

# Metaverse-Based Demonstrators as an Alternative to Traditional Presentations: Case Fossil-Free Steelmaking Processes

UNIVERSITY OF TURKU  
Department of Computing  
Master of Science (Tech) Thesis  
Software Engineering  
June 2025  
Tommi Immonen

Supervisors:  
Teijo Lehtonen  
Seppo Helle

The originality of this thesis has been checked in accordance with the University of Turku quality assurance system using the Turnitin OriginalityCheck service.

UNIVERSITY OF TURKU

Department of Computing

TOMMI IMMONEN: Metaverse-Based Demonstrators as an Alternative to Traditional Presentations: Case Fossil-Free Steelmaking Processes

Master of Science (Tech) Thesis, 102 p., 6 app. p.

Software Engineering

June 2025

---

While the definition of a metaverse varies based on the source, all presented definitions generally refer to a similar idea: a virtual world in which users as avatars can interact with each other and the environment. The first metaverses were created already in the early 2000s, which has led to significant advancements in their development until the present day.

The latest generation of virtual reality devices has been in development for nearly a decade, because of which the technology is nowadays seen as a revolutionary technology capable of presenting deeply immersive content. Using these two technologies, immersive metaverse experiences capable of significantly improving the understanding received about the presented content can be achieved.

The advancements of both metaverse and virtual reality industries have enabled them to develop to a point in which virtual reality metaverses targeted for enterprise usage are feasible. Metaverses naturally enable two-way communication between the users, which is why they can be seen as an improvement over the current business-to-business (B2B) communication methods using only one-way communication methods, such as PDFs, pitches, and brochures.

This thesis aims to evaluate the feasibility of metaverses when used as an alternative to traditional presentation methods, which employ one-way communication and static content. In order to conduct the evaluation, a standalone metaverse experience using virtual reality is developed as a prototype, and then tested with user testing. The test users are linked with the maritime industry being either maritime professionals, or researchers working in the industry. The analysis of the test results clearly showed the suggested potential of enterprise-targeted metaverses in practice, highlighting their feasibility as an alternative presentation method. Based on the results, showcasing complex topics with immersive and gamified metaverse experiences using virtual reality devices can significantly help to make them more understandable and user-friendly. This correlates as a result to the upcoming fundamental transformation in B2B communication identified by earlier research.

Keywords: Virtual reality, Metaverse, Steelmaking, Marketing, Communication, Sustainability, Process visualization

# Contents

<b>List of Figures</b>	<b>iv</b>
<b>List of Tables</b>	<b>vi</b>
<b>List of Acronyms</b>	<b>vii</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Motivation . . . . .	1
1.2 The research need and SusFlow project . . . . .	2
1.3 Research questions . . . . .	3
1.4 Thesis structure . . . . .	4
<b>2 Maritime export organizations and B2B communication</b>	<b>6</b>
2.1 Historical development of Finnish export promotion . . . . .	6
2.2 Business Finland and Finnish export promotion nowadays . . . . .	9
2.3 Motivations for a change in B2B communication methods . . . . .	10
<b>3 Metaverse as a concept and metaverse platforms</b>	<b>13</b>
3.1 Multiple definitions of the metaverse . . . . .	13
3.2 Metaverse characteristics and their evaluation . . . . .	19

3.3	Platforms implementing the metaverse . . . . .	24
3.3.1	Different platform types . . . . .	24
3.3.2	A brief history of VR devices and metaverse platforms . . . . .	28
3.3.3	Metaverse platforms nowadays . . . . .	31
3.3.4	The customization levels . . . . .	36
<b>4</b>	<b>Analysis of potential metaverse platforms</b>	<b>40</b>
4.1	General requirements for the platform . . . . .	40
4.2	NVIDIA Omniverse . . . . .	41
4.3	Meta Horizon Workrooms . . . . .	43
4.4	Microsoft Mesh . . . . .	44
4.5	Selection of the implementation platform . . . . .	45
<b>5</b>	<b>Prototype design and implementation</b>	<b>47</b>
5.1	Designing the prototype . . . . .	47
5.1.1	Gathering the general design requirements . . . . .	47
5.1.2	Designing the prototype . . . . .	49
5.2	Implementing the prototype . . . . .	50
5.2.1	Selecting the scripting method . . . . .	51
5.2.2	Models of the process components and their placements . . . . .	53
5.2.3	Script organization and functionalities . . . . .	59
5.2.4	Building and uploading a custom project for end devices . . . . .	67
<b>6</b>	<b>User feedback survey and testing results</b>	<b>72</b>
6.1	Test environment and survey description . . . . .	72
6.2	Test results . . . . .	74

6.2.1	Survey answers . . . . .	74
6.2.2	Observed results . . . . .	85
<b>7</b>	<b>Discussion and future research</b>	<b>87</b>
7.1	Addressing the ideas and suggestions from the test sessions . . . . .	87
7.2	Possible issues from the usage of Mesh . . . . .	90
7.3	Future research . . . . .	91
<b>8</b>	<b>Conclusion</b>	<b>94</b>
	<b>References</b>	<b>103</b>
	<b>Appendices</b>	
<b>A</b>	<b>User feedback survey questions</b>	<b>A-1</b>

# List of Figures

3.1	Metaverse category types: main categories. . . . .	25
3.2	Metaverse category types: subcategories. . . . .	26
3.3	Examples of current entertainment metaverse platforms. . . . .	34
3.4	Examples of current enterprise metaverse platforms. . . . .	35
4.1	An example of a meeting inside Meta Horizon Workrooms. Image from <a href="http://www.meta.com">www.meta.com</a> . . . . .	44
5.1	The default script nodes of Mesh Visual Scripting. . . . .	51
5.2	The native Cloud Scripting GameObject, and the default C# func- tions for Cloud Scripting. . . . .	52
5.3	A comparison of the traditional and fossil-free steelmaking processes used in the case. Image from <a href="http://www.hybritdevelopment.se">www.hybritdevelopment.se</a> . . . . .	54
5.4	Creating the steelmaking models in Blender. . . . .	56
5.5	A meetup with the expert inside the experience. . . . .	57
5.6	A simplified 2D diagram of the fossil-free process. . . . .	58
5.7	An example of what the outline lighting could have looked like. . . . .	60
5.8	Side-to-side preview of the unlit and lit states of different components. . . . .	61
5.9	An example of the buttons controlling the experience flow. . . . .	62

5.10	An example of a phase in the traditional Blast Furnace process. . . . .	63
5.11	An example of the molecule catching game logic implemented with Cloud Scripting. . . . .	64
5.12	A part of the molecule catching game logic implemented with Mesh Visual Scripting. . . . .	65
5.13	A player catching CO <sub>2</sub> molecules during the emission phase. . . . .	66
5.14	An overview of the build and upload process for a Mesh project. . . . .	68
5.15	Details required by the Mesh Environments tool when creating an environment. . . . .	69
5.16	Building details required by the Mesh Environments tool after cre- ating the environment. . . . .	70
5.17	A published and visible event in the Mesh application for Windows. . . . .	71
6.1	The division of tester professions based the survey answers. . . . .	74
6.2	The amount of previous VR usage among the testers. . . . .	75
6.3	Tester answers to the usability-related statements presented. . . . .	75
6.4	Tester answers to the sustainability-related statements presented. . . . .	78
6.5	The presentation methods given as options and their resulted rank- ing in the eighth survey question. . . . .	80
6.6	The ranking differences based on answerer background in the eighth survey question. . . . .	81
6.7	How relevant the testers thought metaverses would be for their or- ganizations. . . . .	82
6.8	How the experience testers felt about their organization using Mi- crosoft Mesh or some other metaverse. . . . .	83

# List of Tables

3.1	Identified definitions for the metaverse . . . . .	17
3.2	The metaverse characteristics under evaluation . . . . .	19
3.3	Categories for the metaverse characteristic evaluation . . . . .	21
3.4	Levels of customization freedom for avatars and environment assets.	36
5.1	A list of the needed 3D models for the steelmaking processes. . . . .	55
6.1	A list of the general themes among the received improvement suggestions to the fifth survey question. . . . .	77
6.2	A list of the general themes among the communication suggestions received to the seventh survey question. . . . .	79
6.3	A list of the general themes among the benefits and issues answered to the seventh survey question. . . . .	84

