform through web

Scenario

Before starting the test, every participant was introduced with the following scenario in order[o] to help them to be in the desired context:

"Now you will play the role of a member of Hardt who is not usually taking part in the development of a prototype inside the company (Market Development), but the design team wants to involve you in the process by collecting earlier feedback than what would normally provide once the physical prototype was already built. We will both decide the preferred design and materials, and a photo of it will be taken."

Moderate Testing

The chosen method for the testing was moderated testing, where the participant was guided throughout the virtual platform by the researcher, giving the participant the possibility to ask questions, while they follow the required tasks provided. As the concept is not completely finished, this method is recommended in case of confusion, so the testing can go smoothly (Moderated vs Unmoderated Usability testing: which do you need?, 2019). Furthermore, the platform is meant to be multi-user, so the learning curve is expected to happen with communication in the final product.
The session starts by sharing the IP address with the participant and logging in to the platform through a chosen web browser. Once the participants start to use their avatar to move around, the moderator will tell the participants how to explore the environment, together with a small tutorial. The participants may express motivations, concerns and thoughts, while the moderator answers questions and gives tasks on how to change the different designs and materials. The moderator will join the session, so the participants can realize the multi-user functionalities. Together, the moderator and the participants will choose a preferred design and take a snapshot that can be shared with other people. With these activities, the researcher can analyze how fluent the participants feel with the platform. As a final step, the researcher asks the participants for feedback on the user ś thoughts.

Interview

After the interaction activity, the participants go through a questionnaire with the possibility to continue using the platform. During the interview, topics like usability, design, communication and involvement were covered. The intention of the questionnaire is to go deeper into the thoughts of the participants. Within the questionnaire, the short UEQ (User Experience Questionnaire) is included to gather data with regards to pragmatic and hedonic quality per person. This questionnaire consists of 8 items with opposite descriptions that can be found in Appendix P. The results were processed with the data tool from (User Experience Questionnaire (UEQ), n.d.) in order to interpret them.

7.4 Results

Useful insights were gathered out of the user testing, which could potentially improve the future interactions of the concept and these useful insights could also validate the concept of the Hardt Digital Lab. More detailed information related to the topics explored during the sessions with the participants and related to the thoughts regarding the concept can be found in this section.

Concept Validation

Mainly, it was a very easy and intuitive way to showcase designs in detail at different levels from an overall 3D perspective to get into the different parts with high-fidelity visuals.

The concept was received positively by the participants. It was easy to understand and the participants could explore it freely. The biggest benefit was to validate inside the same environment the option preferred seamlessly.

"If designers can load in their concepts at a reasonable pace then we can work towards narrowing down the design idea early on in the project and that is very welcome."

What would make it valuable is the seamless integration in the workflow of the company. Time is very valuable in the company and even if they see the potential in it, they want to know if it would really slow down their process or speed it up. It is clear that it is accessible, but the time spent on the updates is what would really make a difference.

UEQ with QUESI

QUESI quatitative results had a good tendency regarding usability. Even though the trend was working properly, it was recommended the implementation of a different usability test. The goal of UEQ was to analyse the usability with a different questionnaire in order to give more consistency to all the data collected. The result from the pragmatic quality was 2.125 -3 is the maximum-, so the result was excellent. The UEQ tool provides an alpha value that indicates the scale consistency and determines if the number of samples is enough. The alpha value needs to be >0.7, being the 0.73 the result of these 6 samples. With regards to the Hedonic quality, the result is even higher with a 2.29, but the alpha correlation is 0.49. More data is needed to have consistent results regarding the user experience, even though the interviews were supporting these results. Pragmatic and Hedonic results can be seen in Figure X.

Scale	Mean	Comparisson to benchmark	Interpretation
Pragmatic Quality	2.125	Excellent	In the range of the 10% best results
Hedonic Quality	2.291666667	Excellent	In the range of the 10% best results
Overall	2.20	Excellent	In the range of the 10% best results

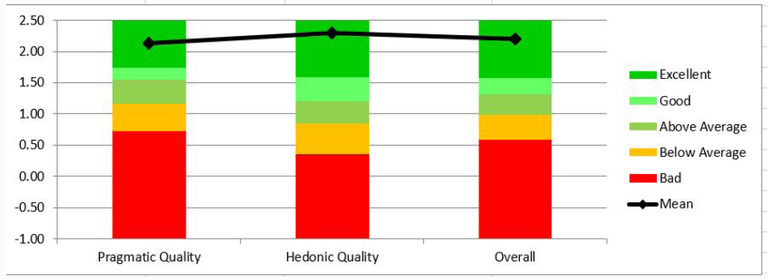


Figure 111: Results of the short UEQ testing

Navigation

Regarding navigation, it is important participants who had a poorer Internet connection did not have a very good experience. The option of preset views was used as a backup. If a user presses one button, this function brings the users to a specific spot in the virtual environment. This was helpful in two ways. Firstly, those people who got confused navigating through the virtual environment could reset the perspective. Secondly, this preset view is not damaged by the low latency from the Internet. The overall speed of the navigation should be reduced in future iterations.

Design

When it comes to design, the use of this virtual environment and its interface was simple and user-friendly, but it had its limitations when providing information about the different parts of the design.

List of Improvements

After conducting the six user tests, a great amount of information was collected in order to create a list of improvements. This list of improvements largely coincides with the recommendations of RITE's last chapter.

Selectable Products with Information (Digital Pointer)

Participants thought that when using the digital pointer with a certain product, they could use the User Interface to modify it. This misunderstanding happened also during the RITE usability test.

Environment adjustments

Participants asked for interactive lighting settings.

Multi-User performance

The GPU used in the user test was a GeForce 3060 RTX. When using the multi-user feature, the PC has to render both users with the same GPU. The 70% of the GPU was in use when it was using one user for this setup. See Figure X. The GeForce 3060 RTX has 16,609 average G3D mark points (PassMark, 2021). Every user activity on the PC requires at least 11,626 points. For the implementation of multi-user, two users must run at the same time. A minimum of 23,256 points is required, so at least the GeForce RTX 3080 GPU(24,440) is needed.

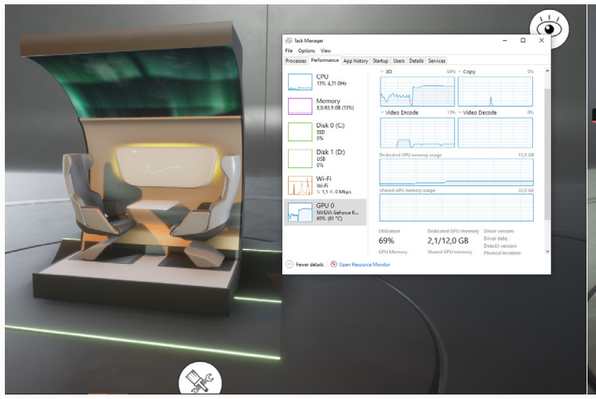


Figure 112: 70% GPU Benchmark one user

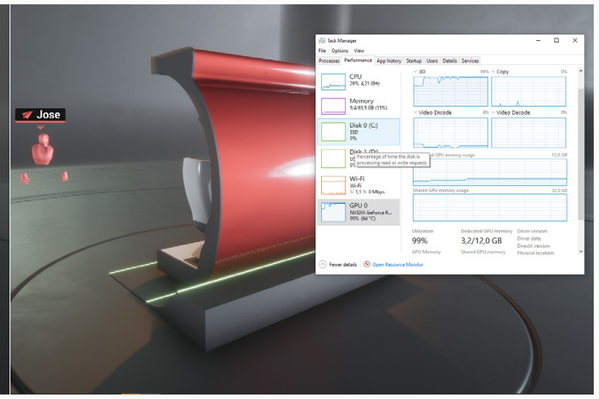


Figure 113: 100% GPU Benchmark two users

Opinions from Hardt Digital Lab

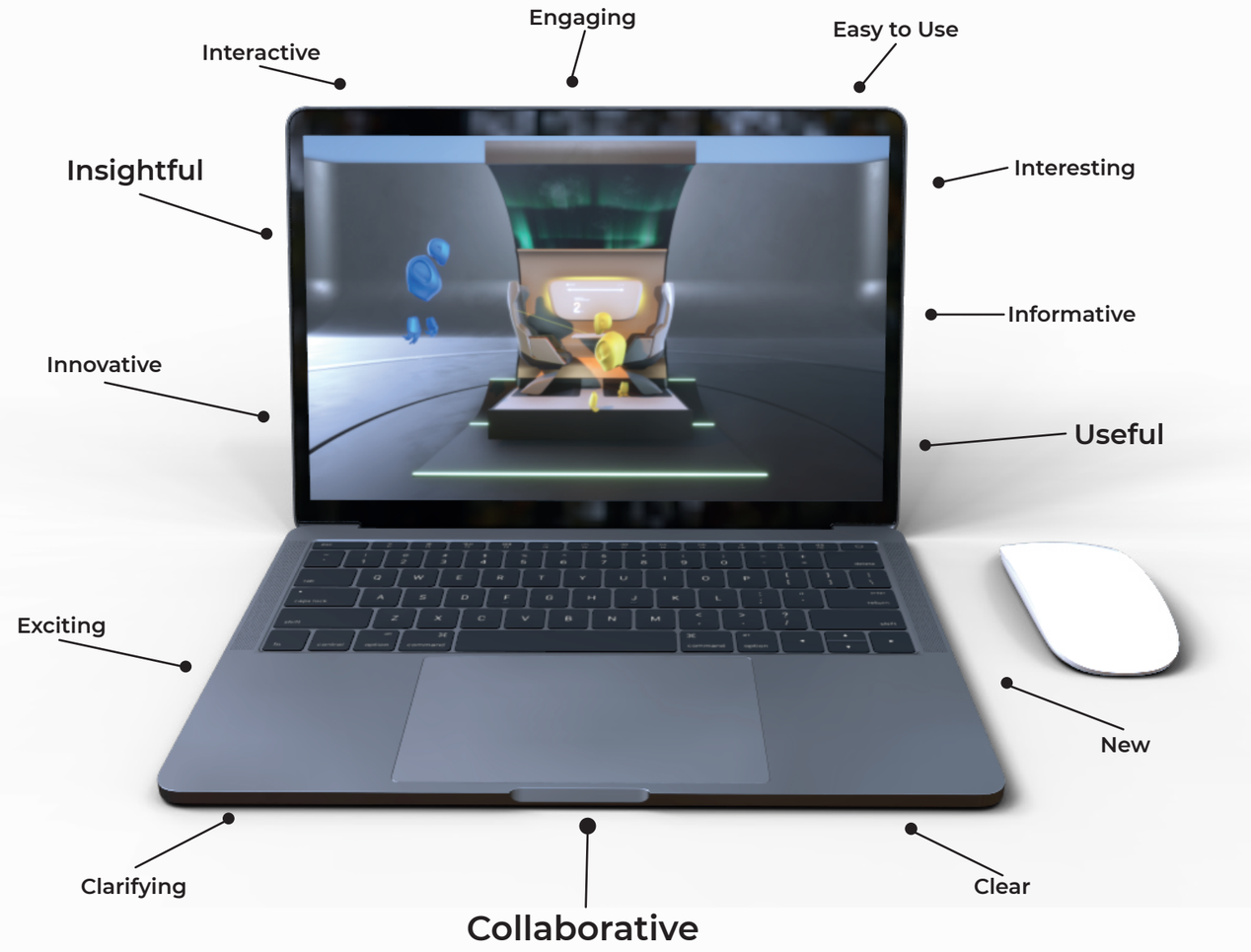


Figure 114: Collection of words from the qualitative approach. What people think about Hardt Digital Lab

7.5 Requirements Evaluation

Once the user testing with the participants from Hardt Hyperloop is over, it is necessary to check if the list of requirements of the ideation part has been fulfilled. The current situation of the list of requirements is the following one:

1. Accessible from desktops (Priority), scalable to other platforms (Wish)

The Collab Viewer was able to scale the virtual environment to PC, Mobile and VR.