# List of acronyms

- 3D** Three-dimensional
- AI** Artificial intelligence
- API** Application programming interface
- B2B** Business-to-business
- BF** Blast furnace
- BOF** Basic oxygen furnace
- DRS** Direct reduction shaft
- EAF** Electric arc furnace
- GPU** Graphics processing unit
- HMD** Head-mounted display
- MR** Mixed reality
- PaaS** Platform-as-a-Service
- PDF** Portable document format

**RAM** Random access memory

**SaaS** Software-as-a-Service

**SDK** Software development kit

**VR** Virtual reality

**XR** Extended reality

# 1 Introduction

## 1.1 Motivation

A metaverse is a virtual world in which users can interact with each other and the environment [1]. In these virtual worlds, the users interact with each other and the environment as avatars, which can usually be customized to a certain degree. Over the past 20 years, metaverses in general have developed significantly. Before the successful launch of the first commercially viable virtual reality (VR) headset in 2012 known as Oculus Rift [2], metaverses were only accessible through computers and mobile devices, and the major platforms were only meant for entertainment purposes. One of the first major metaverses, Second Life which was released in 2003 [3], brought the idea of having a virtual world where multiple users can interact with each other and the environment to life. When Second Life caught interest globally among both consumer users and businesses and gained a huge amount of popularity, it took only three years for *Roblox* to follow with their own metaverse implementation in 2006 [4]. Three years after *Roblox*, another mainstream platform in the current world, *Minecraft* entered the competition [5]. Although the necessary multiplayer capabilities of *Minecraft* launched permanently a year after its initial launch [6], it acted as a pioneer next to *Roblox* in spreading the

knowledge about virtual worlds and metaverses among the mainstream audience. Thanks to the attention received by the platforms, another mainstream platform known as *Fortnite* was introduced some years later [7]. Nowadays, all of these four metaverses among others continue to entertain their users with hundreds of millions of monthly active users [8] [9] [10] [11].

Due to the early introduction of the aforementioned entertainment platforms, the industry has had the possibility to develop for many years to become more mature. Because of this and the technological advancements of VR headsets after Oculus Rift [12] [13] [14] [15] the industry is nowadays mature enough for enterprise usage. Major enterprises like NVIDIA, Microsoft and Siemens have already introduced their platforms targeting enterprise usage [16] [17] [18], and businesses are starting to establish presence within the platforms, creating a completely new way to reach their target audience. As an example, BMW will start to use metaverses in its production in 2025 [19]. The company will utilize digital twins, which are reusable, highly accurate digital counterparts of physical objects. Digital twins can support sustainability for example through assisting in process optimization, improving efficiency and reducing costs [20].

## 1.2 The research need and SusFlow project

As stated previously, the maturity of the VR and metaverse industries nowadays makes it possible for enterprises to explore the feasibility of integrating these technologies into their businesses. While some enterprises have already found the technologies to be suitable for their needs and even created new businesses around them, the area still needs more research for example within the maritime indus-

try. This thesis researches the feasibility of using the mentioned technologies for showcasing products of the maritime industry, especially those targeted for export. Specifically, the thesis researches the potential of using VR metaverses as a marketing and communication tool for sustainable solutions in business-to-business (B2B) trade fairs, instead of traditional methods such as slideshows, pitches and brochures. The research was conducted using a case study for a steelmaking company participating in a maritime research project. In the case study, the complex topic of steelmaking was used to demonstrate the advantages of a metaverse platform in a marketing context.

This thesis is conducted as part of the Sustainability through Information Flows (SusFlow) research project [21]. SusFlow researches the flow of sustainability information within the maritime industry and aims to improve it to increase overall sustainability. The project is carried out in collaboration with University of Turku, VTT Technical Research Centre of Finland and several other partner organizations within the maritime industry.

### 1.3 Research questions

Using the mentioned steelmaking case study, this thesis aims to answer the following research questions:

1. **Can enterprise-targeted metaverse platforms be perceived as commercially feasible nowadays?**
2. **What problems do metaverse platforms introduce in an enterprise context?**

3. **How easy and efficient it is to create content for and use the researched metaverse platforms, both as a developer and as a user?**
4. **Can metaverse platforms be used to gain added value compared to the existing B2B communication methods?**

## 1.4 Thesis structure

This thesis has three main parts: Chapters 1-3 introduce the necessary definitions and background information of VR, metaverses and relevant marketing solutions. More precisely, Chapter 1 first introduces motivations for the thesis, the research project under which the thesis was conducted, and the research questions that were formed to evaluate different metaverse platforms and the prototype implementation. Chapter 2 presents examples of Finnish export promotion organizations, going through key highlights of their history, after which it takes a look at the active organizations in the industry and the used solutions. In addition, Chapter 2 discusses the problems that are present with the traditional B2B sustainability communication methods. Chapter 3 then takes a deeper dive into metaverses, discussing metaverse as a concept, and platforms available for implementing metaverse experiences.

The second main part, consisting of Chapters 4 and 5, discusses the implemented prototype: the selection of the metaverse platform using which the prototype would be implemented, design and implementation of the prototype, and finally the results gathered through prototype testing. Specifically, Chapter 4 states the general requirements placed for the metaverse platform during the selection process, after which an analysis several potential platforms is presented.

Finally, based on the analysis, the selected platform is presented and justified. In Chapter 5, first the general design requirements are gathered based on the case study details, hardware limitations and the scenario in which the prototype would be used. Chapter 5 then continues to presenting a detailed design plan for the prototype. Finally, using the presented design requirements and the design plan, the prototype implementation is discussed in detail.

The last main part, consisting of Chapters 6-8, first introduces the user feedback survey designed for the prototype testing sessions in Chapter 6. The test environments in which the prototype was tested are also presented. In addition, Chapter 6 presents both the written survey answers received and the observed results, analyzing the written answers in detail. In Chapter 7, the ideas and suggestions received in Chapter 6 are covered, along with adding discussion around them and presenting ideas for future research. In addition, some potential issues that could arise from the use of the selected metaverse platform are presented. Finally, in Chapter 8 an overview and conclusion of the thesis is presented, along with answers to the research questions.

## **2 Maritime export organizations and B2B communication**

This chapter presents key highlights of the histories and current states of different maritime export organizations. In addition, the current state of B2B sustainability communication and motivations for a change are discussed. In terms of the export organizations, the chapter first presents historical highlights of Finnish export promotion by going through example organizations. After that, examples of Finnish export organizations active nowadays are presented, along with their solutions for export promotion.

### **2.1 Historical development of Finnish export promotion**

The first organization facilitating Finnish export promotion business was established in 1919, being known as the Finnish Export Association at the time. At first, it started with creating an international network of representatives and placing contact personnel into different parts of the world [22]. At first, the organization was only promoting the export of agricultural products, food products, and some

emerging industrial products, only targeting the Eastern Europe. In the 1930s, it started to promote additional categories, such as furniture, gifts and sports equipment, and changed its name to Finnish Foreign Trade Association (FFTA). The organization initially started to organize participation to exhibitions in the 1930s, but it had to interrupt them in 1939 due to wars. They were restarted in 1946, and because of the devaluation of 1957, general interest towards export grew significantly, resulting in several industries and companies starting to use exhibitions as a marketing tool. The optimism towards export grew even more when Finland became a member of the European Free Trade Association (EFTA), and corresponding customs benefits were given to the Soviet Union also [23]. In 1964, the FFTA decided to transform the separate exhibitions into a few major events that would be arranged yearly in selected market areas, which brought the FFTA new business areas and improved knowledge of the target areas [22]. In 1970, the Finnish government transferred its own export promotion activities to be centrally handled by the FFTA.

From the last decades of the 20th century until 2018, the FFTA continued to grow into a versatile export facilitator, organizing export activities for different industry sectors. During this time span in 1999, the FFTA also went through another name change, this time changing its name to Finpro [22]. In 2018, Finpro merged with the Finnish Funding Agency for Technology and Innovation (TEKES), forming Business Finland [24].

Another example of Finnish export promotion organizations is a cooperative called Viexpo. It was founded in 1970 as the first regional export promotion organization in Finland, and it still exists in the present day [25]. Viexpo is selected as an example because it focuses more on regional, hands-on support through

practical activities like trade fairs. In addition, Viexpo is mainly targeting small and medium-sized enterprises [26]. The establishment of Viexpo was a result of actively developing foreign country connections within Finland's economic sector, although the development focused strongly on the Helsinki metropolitan area. While in the beginning Viexpo only had 31 members, its regional activities began to grow fast because the foreign country connections to Sweden already had a good development pace due to two things: the expansion of the school of commercial training, and the beginning of ship traffic. The original idea with Viexpo was to build a permanent exhibition hall that would serve the industry of the area with export matters. This exhibition hall was opened in 1970, having about a hundred exhibition departments inside. In addition, Viexpo arranged contact trips to foreign exhibitions in London, Leningrad, Oslo and Stockholm during the 1970s.