2. No installation required - Works with Internet

Technology has to develop until VR can work properly through Pixel Streaming. Right now, only smartphones and PCs are available without installation.

3. Give 3D visualization access to non-tech

All participants from the user testing felt in control of the platform and comfortable when discussing with other members.

4. Adapt usability to the User-defined

During testing, the target group was validated by asking if they felt the platform was designed for people like them, but also how smooth they used the navigation options. All participants were able to finish the tasks they were told, and they also felt part of the target group.

5. Interactive

Coding inside the Unreal Engine was successful.

6. Slight personalization (Wish)

Only the name, which was already inside the Collab Viewer template, was introduced.

7. Validate Assemblies

Animations on how to assemble a product were prototyped, but not tested.

Fulfilled

Still needs more work

Not Fulfilled

8. Validate Ergonomics

Only if using Virtual Reality. Prototyped, but not tested.

9. Fluid Performance (72 fps)

Only with one user. More GPU is required to use multiple users in the same platform.

10. Ability to share ideas

Limited information was available. Sharing and commenting on the design was working properly, a more detailed configurator is needed. Post-its and Whiteboard were not fully prototyped.

11. Collaborative as an option

GPU limits this function right now. Limited if you keep the no-installation. The project should be scaled up to a server.

12. Track sessions

Snapshot is the only function to track a session. The modifications inside the environment must be saved in future iterations.

13. Animations

2D videos tested properly and 3D animations too.

VR Communication Tool José Manuel Rodríguez Díaz

7.6 Conclusions on Evaluation

The user testing provided positive feedback from Hardt's members. Being able to configure different options in the same environment was received positively, and it opens up new ideas of what could be done at Hardt Digital Lab.

It was a disadvantage that multi-users could not be fluent with the current setup, but there are some solutions in the market. This was already known during the RITE evaluation, that is why the approach of this user testing had a bigger focus on the concept validation, rather than measuring collaborative features.

The Digital Pointer must be improved or done from zero. If this environment is used with a larger project such as the European Hyperloop Centre, or the whole interior design of the hyperloop, selectable products are a must. The current digital pointer is a clear showstopper.

Regarding the engineers who participated in the user testing, they were able to see the assembly feature. Even though they knew this feature was not part of the test, they had positive feedback with the potential of the assembly step-by-step explanation.

One of the participants was impressed by the fact that the virtual environment could be used by only using the web browser. This prototype has been developed with the Cabin-1 in mind, which is an already developed prototype. Participants were fascinated with the product and the number of possibilities, but they would only see a big potential of the virtual environment if the integration of new designs did not slow down their current workflow. Knowledge regarding Unreal Engine is required inside the company if they want to develop more digital twins in the future and measure if the collaborative features are beneficial for the communication of the company.

8. Conclusion

In this chapter, the

This last chapter will consider the conclusions of the project, which will be divided in four different sections.

Problem Definition

Hardt had issues of communication with the different members of the hyperloop ecosystem. This was due to a gap of knowledge regarding engineering knowledge between stakeholders and Hardt members. This situation got even worse due to the COVID-19 pandemic. Hardt is a company focused on transportation and infrastructure and the company was greatly affected for the physical limitations of the pandemic, like lockdowns, social distancing, and many other strict measures when it comes to communicating with external parties.

Due to the pandemic, companies started to use several technology tools to adapt to the situation. These tools are Zoom or Teams, among others, and are quite effective but have some limitations in comparison with the face-to-face meeting. Digitalization has increased all over the world, and it may be a good opportunity to use extended reality solutions technologies to cover the interaction gaps when communicating with others.

Proposal

Therefore, the researcher proposed the use of remote collaborations in virtual environments. This way, the benefits of the face-to face will remain together with the benefits of remote solutions. The researcher opted to develop the concept of Hard Digital Lab, a virtual environment where everyone could visualize virtual prototypes to share ideas and concepts of the hyperloop.

Results

Two different sessions of user testing were conducted. The first session was focused on the improvement of the usability. The QUESI Qualitative and Quantitative questionnaire was used to measure the improvements and gather feedback for future iterations. This resulted in a positive improvement although it was necessary more data to validate the results. The last iteration of RITE method allowed to validate the concept of the Hardt Digital Lab. The user testing had a qualitative approach where it was not necessary a great number of participants. Furthermore, short version of the UEQ to measure the usability and the user experience. UEQ tool allowed the comparison of usability data in comparison with the QUESI results.

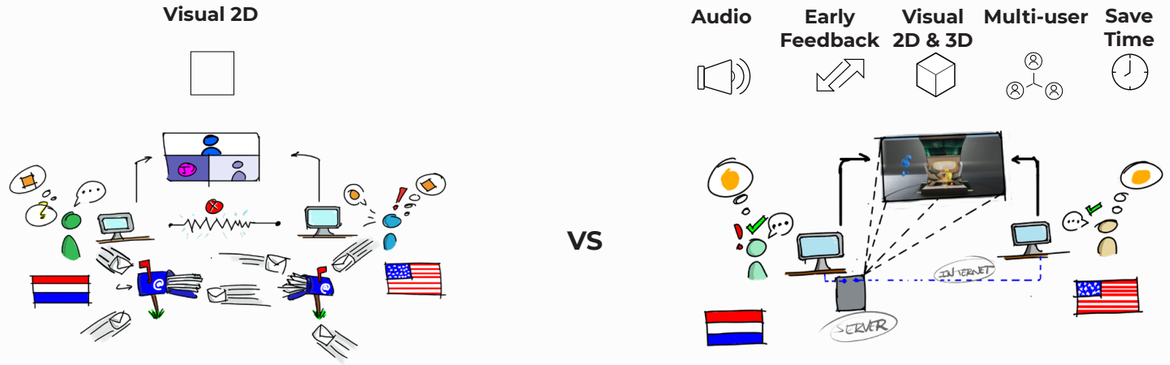
The overall acceptance was very positive from the side of Hardt members. They were impressed on how a powerful tool could work with only the web browser. They found the environment as a useful tool to explore the design of the Cabin-1, which was the selected product to have as a virtual prototype, together with a proper visualization.
From the participants it was noticed that two important improvements were needed. First, the multi-user functionalities could not be tested properly due to a lack of GPU. Another GPU is needed, and due to the constant improvements of this virtual environment, Amazon Web Server, a cloud solution, is recommended. Different GPUs can be accessed with this cloud solution.

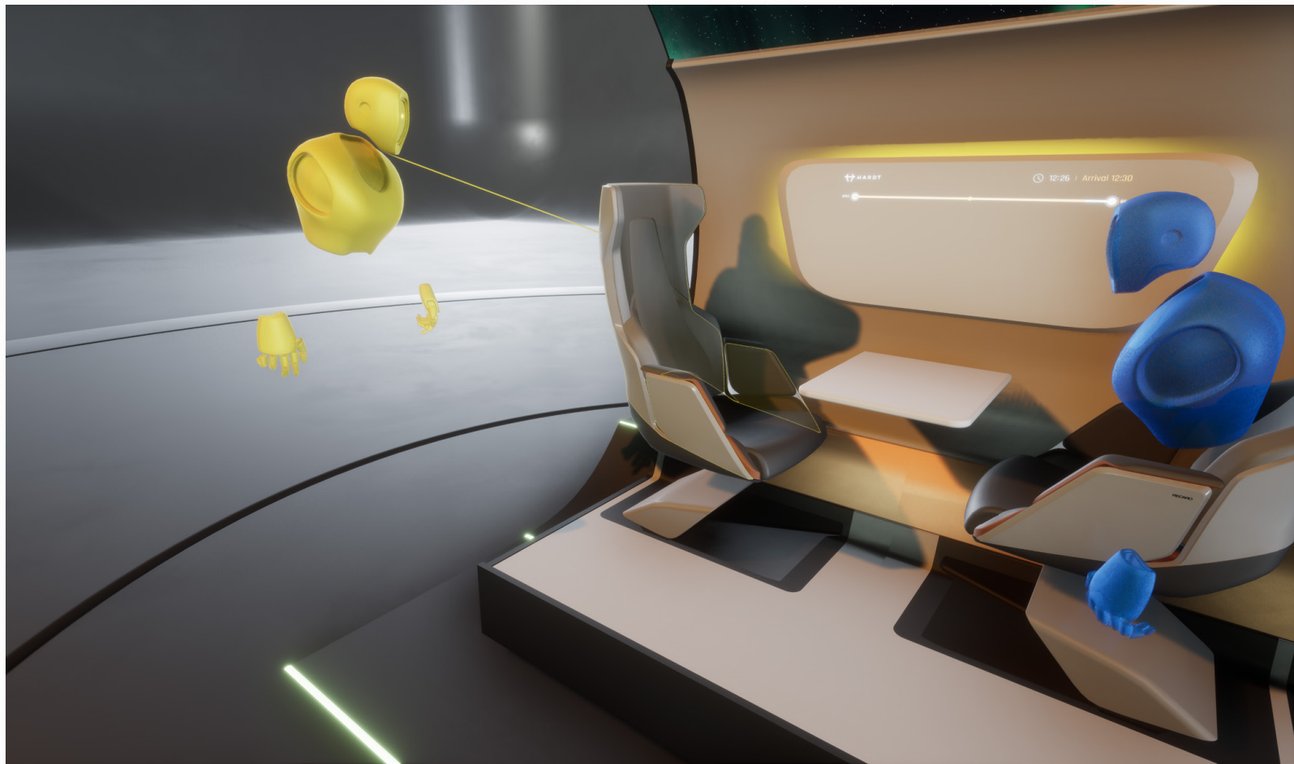
Recommendations

The second improvement needed is a better digital pointer that can access information inside different components. The current digital pointer is not flexible with the functions developed and brings confusion to the participants.
As a future recommendation, the functionalities for the technical users must be tested (Measurements, Step-By-Step, etc.). Virtual Reality can be very beneficial to validate ergonomics within this environment, giving a better approach from the engineering side.

To conclude, I recommend Hardt to continue working on virtual environments as a tool for product and market development. Game engines such as Unreal Engine are improving dramatically in the last years. The impact that they can have in the future development of large products and architecture can change the whole workflow. It is true that the integration of CAD models is still not there yet when it comes to have a fluent environment, but every update that comes is getting better. The bigger the product, the more value you can add on a project with this technology, thanks to the seamless and scalable integration of game engines.

Unreal Engine 5 is about to be released and it will become a game changer. Automotive companies are already transitioning to real-time 3D renderings. The hyperloop still needs some years until we can make use out of it. We need people to believe in the hyperloop, but until it is built, Hardt needs to show it virtually. Virtual Reality is the most flexible, cost-effective and sustainable solution I have found for a product of this scale.