In the 1980s, Viexpo raised its member count to 191 [25], which also led to the organization starting to publish its own info leaflet to achieve better information sharing. In 1990, Viexpo gained more interest in the eastern markets by moving its initial exhibition hall to new premises. As a result, after the fall of Union of Soviet Socialist Republics, the organization started to organize trips to for example Russia and the Baltic countries. In addition, the organization started new ways of operations: as companies had gathered a lot of important information about their markets during the trips of Viexpo, there was an export network which brought together several complementary companies to work together to gain access to a new target market. In the beginning of the 21st century, Viexpo turned its operations into field-specific sectors including several fields such as machine and metal, construction and furniture, and boat and vehicle industry [25]. This was due to the rapid market changes that had been present during the century.

## 2.2 Business Finland and Finnish export promotion nowadays

In 2018, Finpro and TEKES merged together, forming a new organization known as Business Finland. The object of the new organization was to make public business services more effective by providing companies with support in for example internationalization, innovation funding and foreign investment through one organization [27]. Since then, Business Finland has been actively practicing Finnish export promotion together with other organizations part of Team Finland - a network that brings all organizations offering public internationalisation together. Viexpo is also part of the same network [28], and the organization focuses on Scandinavia and Europe nowadays, providing Finnish organizations with possibilities to participate in international exhibitions. The most popular fields of Viexpo in the present day include forestry, construction, food and energy [25].

The export promotion practiced by Team Finland organizations relies on promotion materials published by different organizations of the industries - the maritime industry in the context of this thesis. This material is curated by several organizations including Business Finland and regional offices of economic development. Although the field has evolved throughout the years, the materials are still made of static content in a catalogue-type form, for example PDF files listing solutions offered by the companies [29] [30]. The materials for the catalogues are gathered occasionally from interested organizations by relevant members of Team Finland, and participating in the catalogues is free [31]. After the material is curated, the catalogues will be used by the global network of Business Finland, Team Finland and Finnish Embassies in different export promotion activities globally.

While the PDF versions of export promotion catalogues might be sufficient, more modern and innovative ways of showcasing the solutions are possible nowadays because of technological advancements. With the current catalogue form, it is very difficult to for example present sustainability, efficiency and cost savings opportunities in a user-friendly and visualized way. Especially when dealing with complex topics, showcasing the improvements provided by new solutions in a clear way can become difficult, because the information cannot be showed in pieces.

## **2.3 Motivations for a change in B2B communication methods**

Corporate sustainability communications can be divided into three different cases based on the communication goals: The public case where contributions to society are emphasized, the business case where internal sustainability management is emphasized, and the marketing case where communications are used to supplement marketing goals [32]. While the case in this thesis falls within the marketing case, these cases are not mutually exclusive. Societal and market demands for sustainable solutions can result in new processes that need to be understood by customers before they can be bought [33]. In addition, integrating sustainability communication into a business strategy can lead to collecting sustainability data regarding how the company operates. This data can later be repurposed as marketing material.

B2B trade fairs are marketing events that can reduce the cost of a sale by as much as 75 % [34]. Included in this cost is the dramatic reduction of the amount

of communication needed to close in on a deal. While the efficient communication that metaverse experiences can provide is desirable in any context, it can be especially fitting for trade fairs with their function of shortening communications within the limited time frame a visitor is at a booth. The typical ways of communicating with visitors at booths, personal conversations and displaying promotional material, can both easily be integrated into metaverse experiences.

Metaverse experiences naturally enable two-way communication, as they focus on multiple users interacting with each other and the environment. This process is something that current B2B communication methods, such as slideshows, pitches and brochures, are lacking according to earlier research [35] [36]. Focusing on the perspective of the visitor is a trend in current trade fair research [37]. The trade fair research also suggests utilizing an innovative trade fair strategy, which positively correlates with trade show performance. The usage of metaverse experiences at trade fairs could be considered as innovative, thus correlating with the suggestion.

While traditional methods, such as slideshows, pitches and brochures have established their position as the standard tools for B2B marketing and visualization, metaverse platforms targeting enterprise usage have the potential to make even complex processes more user-friendly and perceivable. For example, metaverses employing VR can give the user a feeling of being in another customizable virtual space, in which the marketed products could be inspected in more detail. The development of metaverse platforms has the potential to revolutionize the marketing and communication industry, and it is expected to do so in the future [38]. Industrial metaverse platforms and VR, among other related technologies, are expected to fundamentally change how businesses interact in both physical and virtual worlds, which will allow significantly more user-friendly and

immersive experiences based on complex processes [38] [39]. With the features of a well-equipped metaverse platform, the possibility to have custom 3D objects and logic enables organizations to produce detailed representations of the subject under demonstration. In addition, the user can have an expert with them in the same session, answering questions and giving more details. Applying this kind of approach in design reviews of cruise ship interiors has been previously experimented in [40].

# 3 Metaverse as a concept and metaverse platforms

This chapter first focuses on discussing metaverse as a concept, presenting several definitions that have been suggested for it. The chapter then continues to discuss characteristics that could be attached to the concept and their necessities. Finally, the chapter takes a look at practical metaverse implementations, first covering different platform types and key highlights of the histories of VR devices and metaverse platforms. After the histories, metaverse platforms active nowadays are presented, and finally how the active platforms could be categorized based on their customization possibilities.

## 3.1 Multiple definitions of the metaverse

It is important to note that metaverse is more of a broader concept than only one specific place providing functionalities that can be connected to the concept. Because of that, in this thesis the term *the metaverse* will be used to refer to the concept. As a study by Park and Kim [41] states, there is not only a single definition that can be connected to the concept, but instead multiple ones from different

years, some of which do not even explicitly mention the definition belonging to the metaverse. One of them originates from the science fiction novel *Snow Crash* by Neal Stephenson, released in 1992 [42], which is generally agreed to be the first definition for the term, as mentioned by Park and Kim. Instead of directly giving a definition for the metaverse in the book, Stephenson focuses on describing what the place is like, and directly calls it the metaverse. The book is set in the early 21st century [43], and it describes the concept with the following phrases:

*"A computer-generated universe that is drawn to shiny goggles wrapping halfway around the wearer's head. ... By drawing a slightly different image in front of each eye, the image can be made three-dimensional. By changing the image seventy-two times a second, it can be made to move. ... He is not seeing real people, of course. This is all a part of the moving illustration drawn by his computer according to specifications coming down the fiber-optic cable. The people are pieces of software called avatars. They are the audiovisual bodies that people use to communicate with each other in the Metaverse. ... Hiro's avatar is now on the Street, too, and if the couples coming off the monorail look over in his direction, they can see him, just as he's seeing them. They could strike up a conversation: Hiro in the U-Stor-It in L.A. and the four teenagers probably on a couch in a suburb of Chicago, each with their own laptop."*

The word itself is a combination of two things: an ancient Greek word "meta", which means beyond, across or after [44], and the suffix "verse" from the English word "universe" [45]. It has been since mentioned in numerous other places also,

with and without directly using the term itself. The Oxford English Dictionary [46] defines the term with the following:

*"A (hypothetical) virtual reality environment in which users interact with one another's avatars and their surroundings in an immersive way, sometimes posited as a potential extension of or replacement for the internet, World Wide Web, social media, etc."*

In a science fiction novel *Ready Player One* released by Ernest Cline in 2011, a place called *OASIS* exists, which the book describes as a *massively multiplayer online game*. The novel has been later adapted into a movie with the same name [47] that was released in 2018. In the movie adaptation, one of the characters describes *OASIS* with the following:

*"This is the Oasis. It's a place where the limits of reality are your own imagination. You can do anything, go anywhere. Like the Vacation Planet. Surf a 50-foot monster wave in Hawaii, you can ski down the Pyramids, you can climb Mount Everest with Batman. Check out this place. It's a casino the size of a planet! You can lose your money there, you can get married, you can get divorced, you can...you can go in there. People come to the Oasis for all the things they can do, but they stay because of all the things they can be: tall, beautiful, scary, a different sex, a different species, live action, cartoon, it's all your call. Yeah, that's me...well, that's my avatar, at least until I feel like changing it. Except for eating, sleeping and bathroom breaks, whatever people want to do, they do it in the Oasis. And since everyone is here, this is where we meet each other. This is where we make friends."*