References

Affairs, A. S. for P. (2013, October 9). Use Cases. Department of Health and Human Services. use-cases.html

Badke-Schaub, P., Lauche, K., & Neumann, A. (2007). Team mental models in design. CoDesign, 3(1), 1–3. https://doi.org/10.1080/15710880601170743

Badke-Schaub, P., Neumann, A., Lauche, K., & Mohammed, S. (2007). Mental models in design teams: A valid approach to performance in design collaboration? CoDesign, 3(1), 5–20. https://doi.org/10.1080/15710880601170768

Bekebrede, G., Lo, J., & Lukosch, H. (2015). Understanding Complex Systems Through Mental Models and Shared Experiences: A Case Study. Simulation & Gaming, 46(5), 536–562. https://doi.org/10.1177/1046878115621463

Benefits of Working in an Office vs. Remote Work. (2020, August 11). INAA. https://www.inaa.org/benefits-of-working-in-an-office-vs-remote-work/

Boston, W. (2020, September 15). COVID-19 Has Forced a Radical Shift in Working Habits. Wally Boston - American Public University System. https://wallyboston.com/covid-19-radical-shift-working-habits/

Bowman, D. A., & McMahan, R. P. (2007). Virtual Reality: How Much Immersion Is Enough? Computer, 40(7), 36–43. https://doi.org/10.1109/MC.2007.257

Client-Server Model. (n.d.). Retrieved January 11, 2021, from https://docs.unrealengine.com/en-US/Interactive-Experiences/Networking/Server/index.html

Definition of Interactive Visualization—Gartner Information Technology Glossary. (n.d.). Gartner. Retrieved May 25, 2021, from https://www.gartner.com/en/information-technology/glossary/interactive-visualization

Ens, B., Lanir, J., Tang, A., Bateman, S., Lee, G., Piumsomboon, T., & Billinghurst, M. (2019). Revisiting collaboration through mixed reality: The evolution of groupware. International Journal of Human-Computer Studies, 131, 81–98. https://doi.org/10.1016/j.ijhcs.2019.05.011

Fox, M. (2020, July 28). Remote work burnout is growing as pandemic stretches on. Here's how to manage it. CNBC. https://www.cnbc.com/2020/07/28/remote-work-burnout-is-growing-as-coronavirus-pandemic-stretches-on.html

Game engine. (2021). In Wikipedia. https://en.wikipedia.org/w/index.php?title=Game_engine&oldid=1000737032

Gibbons, S. (2018, December 9). Journey Mapping 101. Nielsen Norman Group. https://www.nngroup.com/articles/journey-mapping-101/

GLOBAL FLEET AND MRO MARKET FORECAST 2021-2031. (n.d.). Retrieved June 3, 2021, from https://www.oliverwyman.com/our-expertise/insights/2021/jan/global-fleet-and-mro-market-forecast-2021-2031.html

Goldschmidt, G. (2007). To see eye to eye: The role of visual representations in building shared mental models in design teams. CoDesign, 3(1), 43–50. https://doi.org/10.1080/15710880601170826

Greenwald, S. W., & Maes, P. (n.d.). Multi-User Framework for Collaboration and Co-Creation in Virtual Reality. 2.

Hosting and Networking Guide. (n.d.). Retrieved January 11, 2021, from https://docs.unrealengine.com/en-US/SharingAndReleasing/PixelStreaming/Hosting/index.html

Jackson, R. L., & Fagan, E. (2000). Collaboration and learning within immersive virtual reality. Proceedings of the Third International Conference on Collaborative Virtual Environments - CVE '00, 83–92. https://doi.org/10.1145/351006.351018

Lau, H. Y. K., Mak, K. L., & Lu, M. T. H. (2003). A virtual design platform for interactive product design and visualization. Journal of Materials Processing Technology, 139(1), 402–407. https://doi.org/10.1016/S0924-0136(03)00510-7

Lee, B. P. H. (2001). Mutual knowledge, background knowledge and shared beliefs: Their roles in establishing common ground. Journal of Pragmatics, 33(1), 21–44. https://doi.org/10.1016/S0378-2166(99)00128-9

Medlock, M. C., Wixon, D., Terrano, M., Romero, R. L., & Fulton, B. (n.d.). Using the RITE method to improve products; a definition and a case study. 7.

Mendoza, N. F. (2020, August 24). COVID-19 has exacerbated a 75% job burnout rate, study says. TechRepublic. https://www.techrepublic.com/article/covid-19-has-exacerbated-a-75-job-burnout-rate-study-says/

Mirko. (2020, January 6). The main advantages of Real Time engines vs Offline rendering in Architecture. | Oneirosvr. https://oneirosvr.com/real-time-rendering-vs-offline-rendering-in-architecture/

Networking and Multiplayer. (n.d.). Retrieved January 11, 2021, from https://docs.unrealengine.com/en-US/InteractiveExperiences/Networking/index.html

Nielsen, J. (2000, March 18). Why You Only Need to Test with 5 Users. Nielsen Norman Group. https://www.nngroup.com/articles/why-you-only-need-to-test-with-5-users/

One, V. H. (2020, December 9). Hyperloop Technology Included in European Union Sustainable and Smart Mobility Strategy. GlobeNewswire News Room. https://www.globenewswire.com/news-release/2020/12/09/2142206/0/en/Hyperloop-Technology-Included-in-European-Union-Sustainable-and-Smart-Mobility-Strategy.html

PassMark. (2021). Videocard Benchmarks. https://www.videocardbenchmark.net/high_end_gpus.html

Pixel Streaming Overview. (n.d.). Retrieved December 7, 2020, from https://docs.unrealengine.com/en-US/SharingAndReleasing/PixelStreaming/PixelStreamingOverview/index.html

PricewaterhouseCoopers. (n.d.). Returning to the workplace after COVID-19: What boards should be thinking about. PwC. Retrieved July 26, 2021, from https://www.pwc.com/us/en/services/governance-insights-center/library/covid-19-returning-workplace-boards.html

Qualitative Usability Testing to Validate Your Product Idea Fast. (2021, January 26). https://www.userinterviews.com/ux-research-field-guide-chapter/qualitative-usability-testing

Radkowski, R., Herrema, J., & Oliver, J. (n.d.). Augmented Reality-Based Manual Assembly Support With Visual Features for Different Degrees of Dificulty. 13.

Reducing Emissions from Aviation. (n.d.). Retrieved June 3, 2021, from https://ec.europa.eu/clima/policies/transport/aviation_en

Twitter, LinkedIn, & Facebook. (2015, March 17). What is the framework for innovation? Design Council's evolved Double Diamond. Design Council. https://www.designcouncil.org.uk/news-opinion/what-framework-innovation-design-councils-evolved-double-diamond

UMG UI Designer. (n.d.). Retrieved January 11, 2021, from https://docs.unrealengine.com/en-US/InteractiveExperiences/UMG/index.html

User Experience Questionnaire (UEQ). (n.d.). Retrieved September 2, 2021, from https://www.ueq-online.org/

Zimmermann, N. (2020, April 16). Your next business meeting could be inside a VR headset | DW | 16.04.2020. DW.COM. https://www.dw.com/en/your-next-business-meeting-could-be-inside-a-vr-headset/a-53143501

VR Communication Tool José Manuel Rodríguez Díaz

Appendix A

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

The hyperloop is a complex system, and its development requires alignment at all levels, from component design to implementation and marketing strategies. Hardt is unable to effectively communicate ideas, concepts, and progress. This happens because stakeholders understand things differently internally and externally. When communication is not fluid, the design process, marketing strategies, and development slow down. Therefore, an alignment of stakeholders is needed. With interactive environments, stakeholders can ground into the same idea, improving the current communication strategies. With my prior experience related to interactive rendering, Hardt team, and the experts I know, I think this project can be successful.

The result of the project will be the development of a demonstrator of the capabilities of the above-mentioned technology within the company's context.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in “problem definition”. Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, … . In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

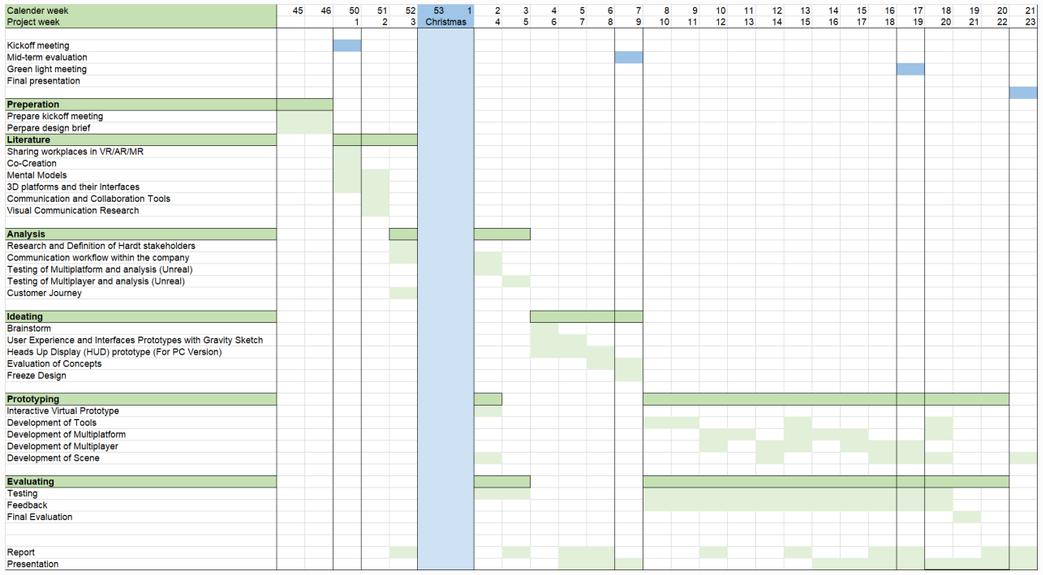
This project will research the potential impact that interactive 3d rendering can have in stakeholder communication. With interactive 3d rendering we mean for example virtual reality applications, but we don’t resctrict applications to Head Mounted Displays. Sharing knowledge can increase team performance, predict behavior, ease communication, and distribute knowledge for the hyperloop development.

Furthermore, I will propose a communication strategy and develop a digital tool where I can evaluate my findings improving grounding between stakeholders, bridging the knowledge gap between them. My expected contribution is to improve the communication internally and externally with all the stakeholders involved in the Hyperloop system. This will result in a boost in the design process, saving money and time. The goal is to achieve alignment between different stakeholders regarding a design and notify about the project´s stage.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 1 - 12 - 2020 11 - 5 - 2021 end date



I am planning to develop an interactive visualization that can enhance the collaboration between the stakeholders involved in the hyperloop system. This interactive visualization can be displayed with different devices that support Real-time 3D renderings, such as VR headsets and PC.

Literature and Analysis: First of all, I have to do extensive research in order to understand the different stakeholder's needs and common ground involved in the hyperloop system, the information that I want to communicate, and how I will do that. Secondly, I will research the possibilities of the connectivity between devices with the use of Unreal Engine in order to validate collaborative systems inside the project.

Ideation: During this phase, I will create fast 2D and 3D User Interfaces prototypes. I will evaluate the ideas with users.

Prototyping Phase: For the development of this interactive visualization, I will use the RITE Method. RITE is a method that is based on constant iterations and user feedback. Errors and failures must be identified in every iteration. Errors are the mistakes that the user makes during the test, while failures are the moments that the user does not know what to do. During the whole development, I will work on the environment, connectivity, and tools that users will need. Finally, I will do an Evaluation of the Prototype in order to see outcomes.

For the development of the project I will need a VR Ready workstation and a VR Headset, so I can validate the importance of spatial understanding within real-time visualizations. The external knowledge that I need is from the VR Zone, where they have already worked on a multiplatform interactive project and multiplayer.

Appendix B

What is the Hyperloop?

Hyperloop is a new mode of transportation for large volumes of passengers and cargo. Pressurized vehicles travel inside a low-pressure tube by means of a magnetic levitation and propulsion system. The latter operates generating no mechanical friction, and the air resistance is dramatically reduced by the low-pressure tube. The result is a transportation system that can reach speeds north of 1000 km/h and consume ten times less energy than aircrafts.

The hyperloop is commonly known as a novel transportation system that aims to move small capsules of people from one place to the other at transonic speeds. The concept consists of a series of capsules that travel independently and autonomously through a low-pressure tube. The easiest way to understand it is thinking of a one-wagon autonomous train, in which each wagon travels to a different destination and makes no stops in between.