A more realistic description from the 20th century is presented by Stanley G. Weinbaum in the book *Pygmalion's Spectacles* [48], which was originally published in 1935 [49]. In the book, one of the characters describes magical spectacles that could produce an experience like the following:

*"A movie that gives one sight and sound. Suppose now I add taste, smell, even touch, if your interest is taken by the story. Suppose I make it so that you are in the story, you speak to the shadows, and the shadows reply, and instead of being on a screen, the story is all about you, and you are in it."*

In the critically acclaimed and bestselling book [50] *The Metaverse: And How It Will Revolutionize Everything* [1] written by a former Amazon Studios executive Matthew Ball, the following definition is presented explicitly for the term:

*"A massively scaled and interoperable network of real-time rendered 3D virtual worlds and environments which can be experienced synchronously and persistently by an effectively unlimited number of users with an individual sense of presence, and with continuity of data, such as identity, history, entitlements, objects, communications, and payments."*

In addition, there are more dystopian-like definitions too that could be at least partially connected to the metaverse. For example, in the book *Neuromancer* published by William Gibson in 1997 [51], a term *cyberspace* is presented and defined with the following:

*"A consensual hallucination experienced daily by billions of legitimate operators, in every nation, by children being taught mathematical concepts . . . A graphic representation of data abstracted from the banks of every computer in the human system. Unthinkable complexity. Lines of light ranged in the non space of the mind, clusters and constellations of data. Like city lights, receding."*

From the presented texts, only the definitions from *Snow Crash*, Oxford English Dictionary and *The Metaverse: And How It Will Revolutionize Everything* explicitly mention the term and give it a definition, while the others talk about a concept that could be connected to a dystopia or a futuristic science fiction world also. Hence, we can use them as references of what the metaverse should generally be, and refer to them later in this thesis. To enable this, each of them will be given an ordinal number.

Table 3.1: Identified definitions for the metaverse

#	Definition	Appeared in
1	<i>"A (hypothetical) virtual reality environment in which users interact with one another's avatars and their surroundings in an immersive way, sometimes posited as a potential extension of or replacement for the internet, World Wide Web, social media, etc."</i>	<i>The Oxford English Language Dictionary</i>

Table 3.1: Identified definitions for the metaverse

Char- ac- ter- istic	Description	
2	<p><i>"A computer-generated universe that is drawn to shiny goggles wrapping halfway around the wearer's head. ... By drawing a slightly different image in front of each eye, the image can be made three-dimensional. By changing the image seventy-two times a second, it can be made to move." ... "He is not seeing real people, of course. This is all a part of the moving illustration drawn by his computer according to specifications coming down the fiber-optic cable. The people are pieces of software called avatars. They are the audiovisual bodies that people use to communicate with each other in the Metaverse." ... "Hiro's avatar is now on the Street, too, and if the couples coming off the monorail look over in his direction, they can see him, just as he's seeing them. They could strike up a conversation: Hiro in the U-Stor-It in L.A. and the four teenagers probably on a couch in a suburb of Chicago, each with their own laptop."</i></p>	<i>Snow Crash</i>
3	<p><i>"A massively scaled and interoperable network of real-time rendered 3D virtual worlds and environments which can be experienced synchronously and persistently by an effectively unlimited number of users with an individual sense of presence, and with continuity of data, such as identity, history, entitlements, objects, communications, and payments."</i></p>	<i>The Metaverse: And How It Will Revolutionize Everything</i>

## 3.2 Metaverse characteristics and their evaluation

Based on the metaverse definitions presented in Section 3.1, research done by Tommi Immonen, Eero Nirhamo, Taneli Nyysönen and Seppo Helle for the University of Turku, and several studies [45] [52] [53], we can form certain characteristics for the metaverse. These characteristics provide a way to evaluate different metaverse platforms against the concept, and they can be seen in Table 3.2.

Table 3.2: The metaverse characteristics under evaluation

Characteristic	Description
Synchronous and on-line	There can be multiple events and interactions occurring at the same time. It allows users from different physical locations to connect and interact with each other.
Real-time collaborative interaction	The users can interact with each other and the environment with as minimal latency as possible.
Individual presence and avatars	The users feel like they would actually be in the metaverse by themselves through immersion. The user can have an avatar in the world, and the other avatars and the environment can react to the behaviour of the user.
Three-dimensional (3D)	The environment and the users can be perceived as three-dimensional.
Virtual	The environment and the users do not physically exist in the same location, but instead are virtually brought together by different technologies like they would.

Table 3.2: The metaverse characteristics under evaluation

Characteristic	Description
Usage of advanced technologies	The metaverse platform leverages advanced technologies available to provide the users the best experience possible. These technologies can include for example blockchain, AI, VR and AR.
Scalable	The experience has support for a large amount of users at the same time, without sacrificing performance or increasing the latency compared to a smaller amount.
Cross-platform	The metaverse platform allows users to participate from different devices (e.g. VR headsets, computers and smartphones).
Economy	The metaverse platform offers a way for the players to purchase items directly from the developer, and/or to sell items that they have accumulated.
Persistent	When the users produce content or progress in a specific metaverse platform (e.g. gaining experience) to a different situation than what they began in, they can exit from it and enter again without losing the progress they have made. The produced content or progress they have gained does not require the user to be online in order to be available.
Interoperable	The users can use their avatars made for a specific metaverse platform in other metaverse platforms, or import their avatars from the other platforms. The specific platform also supports importing content produced and goods purchased in the others.

In addition, we can categorize the characteristics based on how mandatory they are to fulfill the concept. To achieve this, a three-step categorization will be used: *mandatory*, *important* and *optional*. Explanation for each category is shown in Table 3.3.

Table 3.3: Categories for the metaverse characteristic evaluation

Category	Description
Mandatory	These characteristics are directly derived from the definitions, and they can be thought of as must-have ones.
Important	These characteristics are recognized as important ones regarding the definitions, but the metaverse could potentially be accomplished without them also.
Optional	These characteristics are those that can be seen as complementary for the metaverse, but without which the metaverse can still be fully functional.

And finally, we can assign the presented characteristics into the categories, based on the category descriptions and literature.

### **Mandatory characteristics**

Some of the characteristics presented in Table 3.2 are directly or indirectly mentioned in all of the definitions presented in Table 3.1: synchronous and online, real-time collaborative interaction, individual presence and avatars, and virtual. All of them also appear on several lists of key characteristics for the metaverse [45] [52] [53], although not with the exact same terms. In addition, they are covered by the SPICE model proposed by Kim [54]. Because of this, the mentioned char-

acteristics can be seen as mandatory to fulfill some of the key requirements for the metaverse.

It is worth noting that while fulfilling a characteristic without a careful evaluation might be enough for the concept, it might not be enough for the actual users, depending how much they value the given characteristic in the experience. As an example, providing the possibility to have avatars but having no customization choices for them could lead to unpleasant experience for the users that place value and invest time in it [55] [56].

### **Important characteristics**

A metaverse does not necessarily need to be three-dimensional (3D), as for example *Terraria* [57] provides a metaverse experience happening completely in a two-dimensional virtual world. Thus, the three-dimensional characteristic is categorized as important, because many of the popular metaverses tend to be 3D, for example *Minecraft* and *Roblox*. When a metaverse platform has been established and the mandatory characteristics have been fulfilled, there needs to be some kind of an economy, whether it is developer-to-player or player-to-player or both, to keep the platform running especially if it is a commercial one. This is also mentioned in the form of payments in Definition 3 of Table 3.1. The economy could be based on a real-world currency so that people buy the goods available with e.g. euros or dollars directly, or the platform could have its own virtual currency which is used in transactions and bought with real money, like for example *World of Warcraft* [58], *Decentraland* [59] and *Roblox* [60] have been doing. When an economy is introduced into the platform, persistence becomes almost mandatory so that the users do not lose the goods they have bought upon exiting the platform.

In addition, if a a metaverse platform wants to become successful and grow itself in popularity, scalability becomes mandatory so that the experience does not suffer whether there is a small or large amount of users online on the platform.

### **Optional characteristics**

From the characteristics mentioned in Table 3.2, only cross-platform, usage of advanced technologies and interoperability are yet to be evaluated. The first one can be seen as an optional characteristic because a specific metaverse platform might want to target itself only to certain users, e.g. only those with a VR headset or a computer, to achieve the best possible experience. This is for example what World of Warcraft does, being available only for Windows and Mac [61]. Bringing the experience to more platforms could also require more resources, depending how flexible the development environment is. In terms of the advanced technologies, VR and blockchain are perhaps the most visible ones encountered. While neither of them are not de facto technologies that are used everywhere, a few popular choices implementing them have already been risen by the users [62] [63]. And with the relatively new AI interest across businesses, we might start to see that being integrated somehow also.