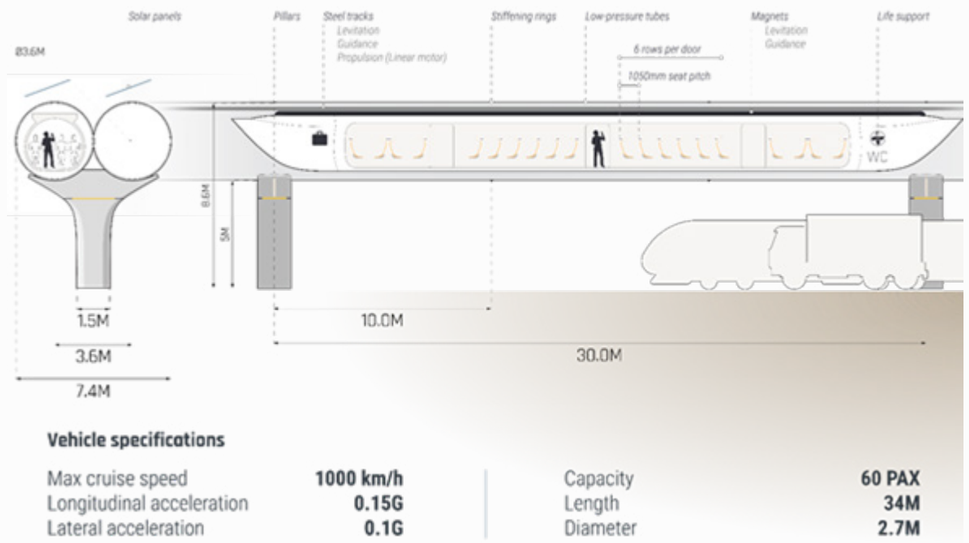
The Hyperloop Alpha paper first described by the SpaceX team, proposes the hyperloop as a transportation system for a specific use case (Los Angeles to San Francisco), so the transportation system is envisioned in isolation to meet the 840 passenger per hour demand (SpaceX, 2013).

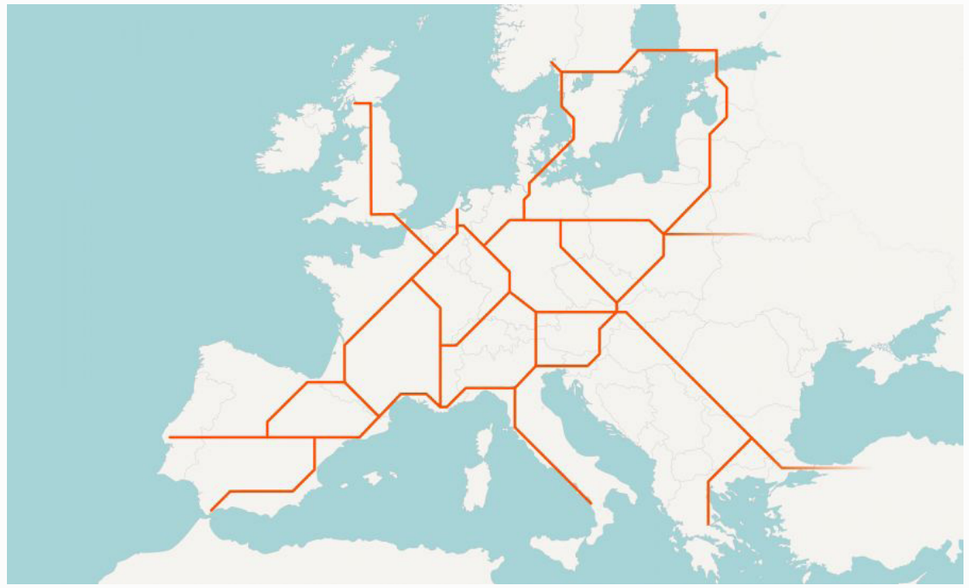
Several hyperloop initiatives have emerged since the Alpha paper was released, with the aim to develop this transportation system. However, one use case does not meet all and several conceptual, technical, and operational aspects have evolved to meet the vision of each of the hyperloop developments.

The hyperloop system envisioned by Hardt shares some of the operating principles with the original concept, but it has taken different approaches in other areas, such as the system capacity, operating speed and levitation system.

The concept is based on a European hyperloop network model that was developed with the purpose of replacing short haul flights throughout Europe and enable long distance commuting. Different operational parameters, such as vehicle capacity, tube diameter, cruise speed, accelerations etc. were evaluated with the purpose of further understanding how the hyperloop should fit in the mobility landscape.

The implementation of this network, as with any other transportation network, will occur in a phased approach. The first line is envisioned to be operated in the year 2030, after which 20 years of network expansion will follow until the full European network is operational by approximately 2050. Hardt's hyperloop is being developed for the future mobility demand that will be exerted onto this network.





Appendix C

Structure of the Interview:

Co-creation & Interview with stakeholders

Intro (5 min)

Welcome, I introduce myself and the purpose of the session: to know more about the communication with partners
Thank you very much for your participation
Please Think out loud, the more critical and honest you are, the better.
There are no wrong answers
Permission to record the video call
Duration: X minutes and X parts

Contextual questions - Sensitising the user (5 min)

Tell me a little bit about yourself and your role at the company
How does a typical day at work look like?
Why?
How do you communicate with your colleagues/peers?
Why?

Communication (20 min)

Please could you explain to me step-by-step how do you communicate with other stakeholders (Journey mapping AS IS) -
Now, I would like you to map where the main miscommunications take place.
How might we X? (resolve pain points)
Now I would like to ask you why you think those miscommunications take place (root problem).
Please could you explain to me step-by-step how would you like to communicate with other stakeholders (Journey mapping TO BE) -

Wrap up & Goodbye

We have reached the end of our session, thank you very much.
Your comments have been very useful and will help us to improve a lot.
General feedback: What did you think of the session?
Before closing: Do you have any questions for me and would you like to share anything else?

NOTES WITH RIK:

Communicating Externally the cargoloop
Stakeholders on board for the feasibility of the project (Demonstrate the Feasibility of the study)
Private entities and governmental

Typical Week
Activities:
Regularly talk to new stakeholders to take on board of the project
Connect the people of the team to the stakeholders to have information available

“Not everybody is constantly aligned with the newest direction”
“Things change pretty fast, and not everybody is acquainted” (adaptability)
Rik Role is to have everybody aligned

Rik is comfortable with email (text, because it can be traced) and calls(audio communication)
Not comfortable with the Teams channel because it’s like giving assignments, task model.
He thinks an innovative company should have time to discuss and agree. (He wants more coordination and communication within the team members)

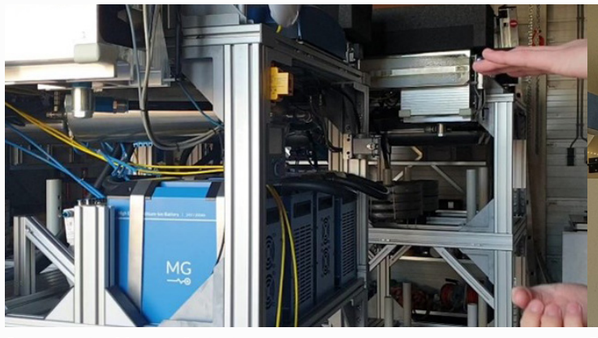
With emails, people can have as pain points:
receive too many
not read if it is too long
Wait a while to reply

Gains:
Trace the information
Big overview
Involve many people together
Confirm what you have been discussing before (Black or White)
Add nexus (Annotating)

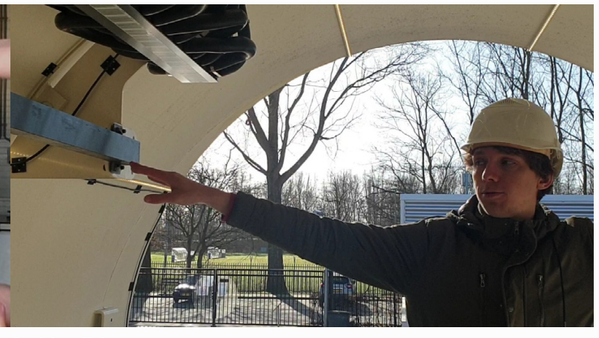
Teams is a methodology to keep me up to date, rather than communicating.
He would prefer a chat in the office if it was not because of the covid crisis.
He uses a very simple Powerpoint presentation.

Why did the Royal Flora Holland casework?
They had a certain picture in mind, we had a certain picture in mind. Only when the picture was on the screen, the conversation started in a one-dimensional way. Very helpful to stand in the same environment and have a common perception and understanding of what we are seeing.

Appendix D



Representation Magnetic Levitation



Real Size Tube

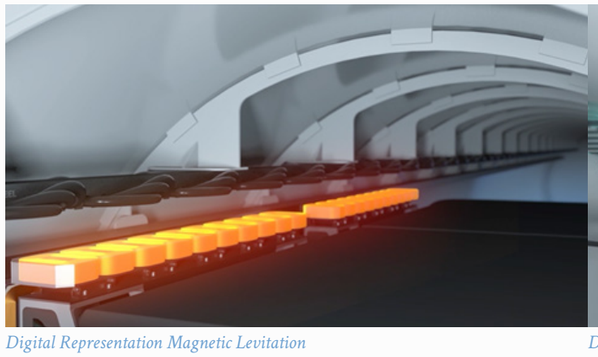
Representation Magnetic Levitation

Representation Propulsion

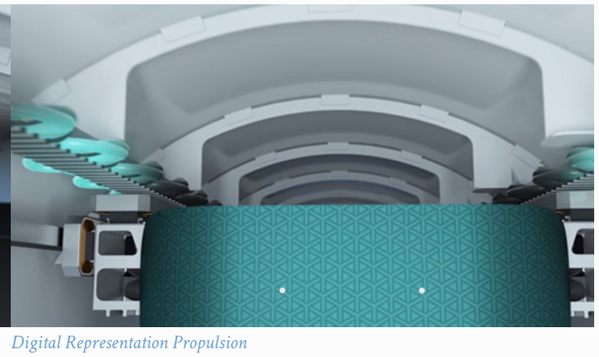
Representation Switch Lane

Representation Switch Lane

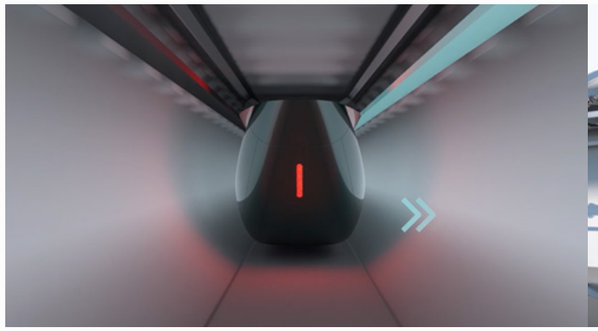
Appendix E



Digital Representation Magnetic Levitation



Digital Representation Propulsion



Digital Representation SWITCH

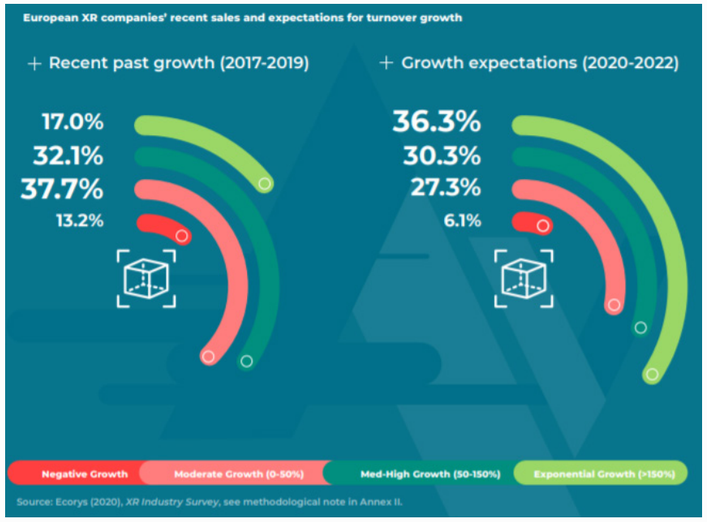
Digital Representation Vacuum

Appendix F

COVID-19 has created the perfect conditions for XR to have a positive impact. The demand for virtual meetings and remote collaboration is increasing due to travel restrictions. Therefore, companies offering remote maintenance with the use of AR have seen a dramatic increase of the use of their services, and companies that had an XR service before the pandemic, now have seen that their products are becoming more popular than expected. The pandemic is affecting people's behavior, and these changes might continue after the crisis. It is important to know and consider these changes in people's behavior in order to adapt to consumer's needs and to the new reality.