The last but not least to mention is interoperability. While this was highlighted among the key characteristics by some studies [52] [53] and in the Definition 3 of Table 3.1, in this thesis it will be evaluated as optional. This is because while in theory it could be important, achieving it currently between different vendors can be seen as hard due to for example the vendors' own preferences, and technical differences like 3D rendering engines and physics [64]. Still, there are attempts to standardize ways to achieve the interoperability, with for example the "Defining

and Building the Metaverse Initiative" launched by World Economic Forum in May 2022 [65], which produced a report highlighting the key opportunities and challenges for the topic [66]. Still, it is worth noting that interoperability could rise to the level of being a key characteristic if or when it starts getting more attention from the platform vendors.

### **3.3 Platforms implementing the metaverse**

#### **3.3.1 Different platform types**

Before diving into different platforms implementing the metaverse and their history, it is important to highlight that there can be major differences between platforms, depending on what use case the platform is designed for and how it is being marketed. The use cases can be divided into categories, which vary between different sources. Depending on the source the categories can include for example: gaming, social media, industrial, business, VR/AR/MR or Web2.0/3.0 [67] [68] [69] [70] [71].

The categorization presented next is based on the known notable platforms available during the time of writing, and it could change if more platforms from different categories become available and gain popularity. First, it is important to highlight that in this categorization, two different category types will be used: main and subcategories. This is because while on a detailed level there can be a variety of different categories like the aforementioned listing shows, most of the times they can be generalized into two main categories, which are entertainment and enterprise. They are shown in Figure 3.1. The reason for this naming convention

can be found from the subcategories both of these have, but before exploring them, the main categories will be briefly explained.

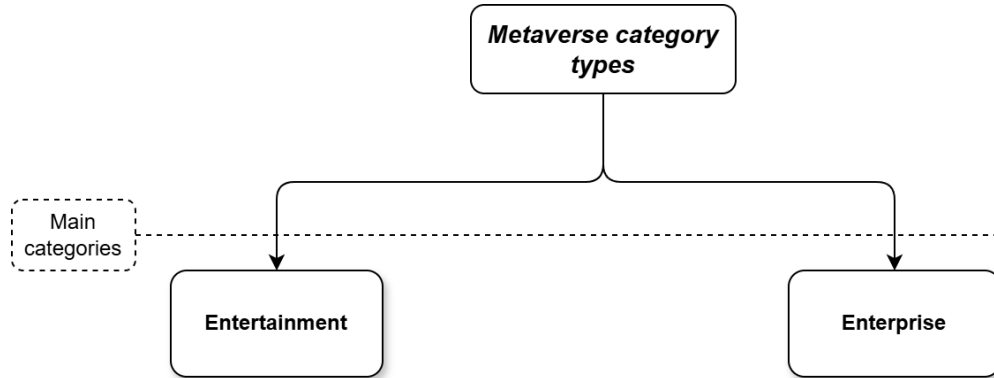


Figure 3.1: Metaverse category types: main categories.

Entertainment includes all platforms that are mainly focused on providing free time activities and content, such as multiplayer games or non-professional conversations. The enterprise category fills the other side, and it includes platforms that are focused on providing professional collaboration or industrial possibilities such as digital twins and heavy simulation. From these two main categories, platforms under the entertainment category are more focused on providing enjoyable and gamified multiplayer experiences which may be unrealistic sometimes. Platforms under the enterprise category on the other side focus more on bringing the surrounding real world into the experience and building on top of that. Not only does that make them seem more professional than the entertainment platforms, but it also helps supporting their needs and making them intuitive, like the mentioned digital twins and professional collaboration.

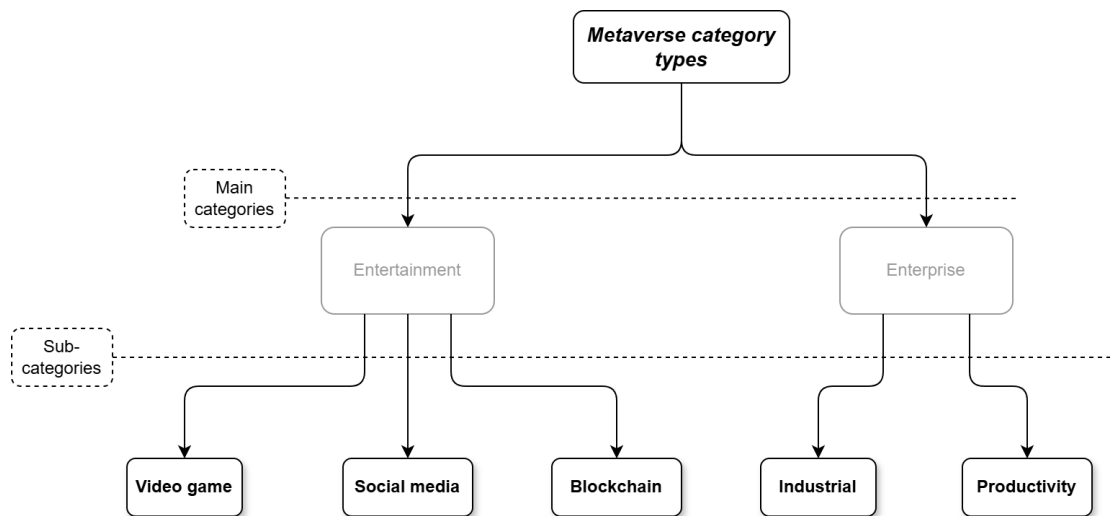


Figure 3.2: Metaverse category types: subcategories.

As can be seen, after introducing the main categories, more division can still be done. Hence, the need for subcategories arises. They are focused on enabling more detailed division within the categorization, allowing the categorization to match the advertised focus of different metaverse platforms better. The identified subcategories for entertainment are: video game, social media and blockchain. They can also be seen in Figure 3.2. From these, the video game subcategory includes platforms that are focused on either providing games or mini games for the users to play, or enabling the users to publish their own. The second mentioned, social media subcategory includes platforms that are focused on allowing people to communicate and share information like opinions, pictures or videos [72]. The final subcategory of entertainment, blockchain is relatively new, as the platforms incorporating such functionalities like blockchain economies and digital ownership through NFTs only started appearing after the launch of Axie Infinity in 2018 [73]. While in some sources the main category entertainment is called gaming, in this context it is not found suitable, as for example the social media subcategory would

not fit under it. In addition, because the video game subcategory fills the needs that the gaming category would require, a broader main category which includes them both and leaves space for others, too, if needed.

For enterprise platforms, the subcategories are industrial and productivity. They can also be seen in Figure 3.2. The industrial one includes platforms that are focused on simulation and production enhancement functionalities, like enabling digital twins. The productivity subcategory includes platforms which are focused on providing an additional layer on top of the current office environments or otherwise aiming to improve it, like enabling the users to have virtual monitors in addition to their physical ones or giving additional possibilities for presentations. This is where the name of the subcategory come from, as the platforms in it are aiming for increased productivity. Here also the subcategory industrial is seen as a main category in some sources, but in this context due to the fact that some purely industrial metaverse platforms may not enable or target enhanced productivity features, the need for a broader concept for including both of them and potentially more in the future arises.

It is still worth noting that these subcategories do not remove the potential minor overlapping between them, as the division it brings is focused on what a particular platform is mainly designed or marketed for. For example, video game platforms may still allow social media functionalities, or vice versa. Likewise, industrial platforms may allow productivity features, and vice versa. In addition, the categorization does not include some minor metaverse types that have been identified in different sources, like for example educational or healthcare [67] [68] as there currently is not enough notable platforms focusing on them to justify the highlight.

### 3.3.2 A brief history of VR devices and metaverse platforms

Entertainment metaverse platforms are nothing new, as they have been around for over two decades already, although not accessible through VR headsets from the start. One of the first ones, a platform focusing on social media functionalities called Second Life was launched by Linden Lab in 2003 [3]. Second Life acted as a pioneer in the field due to its success, gaining over a million regular users during its first year according to the book *The Metaverse: And How It Will Revolutionize Everything* [1]. This sparked up the idea for other organizations, including those in the Silicon Valley, making them think about partaking in the newly emerging field by establishing their own existence on the platform, or instead create their own metaverse platforms. Close to the launch of Second Life, a platform that focused on video game functionalities and is known still in the present day, *World of Warcraft* or WoW was launched [74]. WoW managed to enjoy the ongoing excitement also, as it broke day-one sales records in the U.S. back in 2004 by selling 240,000 units in one day [75], which made it the most successful PC game launch ever [76]. Even though Second Life was more of a social media platform rather than being targeted towards economic usage, Linden Lab did not manage it in a such way, providing for example a stock exchange on the platform in 2007.

During the success years of Second Life and *World of Warcraft*, other mainstream video game platforms known in the present day, *Minecraft* and *Roblox* were also launched [4]. These did not only have technical advancements compared to the platforms launched before them, but because they were directly targeting children and teenager users, they were easier to use and targeted a wider audience. Last

but not least of the blockbuster entertainment platforms to mention was launched in 2017, when Epic Games released *Fortnite* [1] which focuses on the video game subcategory. The release came only a year after the CEO Tim Sweeney had said a comment that can be seen as a possible real world scenario [77]:

*"This Metaverse is going to be far more pervasive and powerful than anything else. If one central company gains control of this, they will become more powerful than any government and be a god on Earth. What we want is not a company but a protocol, that anyone can implement."*

While the release of *Fortnite* might have happened late compared to the other platforms, it managed to surpass the active monthly player count of *Minecraft* already in September 2018, having almost 80 million users [78] [79].

VR devices only started to emerge about 10 years after the launch of Second Life. With the successful Kickstarter launch of the Oculus Rift VR headset by Palmer Luckey back in 2012, there was going to be a new type of device entering the market, and with that a new type of content to be created and consumed [2]. A couple years after the successful introduction of the Oculus Rift, Valve announced a feature in the beta client of Steam called SteamVR, supporting only head tracking in the Big Picture mode of Steam at the time. However, Valve teased that the feature would be more useful by the time when the commercial version of Oculus Rift or their own VR hardware gets released [80]. Almost colliding with the announcement by Valve, a VR experience with focus on interaction and communities called VRChat was released only two days later for the first development kit prototype of Oculus Rift, to be used through a Windows computer [81]. Later

during 2013, a VR company AltspaceVR announced an upcoming platform going with the same name [82]. In the next year, Facebook decided take advantage of the success story of Oculus by buying the company with \$2 billion dollars [83].

The positive attention Oculus received was noticed at Microsoft also, as it entered the VR headset competition by announcing the standalone HoloLens MR headset in 2015, showing people playing *Minecraft* or talking to their friends with it - although it was only available in the U.S. at first [84]. During the same year, AltspaceVR finally released its platform, which got praised for its ease of use and availability [85]. In addition, HTC released its first Vive MR headset in collaboration with Valve Corporation [86], and Facebook announced that it would be shipping the first Oculus Rift devices in Q1 2016 [87]. Despite the early success of AltspaceVR, the platform was quickly left in the shadow of the boundless open-source community creation possibilities offered by VRChat, which allowed it to become a popular platform for creating humorous content. In 2016, while AltspaceVR continued its downfall, a cross-platform VR experience RecRoom was launched with focus on activity and games [88]. In addition, a platform with focus on bringing television watching and cinema to VR called BigScreen was released [89] during the same year. In October 2016, Microsoft decided to broaden the availability of the HoloLens to a global reach by expanding its market area [12].

In February 2017, VRChat was released in early access on Steam, with a goal of letting everyone create and share their own virtual worlds, but more importantly letting the community be a part of and influence the development [90]. The Kronos Group also announced OpenXR as the name of its upcoming open standard for portable VR and AR applications and devices, inviting more partners to join and develop the standard further [91] [92]. In October, Microsoft announced

its decision to save AltspaceVR from its inevitable bankruptcy by buying the company with the intention of "building and expanding it as a leading social VR platform" [93] [94]. In 2018, the first entertainment metaverse platform integrating blockchain technologies, *Axie Infinity* was launched. The platform took advantage of the Ethereum blockchain which had been launched three years earlier, bringing knowledge about indisputable digital ownership certificates known as NFTs to a wider audience [73].

### 3.3.3 Metaverse platforms nowadays

When the COVID-19 pandemic arrived in early 2020, forcing people to spend more and more time online, the development pace had to rapidly increase. While entertainment metaverse platforms had already been known for a while, there was now an opportunity for the enterprise platforms also, as people started to work almost completely online. In 2021, the development outcomes started to become public. Microsoft announced its MR platform, Microsoft Mesh, enabling professional enterprise collaboration with high security requirements through Azure. The platform was announced to be available on two different platforms: as an application for the newest HoloLens 2 headset by Microsoft, and through AltspaceVR, accessible with Windows Mixed Reality headsets. In addition, Microsoft said that the platform would support OpenXR [17]. Only a month later, NVIDIA launched its Omniverse Enterprise platform, focusing on for example enabling production teams to collaborate on complex 3D projects, and creating simulations of digital twins that obey the laws of physics. The platform was said to be available on a subscription basis and that it would include enterprise support services provided

by NVIDIA [16].

In August 2021, Facebook announced its own productivity metaverse platform, known as *Horizon Workrooms* [95]. The platform was claimed to be built for controller-free use and having a pass-through mode that would utilize the surroundings of the user. At first, the service would launch in open beta, being available for free either through a video call on the web or through the Oculus Quest 2 headset [96]. Only two months later, perhaps the biggest turning point of the year occurred, as Facebook announced that it would be rebranding itself to Meta, originating from the word "metaverse". During the announcement, the CEO Mark Zuckerberg also emphasized how the company believes that "the metaverse will be the successor to the mobile internet, we'll be able to feel present - like we're right there with people no matter how far apart we actually are" [97]. In addition, Facebook announced rebranding its social VR platform *Facebook Horizon* - a platform that was actually launched already in early 2020 to a small group of users, but did not gain much popularity [98] - to *Horizon Worlds* [99]. According to the company, the investments in VR and AR work at Facebook Reality Labs Division would grow up to \$10 billion dollars in 2021 alone.

Siemens followed Microsoft, NVIDIA and Meta in June 2022 by launching its open digital business platform called Xcelerator, aimed at "accelerating digital transformation value creation for customers of all sizes in industry, buildings, grids and mobility". Siemens claimed that the platform would have a curated and modular portfolio of IoT-enabled hardware, along with launching a new Software-as-a-Service (SaaS) platform that would be part of Xcelerator. On top of that, Siemens announced that it would be not only partnering with companies like Accenture, AWS and Microsoft for an ecosystem of certified partners, but also connecting the

Omniverse platform to Xcelerator [18]. The last but not least platform to mention is VIVERSE for Business announced by HTC in May 2023 [100]. In the announcement, HTC claimed that VIVERSE for Business would be "an easy and intuitive way for organisations to build their collaborative virtual spaces". HTC had recognized the interest of organizations to hosting immersive spaces for their employees and customers, and supporting remote collaboration. Generally, according to HTC it had been challenging for organizations to find a place suitable for the interest, but with VIVERSE for Business, they could choose from pre-made building blocks which would enable easy and modular design.

In the present day, there are a number of different metaverse platforms in both main categories available. While there has not been any major releases after VIVERSE for Business, the number of available platforms can still be seen as sufficient. Examples of platforms categorized under the entertainment main category can be seen in Figure 3.3. In the video game subcategory, blockbuster hits such as *World of Warcraft*, *Minecraft* and *Fortnite* still keep giving enjoyable gaming experiences. In the social media side, platforms like Second Life, VRChat and Meta Horizon Worlds keep connecting people - although the last mentioned has been losing its popularity [101]. In the case of blockchain worlds, the current platforms are rather new. One of them is *Decentraland*, which although being marketed as an especially decentralized platform through its decision-making infrastructure DAO [102], did not manage to keep its popularity for long, as already in 2022 it was reported to have only 38 active users [103].