The growing European XR Industry

The European XR industry has demonstrated resilience during the COVID-19 pandemic. Given its potential to provide solutions to several issues caused by this crisis and despite a short-term slowdown, its growth rates are expected to increase and eventually surpass the pre-COVID-19 estimates. The European XR industry is expected to reach between €35 billion and €65 billion by 2025, representing a gross added value of between €20 billion and €40 billion, and directly creating employment for up to 860,000 people.



European XR estimated growth (Ecorys, 2021)

1.A Globally expanding XR Industry and Market.

The use of XR applications for companies is making the industry grow in the last few years. We can see this due to availability in XR products, and also the growing demand in XR solutions from companies interested in digitalising part of their processes. Nowadays, companies are starting to realize the benefits in terms of time and money saved by immersive technologies, especially in industrial, business and educational purposes. Even though there is a growth in the business side, XR is also growing for personal uses such as gaming and entertainment, which has been the main investment since the beginning. Sustainability is also something to take into account when considering XR solutions, reducing our footprint with remote collaboration and a considerable reduction in the use of materials and resources, for instance, in prototyping.

2. Solutions offered by XR applications

After the COVID-19 pandemic, the economy has been seriously affected and companies have had to accelerate their digital transformation. The XR market might be more resilient than other sectors in the economy and there are several reasons that prove so. The XR industry has provided solutions quickly and in a short-term. In fact, its growth rates are expected to increase and surpasse the pre-COVID-19 estimations. According to Ecorys (2021), the European XR industry is expected to reach between €35 billion and €65 billion by 2025, representing a gross added value of between €20 billion and €40 billion, and directly creating employment for up to 860,000 people. E.g. Audi, DHL, Airbus, etc. society with regards to generic digital skills, increasing the pool of potential buyers and consumers of XR content.

There is also an increased demand for remote and digital products for private and professional consumption. The XR industry has provided solutions and alternatives to this demand, and very likely, most of the changes imposed after the pandemic (working remotely, virtual meeting, etc.) will remain after the pandemic, so the XR industry has a great potential in the near future.

3. Political priorities and policies

Digitalisation is a trend that is affecting organisations, authorities and people's lifestyle. Therefore, the European Commission (EC) has carried out a new plan that supports both digital transformation and sustainability of industries and companies, called The European Green Deal. 'A Europe fit for the digital age' is the political priority of the EC.

The digitalisation of working processes has the potential to make European companies more competitive and open to new markets. New Technologies (NNTT) are controlling the economy, and authorities know it, and they want to support the companies that use these NNTT. Therefore, we can see that policy initiatives or financial opportunities regarding this domain are more frequent, and also it is important to mention the creation of a legislative framework regarding NNTT, which is essential to ensure good practices of NNTT.

Figure 23: European XR estimated growth (Ecorys, 2021)

XR is environmentally friendly

The XR industry has positive effects when it comes to environmental sustainability for several reasons. One of them is that if activities are done remotely, the use of material and the amount of resources are reduced. If activities are done remotely, there is not a need for travelling, and therefore CO2 emissions from the transport sector, which is one with the highest CO2 emissions, are lower. It is important to mention that the transport sector is responsible for one third of all emissions in the EU (Ecorys, 2021).

The European Union has put in practice the European Green Deal for the period 2019-2024. The main objective of this plan is to transform European economy and generate sustainable advantages for Europe (Ecorys, 2021). The aim is to reduce the carbon footprint, promote the circular economy, reduce emissions, and be carbon neutral.

By using both AR and VR, organisations can contribute to less CO2 emissions, and therefore, be supporting the Green Deal. In fact, the EU supports all the companies that are eco-friendly and work on digitalisation. XR might be a direct tool to decrease the environmental footprint (Ecorys, 2021).

4.3.1 Interactive Visualizations

As we have seen during the project, there is a big potential in interactive visualization when it comes to involving users in a process of decision making. Interactive Visualization is a technology that enables data exploration thanks to the manipulation of chart images, color, brightness, size, shape, and motion of visual objects (Definition of Interactive Visualization - Gartner Information Technology Glossary, n.d.). Thanks to programming, we can set an array of options that will enable users to analyze data by interacting with a visual representation of it. (Definition of Interactive Visualization - Gartner Information Technology Glossary, n.d.)

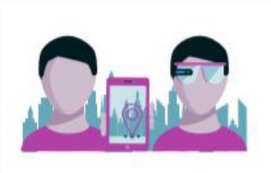
Interactive visualizations have been around for some time already. They were commonly used in video games, and now, thanks to the graphics improvement, we can start finding applications in different areas where high-quality visuals can determine useful information for professionals.

These interactive visualizations or games are developed with Game Engines. A game engine is the core software that allows a game program to run properly(). When we are developing a game, we are developing an interactive visualization. Within Game Engine, we can find a game renderer, which is the one rendering 2D or 3D images. Game renderers work in real-time, not like offline render engines like V-ray or Keyshot. This is because Game Engines make use of the graphics processing unit (GPU), and it has evolved recently a lot. However, Keyshot or V-Ray creates stunning visuals by using the CPU, which takes more time. We are now in a moment where it is difficult to differentiate a render from CPU and one from GPU, especially if the users seeing the visuals are not used to working with visualizations. Therefore, we could consider the use of Render Engines, like Keyshot, a waste of time, especially when we have the skills to use GPU renderings, like Blender, Unity or Unreal Engine 4, both based on motion capture. For a still image, a CPU render can take 8 hours, whereas a Game Engine can take 0.1s. This difference in a still image is huge, but considering that this way of rendering is also used for high-quality videos, **a 3 minutes video can take up to 37 days, whereas real-time rendering can be dropped to only 10 minutes.** (Mirko, 2020).

Figure 23: Comparison between CPU (Most 3D renders) and Real-time rendering (Unity) (Mirko, 2020)

Interactive visualizations have been used for a long time, not only PC but also in Extended Reality (XR). It is important to mention that Interactivity is a key element. Extended reality includes Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). These technologies work with Head-mounted displays (connected to a PC or standalone) and smartphones. Head-mounted displays that are connected to a PC have more computing power, whereas standalone devices allow the user to move freely without wires. On the other hand, we have several use cases of Augmented Reality with the smartphone, such as the famous Pokemon! Go. VR is easy to recognize because once you have put on the Headset the whole environment is digital. However, there is still an ongoing debate trying to differentiate AR from MR.

Virtual Reality (VR):



Augmented Reality (AR):

Mixed Reality (MR):

SWOT Analysis

Strengths

A maturing XR industry with strong software and content creation

A creative culture with high innovation potential

A well-distributed ecosystem with several regional hubs focusing on different application areas.

Europe's leading role in several industries and service sectors where XR demand is trending upwards.

GDPR: a state-of-the-art regulatory framework on data privacy and a leading position setting global stadards for regulating the digital economy.

Weaknesses

Lack of private funding opportunities for XR innovation, in particular risk funding.

Lack of indigenous "big players", i.e. hardware manufacturers.

Scattered approach of XR development.

Lack of entrepreneur mentality in European landscape and of a solvency framework enabling risk-taking.

Opportunities

Old working structures deteriorating due to COVID-19

Favourable policy agenda focusing on digitalisation and greening of the European economy.

Europe's focus on green economy and the untapped potential of XR for sustainability.

Threats

Lack of skilled workforce.

Economic slowdown due to the COVID-19 crisis.

Social acceptance of new technologies linked to the privacy, safety and security concerns.

4.3.2 Remote Collaborations

Once I have seen the positive impact of interactive visualizations compared to traditional visualizations, I decided to research remote collaborations due to the gap found in the matrix of physical and virtual meetings with engagement. As it was recognized, current solutions for virtual meetings can be led to misunderstandings, isolation, and conflicts among individual team members (Bosch-Sijtsema & Haapamäki, 2014), and XR solutions have been very resilient to the pandemic that has increased the demand for remote collaborations through VR (Ecorys, 2021).

Virtual Environments for remote collaboration

As we have seen previously in the section regarding trends related to COVID-19, there is a burnout with the current solutions of remote collaboration. In the SWOT analysis from Ecorys (2021), it is mentioned XR solutions are considered an opportunity because old working structures are being deteriorated due to COVID-19.

In order to work through Virtual Environments, collaboration among parties involved (Virtual Teams) is very important. Virtual teams acquire knowledge by collaboration (through employees, for instance). There are other factors that make virtual teams a reality, like building social relationships, team identity and trust. Bosch-Sijtsema & Haapamaki (2014) confirm that on Virtual Environments (VE) interactivity and engagement support virtual teams, by creating an atmosphere in which the parties involved can collaborate, share and develop knowledge together. We can see that collaboration maximizes the work if tasks and knowledge are well distributed (Badke-Schaub et al., 2007), especially when it comes to creating virtual environments for remote collaboration.

Remote collaboration has the advantage of saving time and costs. Using collaborative augmented reality review sessions, people can be easily connected in different environments, and they all can comment on the same thing at the same time. This not only increases cross-department understanding but also saves a substantial amount of time – in addition to the money that would otherwise be spent on travel costs. (Epic Games, 2020). According to Jurgen Riegel: "Reducing travel costs and removing barriers to fast problem-solving with 3D data is a big time and cost saver," (Epic Games, 2021).

As we can see in the Gartner Hype Cycle from Ecorys (2021), Virtual Reality is now on the slope of enlightenment. We cannot see VR headsets impacting a critical amount of users, so a solution with a PC would be more feasible, as Hardt provided to me. Otherwise, a barrier between Hardt and the stakeholders might be created, if the stakeholders do not have the proper hardware. However, VR is expected to become a great opportunity as a communication tool, so we should consider having a transition from the devices that we have, such as PC and smartphones, to XR devices.

Unreal Engine 4 Collab Viewer Template vs VR Apps

What it does not have (But others do)?

	Change Environment	Sticky Notes	Import Images	Import Videos	Animations
Spatial	✓	✓	✓	✓	✗
Gravity Sketch	✓	✓	✓	✓	✗
MeetinVR	✗	✓	✓	✓	✗
Unity Toolkit	✓	✓	✓	✓	✓
Tvori	✓	✓	✓	✗	✓

Unreal Engine 4 Collab Viewer Template vs VR Apps

What does it have?

	3D Sketching	Measure	Save Session	Viewpoints	Snapshots	X-Ray Material	High Resolution	Cross-Platform
Spatial	✓	✗	✓	✗	✓	✗	✗	✓
Gravity Sketch	✓	✓	✓	✓	✓	✓	✗	✗
MeetinVR	✓	✗	✗	✗	✗	✗	✗	✗
Unity Toolkit	✓	✓	✗	✓	✓	✓	✓	✗
Tvori	✓	✗	✓	✗	✗	✓	✗	✗

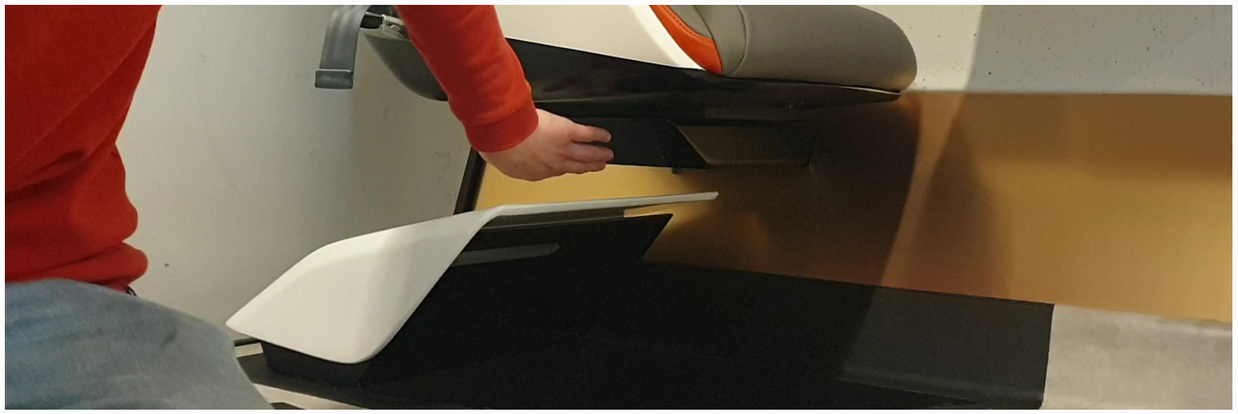
Costs of the Cabin-1

During the design and development of the Cabin-1, as we studied before in the research phase, the 3D shape form validation was done with 3D printing. According to J. Sanchez (2021), the most expensive part of Cabin-1 was the chair due to the development of a mold from scratch. Thanks to the partnership with Recaro, Hardt was provided with an existing mold that would be the starting point of the chair design, significantly reducing the costs. 3D printing was the way to validate the shape and ergonomics of the design. The Design team used the service of Shapeways to 3D print the headrest, the armrests, and the luggage compartment with a total cost of 4300 €. This was the only physical iteration that was done to validate the design in real scale. In case Hardt wanted to do more iterations, that would mean more time needed to print a new piece, more time for logistics (until the piece arrived at Hardt facilities), plus the assembly provided by Recaro, which is done in their Headquarters.

Design Workflow with Interactive Visualizations

With Interactive Visualizations we can have a better spatial understanding due to its 3D visualizations with both VR and PC solutions (Bowman & McMahan, 2007). With interactivity, people will understand by themselves the knowledge that others want to share with them when they have their own autonomy in the virtual environment (Jackson & Fagan, 2000). According to Varjo (2021), **virtual and mixed reality also makes sharing a design with non-designers much easier**, enabling key stakeholders to become involved way **earlier in the design process**. With this technology, a designer can provide a better understanding to an engineer of how an assembly must be done, being able to explore it from different angles before making a decision. Varjo (2021) is certain about the fact that 60%-70% of the total cost is determined by the conceptual design. Before VR simulators, design validations were typically done very late in the project (Varjo, 2021). This means that with Virtual Reality, costs can be reduced, whereas the time for decision-making can increase, improving creative and conceptual decisions. A fast and flexible sketching phase means you can catch more manufacturing errors and ergonomics issues earlier, when both, manufacturing errors and ergonomics issues, are still easy and inexpensive to fix (Varjo, 2021).

Explanation of how it was manufactured



Interactive Visualization in Transport Industry

Siemens

With the use of interactive visualizations, there are several companies which are looking to involve the customers in the design process.

Siemens mobility, in 2018, was already using interactive visualizations to engage future customers in the design process of the trains that were developed. With a tablet and some goggles, Siemens was able to have discussions with people about the different alternatives.
Müslüm Yakisan, Director Commuter & Regional Trains at Siemens AG, says that customers can design the compartments within their expectations, , and he believes that with virtual reality Siemens can ease these choices.

With Virtual Reality, Siemens could change arrangements and directly show it to the customer (Michael Kammler,2018). With this medium, compared to a presentation, siemens was able to provide fully flexible and interactive content.

Siemens does not consider virtual reality just a sales tool (Müslüm Yakisan,2018), **but to design, manufacture, deliver, and offer a better product.**

Figure 31: Virtual meeting using a virtual environment with Spatial

Figure 32: Virtual meeting using a virtual environment with Spatial

Figure 33: Virtual meeting using a virtual environment with Spatial

Figure 34: Virtual meeting using a virtual environment with Spatial

Volvo

Volvo, together with Varjo, a finnish company specialized in Virtual Reality and Mixed Reality headsets have done a collaboration to create a collaborative experience of a Volvo car configurator. People will be able to choose which car they want to purchase through a VR headset. This strategy can provide Volvo to have authorized dealers in the city centre, in smaller offices reducing costs of the company and having more visibility in places where there are more pedestrians and people passing by. Many authorized dealers are away from the city centre, disconnected from the customers. Customers have to go to those places on purpose, right now they only have simple online configurators as a second option.

Volvo has also released an online configurator where people can interact with the new model of XC40. This configurator does not need any installation, it is supported by Furioos, a web plugin for visualizing Virtual Environments. Volvo is pushing the automotive industry into the use of real-time rendering applications to reach new customers through different platforms.

Interactive Visualization in Hyperloop

Zeleros

Zeleros did a partnership together with the students of the master's in design with Virtual Reality from the IED Barcelona. The intention was to involve students in the representation of their concept station, working on the passenger experience, for the thesis of several students. It was developed with Unity and the HMD used was the Oculus Rift.

Juan Vicen, Co-Founder and CMO (Chief Marketing Officer) at Zeleros Hyperloop, the Hyperloop startup based in Valencia said: "We think that Hyperloop is a system that will be used by the society, but we were very focus on the technology aspect, but we think it is also important to focus on the design perspective."

Figure 35: Zeleros station concept in Virtual Reality

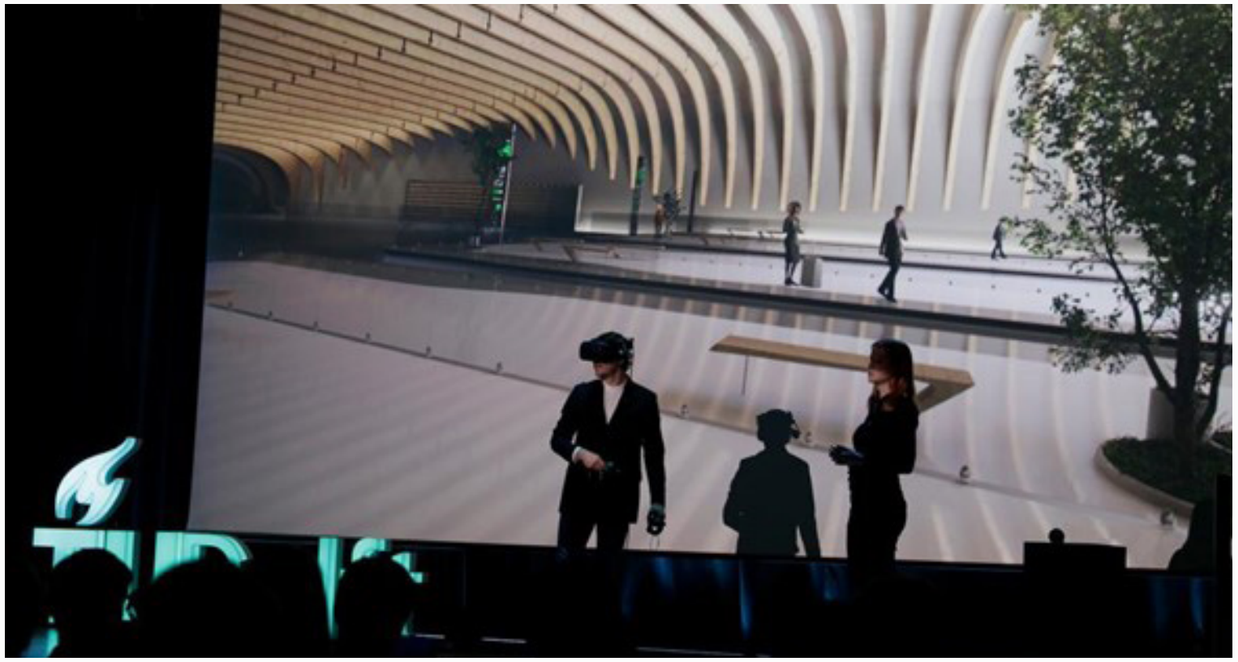


Figure 36: Visualization of the Passenger Experience from Delft Hyperloop Team with Virtual Reality

Delft Hyperloop

Delft Hyperloop, one of the most important Dream Teams TUDelft has, developed together with Altspace, a Computer Generated-Imagery (CGI) design studio, their vision of the Passenger Experience they conceptualise, showcasing their envisioned station. Similarly to what Zeleros did, this Virtual Experience was showcased in the Dutch Design Week during October 2019. Due to the VR setup, I do not think many people have seen this environment through the HMD since corona crisis. From the environment, they also had the output of video, which was uploaded to Youtube, demonstrating the versatility of game engines again.

Appendix K

Hardt Virtual Tour of the Facilities

(Engineer – Stakeholder)

The conversation would happen between an Implementation or Technology Stakeholder, and an Engineer from the company. Back in time, a way to show the tangibility of our projects it was the showcase of our different prototypes, such as the Low-Speed Test Facility. An Engineer would conduct in the past a tour through out the different systems and subsystems the prototype had, demonstrating our proof of technology. This has been done during the last year to engage with the investors proving we can build up the products that we envision and explaining the current roadmap that the company has in its mind. Hardt considers this tour to be honest outside the company, putting everybody to the ground saying at what stage of the project we are. The problem is that coronavirus has tackled this key factor that Hardt has, showing the first test facility from Europe.

Use Case:

The Engineer is going to present the stakeholders a virtual tour of the Low-Speed Test Facility.

Actor:

- Engineer
- Stakeholders

Flow:

1. Engineer conducts a virtual tour from the facility. Engineer prepares the server to share the URL for letting them connect to the App. (Prerequisite)
2. Both join the environment, Engineer as a Host and Stakeholder as a Guest.
3. The app starts by showing a video of the overall facility, so the guest can have a clear overview of what he or she is going to see.
4. Both Host and Guest grab a helmet for virtual safety. Like this the Guest can check that interactivity works.
5. Guest can press a button to open the pipe once everybody has a helmet. Button will not appear unless both have it.
6. The Engineer will explain each part with body language. The Engineer requires a VR Headset. Body language has proven to be key during explanations in the real facility.
7. The guest will have the ability to turn on the maglev.
8. Animation happens.
9. Engineer explains magic point.
10. Engineer can move all users to the next preset view.
11. Engineer explains the switch lane.
12. Stakeholder turns off the left lateral magnet.
13. Stakeholder turns on the propulsion system.
14. Stakeholder activates the brake the system. Alternative is that smashes against the security system at the end of the pipe.
15. Engineer moves users to Vacuum view.
16. Engineer explains vacuum.
17. Tour finishes.

Hardt – PostNL Collaboration

(Business - Stakeholder)

Speak about the different configurations of loading-unloading the product can have inside the Hub.
This case in particular gives accessibility to High Quality Viz to Business Developers without asking any designer.

Use Case: Post NL will have a virtual walkthrough of a digital warehouse, together with a market developer. They will check how goods are transported in the warehouse during the whole process.

Actors:
- Market Developer
- Post NL - Implementation Stakeholder

Flow:
1. Market Developer starts running the server and shares the URL to Post NL
2. They both start the app.
3. It goes inside the warehouse the camera and gives a big picture of the autonomous hub.
4. Post NL can choose between which configuration he wants to speak about.
5. Post NL stakeholder press button to move to the next view.
6. Post NL sees the loading of the product.
7. Post NL can choose from a different loading system. Changes Self Driving Vehicle too.
8. Presses next view.
9. Post NL can change Airlock.
10. Finishes the Tour.

Cargo Different Configurations

Hardt Cabin-1 Experience Prototype

(Designer – Stakeholders - Engineer)

There are different members in the development of this prototype. From an internal perspective, an engineer, a designer, and a design-marketing employee. From an external communication, we have stakeholders from Recaro, which are specialized in design, ergonomics and manufacturing of chairs, Continental with material providers for the infotainment panel and leather from the seats, and Accenture Interactive creating visual content for the infotainment panel and animations for the sky environment. 4 different configurations of cases can happen with this product.

Use Case 1: Feedback session between Engineer and Designer.

Participants:
- Engineer
- Product Designer

Flow:
1. Product Designer sets up the Server to share the URL with the engineer.
2. Both join the session for the multiplayer.
3. Both Move around the design to validate that structurally is feasible.
4. Both check quality of the design. Finding issues What You See is What You Get.
5. Engineer measures distances to check ergonomics.
6. Product Designer explains assembly to Engineer through steps.
7. Only the interesting parts of the assembly are not in X-Ray material to identify central attributes.
8. Engineer uses digital pointer to represent view of interest. Highlights the specific part he wants to speak about.
9. Product Designer can move parts and place it in another place if he wants to speak about something or if it is annoying the discussion.
10. Engineer leaves a floating Comment to give feedback.
11. Product Designer saves the level so he can have access to the discussion later.