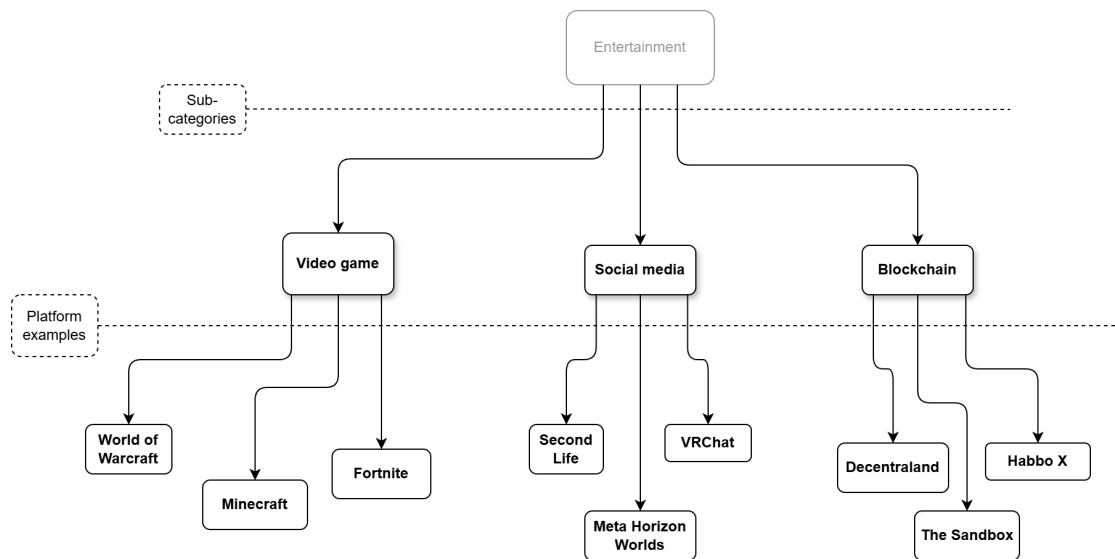


Figure 3.3: Examples of current entertainment metaverse platforms.

Another blockchain platform that did manage to gain a large playerbase despite its late launch in the industry [104] is *The Sandbox*, which was reported to have a monthly active user count of 50,000-100,000 [105]. A smaller but more interesting blockchain platform nowadays is *Habbo X*, released to a limited audience in December 2022 by a company called Sulake, the same one who launched *Habbo Hotel* back in 2000 [106]. In the end of 2021, they launched a limited NFT collection which portrayed normal Habbo avatars but with clothes that could not be obtainable from elsewhere, and later they started to build their blockchain ecosystem around this specific collection [107].

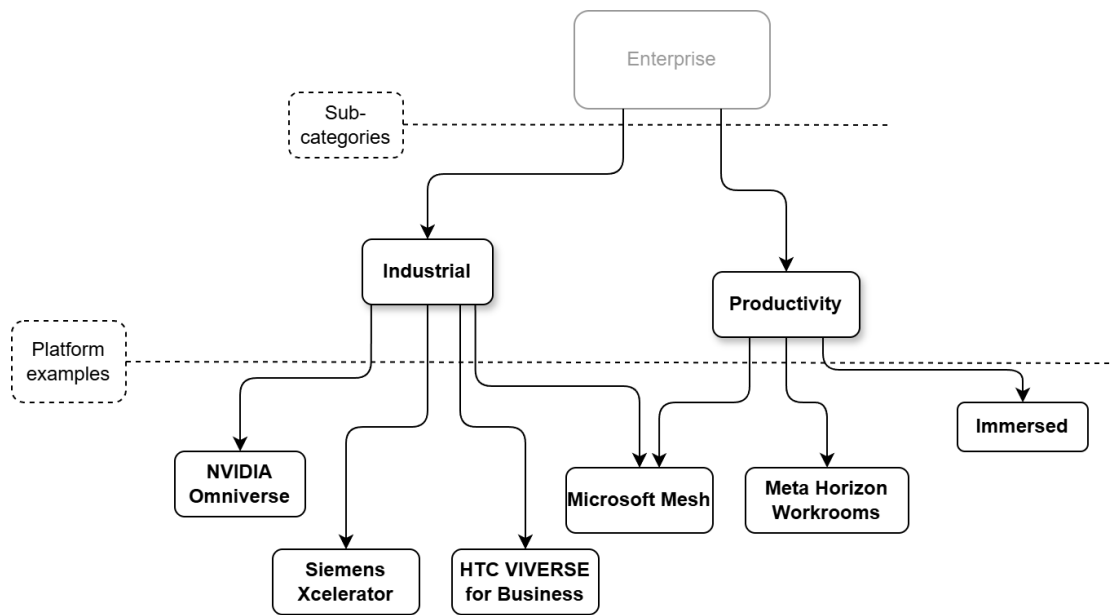


Figure 3.4: Examples of current enterprise metaverse platforms.

For enterprise users, Omniverse and Mesh are still among the major industrial platforms, joined with Xcelerator and VIVERSE for Business. The aforementioned four industrial examples, along with others categorized under the productivity subcategory, can be seen in Figure 3.4. The productivity subcategory has not received the same amount of attention yet though, as for example Horizon Workrooms was said to be "kind of fun, but only in small doses" by some companies that tested it [108]. However, in addition to the Mesh platform supporting industrial needs, it also enables productivity through for example its Teams integration, which might be one of the reasons why the platform has not been reviewed similar to Horizon Workrooms but as more of a enjoyable experience [109]. Microsoft has also been able to bring onboard a number of early adopters from different countries, who have been helping its development and are nowadays offering help in adopting the platform [110]. In addition to the large corporations, a smaller platform called

*Immersed* is also available for enhancing productivity. While Immersed may be somewhat unknown as a company compared to Microsoft and Meta, its platform has gained over 730,000 unique users before going public in the end of 2023 [111].

### 3.3.4 The customization levels

In addition to having the introduced main and subcategories for metaverse types, we also need a way to classify how much customization possibilities different platforms offer for avatars and environment. While there are many studies that focus on researching interaction on metaverse platforms, including concepts such as human-avatar and human-computer interaction, they do not present a way of classifying how much freedom a user has regarding the customization possibilities on a specific platform [112] [113] [114]. A study by Akin and Akin [115] explores a similar topic, researching factors that make users value assets on different platforms, and which factors attract user demand towards the platform. The study could end up facing a similar kind of need with further research, because as discussed in the study and in Section 3.2, more customization freedom tends to attract more user demand.

Table 3.4: Levels of customization freedom for avatars and environment assets.

Level	Avatar customization	Environment customization
0	<i>Can use built-in avatars but cannot edit them or their mechanics</i>	<i>Can use built-in environment assets but cannot edit them or their mechanics</i>

Table 3.4: Levels of customization freedom for avatars and environment assets.

<b>Level</b>	<b>Avatar customization</b>	<b>Environment customization</b>
1	<i>Can use built-in avatars and edit them audiovisually, cannot edit their mechanics</i>	<i>Can use built-in environment assets and edit them audiovisually, cannot edit their mechanics</i>
2	<i>Can use built-in avatars and edit them audiovisually, can edit their mechanics</i>	<i>Can use built-in environment assets and edit them, can edit their mechanics</i>
3	<i>Can use custom avatars</i>	<i>Can use custom audiovisual environment assets</i>
4	<i>Can fully customize avatars</i>	<i>Can fully customize environment assets</i>

Table 3.4 presents a way to classify customization possibilities on metaverse platforms with a five-level scale, separately covering the possibilities offered for avatars and environment assets. The separate coverage of both is needed, because some platforms are offering different customization possibilities for avatars and environment assets. For example, in Meta Horizon Worlds [116] [117], Microsoft Mesh [118] [119] and *Fortnite* [120] [121], the customization possibilities offered for avatar are at level 1, while the possibilities for environment assets can go up to level 4. It is important to note that the classification is viewed from the users' point-of-view, not including what the developers or admins of the platform can or cannot do. The classification shown in the table is developed by Tommi Immonen, Taneli Nyysönen and Eero Nirhamo as part of a research project for the University of Turku (UTU), and it is based on earlier research for UTU, conducted by Taneli

Nyysönen and Panagiotis Markopoulos. Before going through the various levels of the classification, there are some terms that need to be clarified regarding it. The ability to insert environment assets into the experience, so that the users can interact with them, is referred to as using the environment assets. The ability to make purely audiovisual changes to an avatar or environment asset is referred to as editing the avatar or environment asset. The actions caused by assets, which can be targeting avatars or other assets, are referred to as asset mechanics. Finally, changing the way the aforementioned mechanics behave is referred to as editing mechanics.