Use Case 2: Design Review of Leather options from Continental. Color Study.

Participants:
- Product Designer
- Project Manager
- Continental Stakeholder

Flow:
1. Designer sets server with Project Manager and Continental Stakeholder
2. They all log in in the virtual environment.
3. Select the seat and configurator of materials appear.
4. Choose desirable Color in one seat.
5. Select the other seat and materials appear.

6. Select another color so both can be compared at the same time.
7. Select Infotainment
8. Colors appear.
9. User chooses a desirable color.
10. Changes to other color if he likes. (Alternative Flow)
11. Takes Snapshot of the Environment.
12. Saves Environment.

Use Case 3: Validate different options of Sky and Infotainment panels through video display virtually.

Participants:
- Product Designer
- Accenture Interactive

Flow:
1. Setup the server and share the URL.
2. Join the Session.
3. Select the Infotainment.
4. Press play to start the video.
5. Press Next Button to check a different design of interface.
6. Select TV from the top.
7. Press Next Button to change to another Skylight video.
8. Discuss different options verbally.
9. Leave notes.
10. Save Level.
11. Log Out.

Use Case 4: Design Review of the Chair for manufacturing

Participants:
- Product Designer
- Recaro Stakeholder

Flow:
1. Product Designer sets up the server and shares the URL.
2. Both join the session.
3. Designer selects different Design of the chair.
4. Recaro Stakeholder leaves note about manufacturing feedback related to the design.
5. Designer 3D sketches on top of the Design to communicate variations.
6. Recaro Stakeholder takes snapshot with the information about the session.
7. Both Log Out.

Appendix L

SCAMPER Method

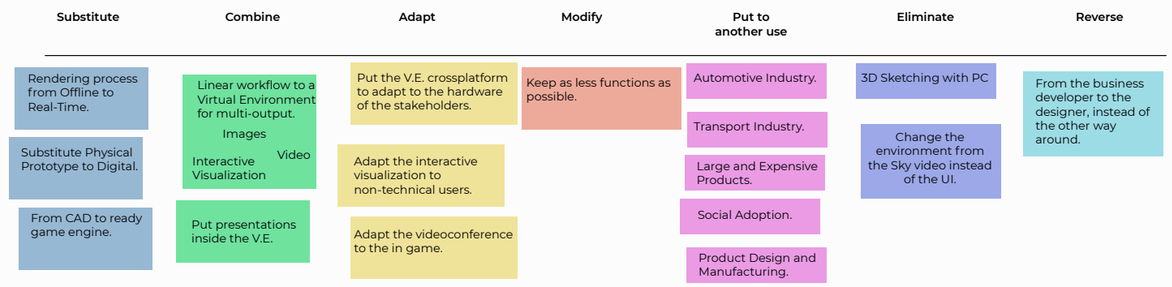
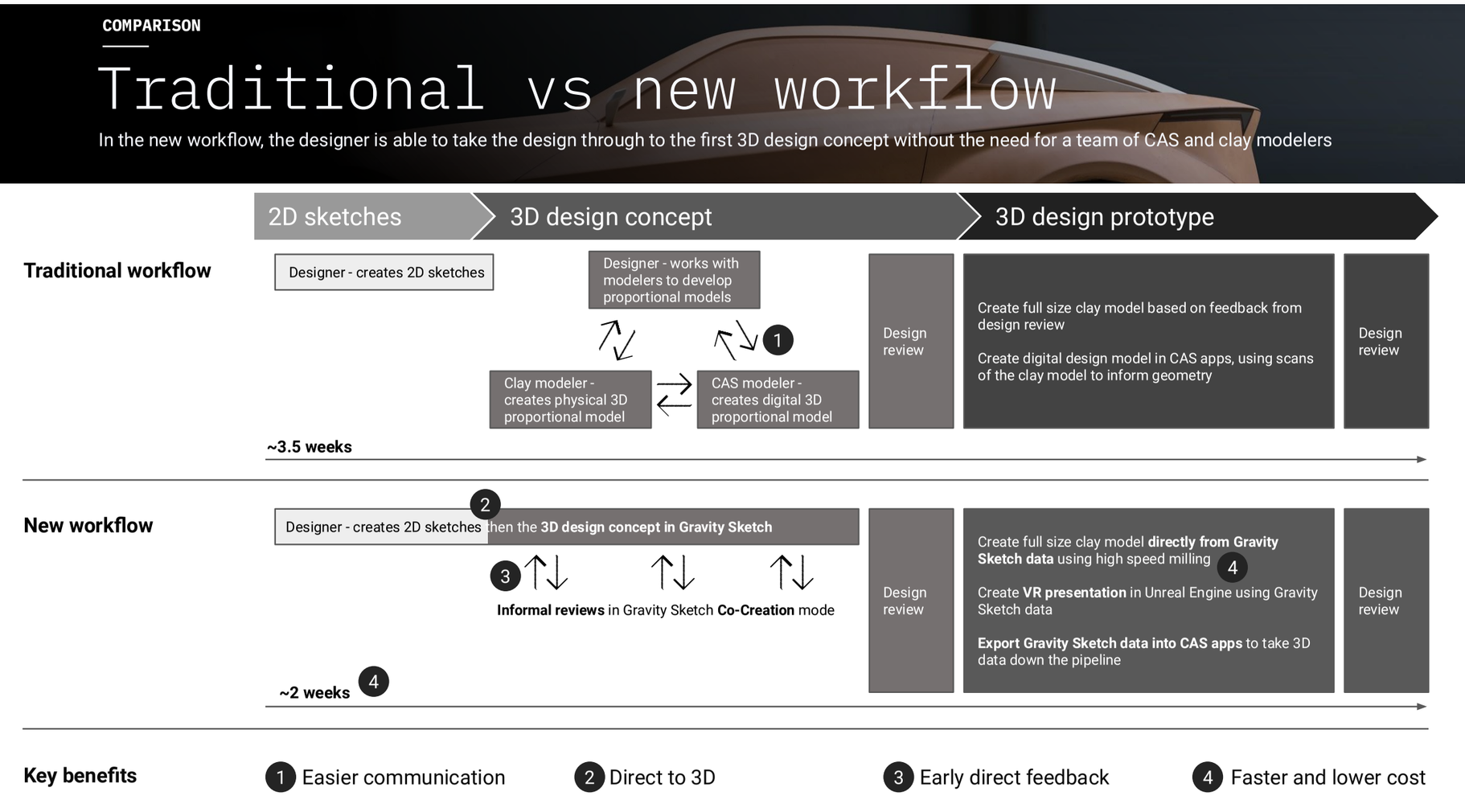


Figure 23: SCAMPER Method

Appendix M



Appendix N

Hardt´s Prototypes

Hardt works on very important projects which require several steps and precision. One of the most important steps in the onboarding process is the presentation of prototypes to the stakeholders. As stakeholders are based all over the world, the idea is to bring stakeholders to Buccaneer (Delft) in order to avoid product's transportation, which might be very difficult and expensive. Therefore, showcased projects are essential to get investors within the ecosystem, and here it is where Hardt makes great efforts. Presentation of prototypes and stakeholders' visits to the office are very important for this company.

Some of the most showcased projects are Magnetic Levitation prototypes, the Low-Speed Test Facility (LSTF), and Cabin-1 from the passenger experience concept.

Low-Speed Test Facility (LSTF) and (PLD)

The LSTF is a prototype created to verify the technology of the switch lane. This pipe prototype on real scale is in Delft campus and shows the integration of the magnetic levitation and propulsion acquired in the PLD prototype together with the switch lane technology to change from one rail to another without any required mechanical system and in a low-pressure environment.

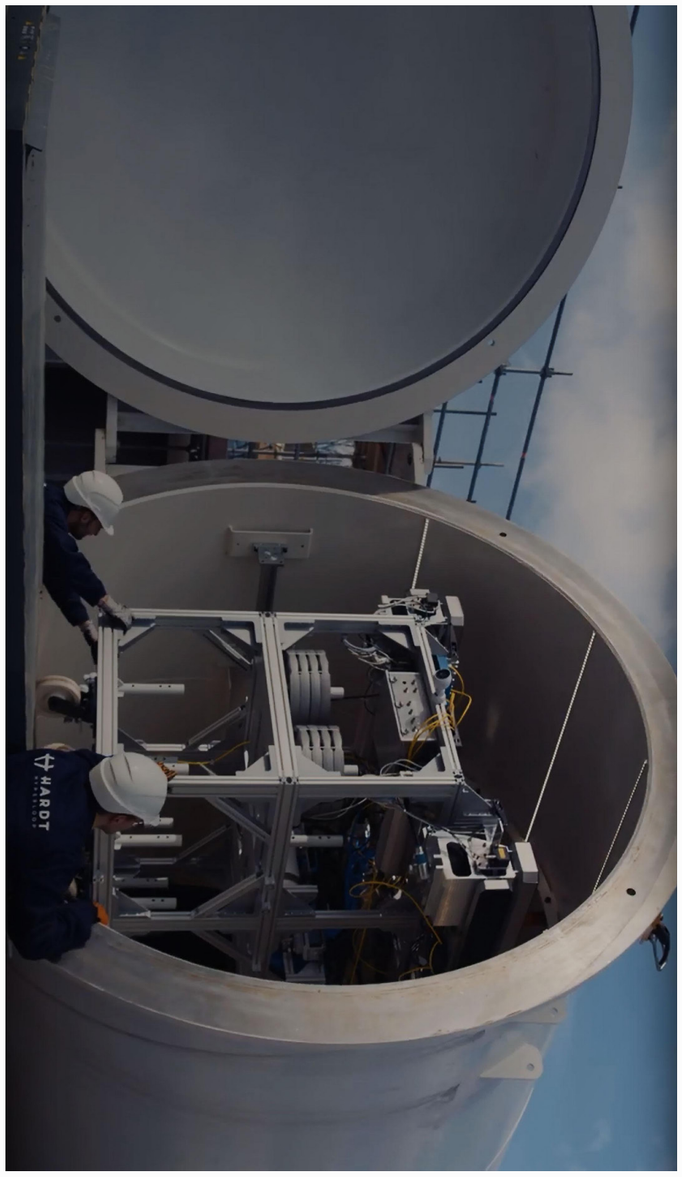


Figure 8: Low-Speed Test Facility - Property of Hardt Hyperloop

Cabin-1

The Cabin-1 is a fully functional life-size segment of the hyperloop interior vehicle. This Prototype was part of the Public Adoption program of the company in collaboration with Accenture Interactive, Recaro, and Continental. The main objective was to tell people a storyline and show them what the hyperloop is and at what stage we were in terms of conceptualizing the passenger experience.

Cabin-1 is both a physical and a digital prototype. By using Augmented Reality and Hololens 2, people are able to experience by themselves the mode of transportation once the physical experience stops. Extended Reality makes it possible for the story to continue digitally.

Figure 9: Cabin-1 Physical Prototype - Property of Hardt Hyperloop

Appendix O

QUESI Questionnaire

		Fully disagree	Mainly disagree	Neutral	Mainly agree	Fully agree
1	I could use the system without thinking about it.	❍	❍	❍	❍	❍
2	I achieved what I wanted to achieve with the system.	❍	❍	❍	❍	❍
3	The way the system worked was immediately clear to me.	❍	❍	❍	❍	❍
4	I could interact with the system in a way that seemed familiar to me.	❍	❍	❍	❍	❍
5	No problems occurred when I used the system.	❍	❍	❍	❍	❍
6	The system was not complicated to use.	❍	❍	❍	❍	❍
7	I was able to achieve my goals in the way I had imagined to.	❍	❍	❍	❍	❍
8	The system was easy to use from the start.	❍	❍	❍	❍	❍
9	It was always clear to me what I had to do to use the system.	❍	❍	❍	❍	❍
10	The process of using the system went smoothly.	❍	❍	❍	❍	❍
11	I barely had to concentrate on using the system.	❍	❍	❍	❍	❍
12	The system helped me to completely achieve my goals.	❍	❍	❍	❍	❍
13	How the system is used was clear to me straight away.	❍	❍	❍	❍	❍
14	I automatically did the right thing to achieve my goals.	❍	❍	❍	❍	❍

Appendix P

Qualitative RITE Questionaire

1. Did you feel like you were able to understand the design?
Why/Why not?

2. Did you feel like you were able to decide on your own about the designs?
Why/Why not?

3. Did you miss any functions?
Which one and why?

4. Do you think some of the functions were not useful?
Why/Why not?

5. Do you think any functions were confusing?
If yes, what and why?

6. Did you feel stressed using the platform?
Why/Why not?

Participant 1

1. Yes

2. Yes, but I had problems choosing them because I was not understanding the user Interface

3. No, but I was missing information for choosing

4. I was feeling lost by only reading chair

5. Snapshot was ok, But the one from the chair I still do not get.

6. Latency and I could not move the camera. Once I could use the mouse, I was not able to move the camera. (Info about Right Button)

Additional Comments:

Right Button to move the camera, and the Chair Button must be clearer. More visible.
When both Players are online, the computer is not powerful enough.
One player with pixel streaming works smoothly.

Participant 2

1. Yes.

2. Yes

3. Yes. I would have liked more options regarding colours.

4. No

5. Yes. Sharing the screen was confusing. I was missing a cross to indicate how to close it, and I didnt like the location of the function, they should be all together. When it comes to the design of the chair, I was confused by the fact that the chair was always there, but I didn't know it was a tool or a clickable button. I would put all the functions down as icons, like in the Mac. They should all be together. (Maybe I should use the hover function)

6. I didn't have a mouse.
When there are two players, the latency was too low to make it usable.

Appendix Q

Concept Validation

1. What do you think about the Platform?

2. Do you understand what it does?

   Marca solo un óvalo.

   - Yes
   - No

3. Can you tell me what you can do in the Virtual Environment?

4. What do you think is the function that would be used the most?

5. Are you missing something?

6. What are your thoughts on the design of the User Interface?

7. What do you think about the number of features?

8. Is there any feature that you completely ignored?

   Marca solo un óvalo.

   - Yes
   - No

9. If yes, which one?

10. Was anything distracting you?

    Marca solo un óvalo.

    - Yes
    - No

11. If yes, what?

12. When exploring the product, were you confused at any time?

Marca solo un óvalo.

- Yes
- No

13. If yes, when?

14. What is the first thing you would like to do on this platform?

15. Would you use this product?

Marca solo un óvalo.

	1	2	3	4	5	6	7	
No								Yes

16. Do you feel like you participated in the development of the virtual prototype that you could see?

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Did not participate								Participated

17. Obstructive - Supportive

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Obstructive								Supportive

18. Complicated - Easy

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Complicated								Easy

19. Inefficient - Efficient

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Inefficient								Efficient

20. Confusing - Clear

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Confusing	◯	◯	◯	◯	◯	◯	◯	Clear

21. Boring - Exciting

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Boring	◯	◯	◯	◯	◯	◯	◯	Exciting

22. Not interesting - Interesting

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Not interesting	◯	◯	◯	◯	◯	◯	◯	Interesting

23. Conventional - Inventive

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Conventional	◯	◯	◯	◯	◯	◯	◯	Inventive

24. Usual - Leading Edge

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Usual	◯	◯	◯	◯	◯	◯	◯	Leading Edge

25. Did you understand the prototype that was inside the platform? (CABIN-1)

Marca solo un óvalo.

- ◯ Yes
- ◯ No

26. Were you feeling comfortable communicating with the designer?

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Uncomfortable	◯	◯	◯	◯	◯	◯	◯	Comfortable

27. If you were able to change something, what would you change?

28. Do you feel like this platform was designed for people like you?

Marca solo un óvalo.

- Yes
- No

29. What would make you use this product frequently?

30. Would you recommend this platform to other colleagues?

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Disagree								Agree

31. Could you tell me 3 words to describe this platform?

RESULTS

1.What do you think about the Platform?

1. Useful
2. Fun to see!
3. Epic
4. it worked fast ont he phone and looked very scifi
5. The platform looks to be a great tool for design reviews that provides a natural way to present or give feedback on mechanical designs
6. Very helpful

2.Do you understand what it does?

1. Yes
2. Yes
3. Yes
4. Yes
5. Yes
6. Yes

3.Can you tell me what you can do in the Virtual Environment?

1. Change between designs, concepts. Explore the environment. Detailed viewing and easy to explore.
2. look around with multiple users
3. Check concepts in detail. Do it with a team mate to make sure that we are on the same page. Cycle through different parts. Cycle through design alternatives, explain concepts to different stakeholders. Check eploded assemblies
4. Show case new designs of the product team to everyone
5. Visualize a mechanical design in 3D while easily navigating the space. This can be done with multiple people to explain a design, visualize its sub elements, change certain features, etc.
6. Getting un understanding of the designed object, get a good idea of a physical object, before being built, and discover which different designs match best.

4.What do you think is the function that would be used the most?

1. Try different concepts for integration.
2. the design changing options are great
3. Cycle through different alternatives. Exploded view for engineering.
4. showcaseing and the exploded view
5. Visualizing mutiple alternatives of a design
6. Design, materials and colors and how they relate to each other in the overall context.

5. Are you missing something?
1. Identification of concepts (selections).
2. the whiteboard/post it function would be handy
3. Change the environment lighting. Also would be nice to have different quality settings. Improved multiplayer performance, polished UI.
4. improved pointer tool
5. An info button that shows the specifications of different parts
6. Objects (3d person for example) you can put next to it as a reference frame and a tool to check the size.

6. What are your thoughts on the design of the User Interface?
1. Add how to exit the mouse at the starting tutorial.
2. I like it, would be nice if it was a little brighter
3. It's basic, but excellent for proof of concept.
4. clear interface, selecting chairs is a bit unclear
5. Simple and intuitive
6. basic, understandable but could be a little more sleek.

7. What do you think about the number of features?
1. I think it is okay for a general view.
2. good
3. Very good, although the accessibility could be better.
4. environment change function is missing
5. Not too many, not too little
6. basic and therefore right now limited

8. Is there any feature that you completely ignored?
1. No
2. No
3. No
4. No
5. No
6. Yes

9.If yes, which one?
1.
2.
3.
4. **I wouldnt know**
5.
6. **explanation thing**

10. Was anything distracting you?
1. No
2. Yes
3. No
4. Yes
5. No
6. No

11. If yes, what?
1.
2. the lagging but that hopefully can be fixed
3.
4. the internet connection was very poor on my side, which meant that the VE was lagging
5.
6.

12. When exploring the product, were you confused at any time?
1. No
2. No
3. Yes
4. Yes
5. No
6. Yes

13. If yes, when?
1.
2.
3. A bit when using the functions prompted by the space bar. For example, clickin on a function and then having to click execute is redundant.
4. because of the lagging the camera view was hard, if the pre select view options would be more clear I could retrieve the view faster.
5.
6. when it delayed and there was a lot of noise.

14. What is the first thing you would like to do on this platform?
1. check the space between legs when two persons are seated
2. think it would be a nice addition for the website
3. Bring investors and external parties for alignment.
4. see moving vehicle would look like, eg it taking a switch, booster section
5. Technical product reviews
6. Load a design concept and check how it looks in a 3D context.

15. Would you use this product?
1. 6
2. 7
3. 6
4. 6
5. 7
6. 7

16. Do you feel like you participated in the development of the virtual prototype that you could see?
1. 5
2. 6
3. 7
4. 6
5. 7
6. 6

17. Obstructive - Supportive
1. 5
2.
3. 7
4. 5
5. 7
6. 6

18. Complicated - Easy
1. 7
2. 7
3. 5
4. 5
5. 7
6. 6

19. Inefficient - Efficient
1. 6
2. 7
3. 5
4. 6
5. 7
6. 6

20. Confusing - Clear
1. 5
2. 7
3. 5
4. 6
5. 7
6. 6

21. Boring - Exciting
1. 7
2. 5
3. 6
4. 7
5. 7
6. 6

22. Not interesting - Interesting
1. 6
2. 7
3. 6
4. 6
5. 7
6. 6

23. Conventional - Inventive
1. 7
2. 7
3. 6
4. 6
5. 7
6. 6

24. Usual - Leading Edge
1. 6
2. 5
3. 6
4. 6
5. 7
6. 6

25. Did you understand the prototype that was inside the platform? (CABIN-1)
1. Yes
2. Yes
3. Yes
4. Yes
5. Yes
6. Yes

26. Were you feeling comfortable communicating with the designer?
1. 5
2. 7
3. 7
4. 6
5. 7
6. 6

27. If you were able to change something, what would you change?
1. Is will be great to move objects
2. n/a
3. Overall optimization and polishin of UI. Multiplayer performance.
4. lighting/environment
5. I would make the components clickable with an info button about specs
6. Nothing right now

28. Do you feel like this platform was designed for people like you?
1. Yes
2. Yes
3. Yes
4. Yes
5. Yes
6. Yes

29. What would make you use this product frequently?
1. The fact that stakeholders can show me their progress always in the same environment and not through screenshots in a ppt presentation.
2. probably not, but i can imagine that if it was integrated into the website it would be
3. If it is implemented efficiently in a server it would be used frequently.
4. that adjustments can be made quickly
5. Occationaly, during design reviews
6. If designers can load in their concepts at a reasonable pace then we can work towards narrowing down the design idea early on in the project and that is very welcome.

Would you recommend this platform to other colleagues?
1. 6
2. 6
3. 6
4. 6
5. 7
6. 6

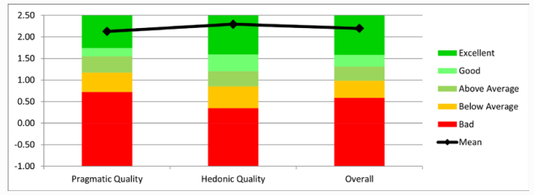
31. Could you tell me 3 words to describe this platform?
1. Innovative, Insightful, Collaborative
2. interactive, interesting, useful
3. Collaborative. Useful. Engaging.
4. exciting, new, clear
5. Collaborative, easy to use, informative
6. Clarifying, useful, insightful

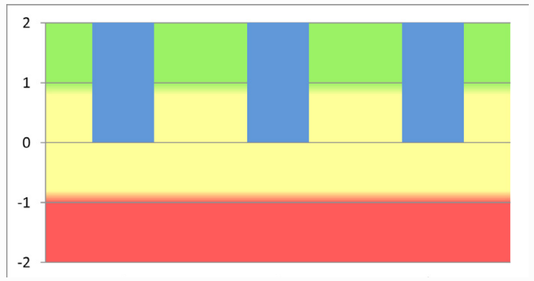
Appendix R

RESULTS Short UEQ

Item	Mean	Variance	Std. Dev.	No.	Negative	Positive	Scale
1	2.0	1.0	1.0	5	obstructive	supportive	Pragmatic Quality
2	2.2	1.0	1.0	6	complicated	easy	Pragmatic Quality
3	2.2	0.6	0.8	6	inefficient	efficient	Pragmatic Quality
4	2.0	0.8	0.9	6	confusing	clear	Pragmatic Quality
5	2.3	0.7	0.8	6	boring	exciting	Hedonic Quality
6	2.3	0.3	0.5	6	not interesting	interesting	Hedonic Quality
7	2.5	0.3	0.5	6	conventional	inventive	Hedonic Quality
8	2.0	0.4	0.6	6	usual	leading edge	Hedonic Quality

Short UEQ Scales	
Pragmatic Quality	2.125
Hedonic Quality	2.292
Overall	2.196





Pragmatic Quality	
Items	Correlation
1.2	0.00
1.3	0.00
1.4	0.30
2.3	0.77
2.4	0.45
3.4	0.89
Average	0.40
Alpha	0.73

Hedonic Quality	
Items	Correlation
5.6	-0.32
5.7	0.00
5.8	0.77
6.7	0.71
6.8	0.00
7.8	0.00
Average	0.19
Alpha	0.49