In the classification, level 0 refers to a bare minimum metaverse platform that fulfills the mandatory requirements for a metaverse platform discussed in Section 3.2. On a such platform, the users would be only able to use built-in avatars offered by the platform, without having the ability to edit them or their mechanics. Similarly, the users would only be able to use built-in environment assets offered by the platform, without the ability to edit them or their mechanics. An example of such a platform could be a custom-made metaverse platform as part of a study made by Nyysönen et al. [122]. In the study, an experiment was made on the platform in which there was one admin and two clients. While the capabilities offered for the admin exceeded the level 0 shown in the table for the experiment to be possible, the capabilities of the clients stayed within the level. In the study, the clients did not have any editing possibilities for their built-in avatars, resulting in them looking exactly same. Similarly, although the platform offered voice communication possibilities, their voice was altered to not reflect the users' real voice and they were not able to edit it.

In level 1 of the classification, in addition to being able to use the built-in

---

avatars and environment assets provided by platform, the users would also have the possibility to edit them audiovisually. In level 2, the users would be able to use and edit the built-in avatars and environment assets provided by the platform, including their mechanics. In level 3, in addition to being able to use built-in avatars and environment assets and edit them, the users could use custom avatars and custom audiovisual environment assets. This would allow them to create their own avatars and assets, and import them into the platform. In level 4, customization of used avatars and environment assets would be fully allowed, now including also creating custom mechanics with scripting tools to enhance the experience.

# 4 Analysis of potential metaverse platforms

This chapter will present an analysis of potential metaverse platforms that could be used to implement a prototype based on the given steelmaking case, which will be discussed in more detail in Chapter 5. First, the chapter presents the general requirements placed for the platform, and why covered platforms were selected as potential ones. After that, the three potential platforms are covered along with their suitability for the given steelmaking case. Finally, the chapter goes through which of the platforms was selected and why.

## 4.1 General requirements for the platform

As discussed in Section 1.1, because of the technological advancements of metaverse platforms and VR, it is nowadays possible to create marketing and B2B content with the possibility to have a significantly better result than with traditional slideshows. But in order for an enterprise to be interested about the possibility, the platform would need to be both integrable into their existing architecture, and published by a trustworthy vendor who is known to take the needs of enterprises

into account. Thus, from the platforms mentioned in Section 3.3.3, only the platforms which can be categorized under the enterprise main category introduced in Section 3.3.1 can be seen to fulfill the requirements. These are NVIDIA Omniverse, Microsoft Mesh, Meta Horizon Workrooms, Siemens Xcelerator, HTC VIVERSE for Business, and Immersed. It is important to notice that the enterprise category includes two subcategories, industrial and productivity, and among the six mentioned platforms, there are platforms that only fall under one of the subcategories. In the detailed analysis that will be presented next, only NVIDIA Omniverse, Meta Horizon Workrooms and Microsoft Mesh will be discussed, because they were seen as the most trustworthy and potential candidates for the given case study.

## 4.2 NVIDIA Omniverse

Omniverse is an industrial platform which focuses on providing tools for complex and large-scale digitalization workflows, including AI-powered robotics and 3D simulation with digital twins [123]. Through Omniverse, organizations can develop solutions for the widely used Universal Scene Description (OpenUSD) ecosystem. The solutions can also use other tools developed by NVIDIA, such as ray-tracing with NVIDIA RTX. As of January 2025, Omniverse is available as a development platform in three options according to its website. The first is through the Omniverse Kit software development kit (SDK), which can be downloaded for free and includes the necessary tools for building and self-hosting the solutions. The second one is through the Omniverse Enterprise subscription, which is available through the partner network of NVIDIA, priced with a fixed cost per graphics processing unit (GPU) per year, or through the NVIDIA Education Pricing Program.

Obtaining the subscription through the partner network also includes full enterprise support provided by NVIDIA. The final option is through the Omniverse Cloud Platform-as-a-Service (PaaS), which is only available as a private offering from NVIDIA. In addition, NVIDIA mentions on the Omniverse website that in future it will also offer Omniverse Cloud application programming interfaces (APIs), which will allow developers to use only the parts of Omniverse that they need.

The self-hosted option was chosen as the development option during the analysis in summer 2024. During that time, Omniverse was using the Omniverse Launcher as a key gateway to features of the Omniverse platform, such as its extensions and the Nucleus collaboration engine, which enables multiple users to connect into the same applications in real time. To access the launcher, an NVIDIA account was needed. Later on, according to NVIDIA on their Developer Website [124], the company was planning to deprecate the Omniverse Launcher on the 1st of October 2025 and incorporate the functionality to the Kit SDK.

As Omniverse is targeted towards complex industrial tasks and provided by NVIDIA, its minimum hardware requirements included the need for a powerful graphics processing unit produced by the company, and 32 GB of RAM [125]. In the case of targeting extended reality (XR) as a platform, which includes the VR space that this thesis focuses on, the requirements are even higher. While this enables high-performance computing features that could be crucial to some organizations, it also limits the content creation on Omniverse only to powerful workstations. The limitations can be immediately seen when opening Omniverse development tools such as the Kit application on a workstation without an RTX GPU, as the app immediately presents an error message because of the missing ray-tracing capabilities, preventing further development on a local workstation without

a suitable GPU. This was seen as a significant risk and a bottleneck for this case study based on the fact that the experience would be developed as a standalone VR experience for Meta Quest VR headsets [126], which would be limited to rather simplified visualizations and not being able to leverage the offered accuracy for the digital twins.

### 4.3 Meta Horizon Workrooms

Horizon Workrooms is a productivity platform, focusing on enhancing the traditional collaboration means with VR with for example enabling engaging brainstorming sessions and business presentations, and providing its users with additional virtual screens [95]. An example of a Workrooms meeting can be seen in Figure 4.1. Workrooms is available with no additional cost for Meta Quest headsets and computers, and Workrooms meetings can be joined with both of the devices. The platform centers on providing meetings occurring in virtual rooms, which can be created and managed through the Workrooms website. The meetings can also be created for Zoom, Microsoft Outlook and Google calendars, although the first mentioned requires a paid Zoom One Pro subscription or higher. To leverage VR features such as the virtual room, Workrooms meetings can also be joined through a VR application offered by Meta, which is in beta as of January 2025. As Workrooms is targeted towards powering traditional business collaboration, it does not offer the possibility of using custom content, such as self-programmed logic, animations or custom 3D models. Therefore, it is not suitable for this case study, as visualizing the steelmaking processes would require the possibility to use custom content.

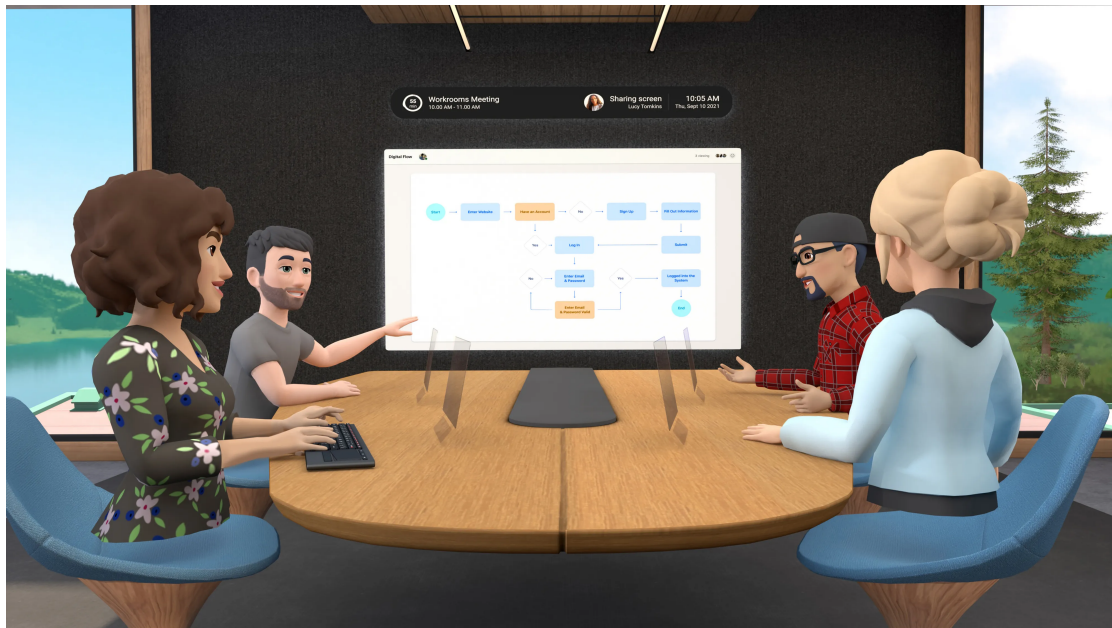


Figure 4.1: An example of a meeting inside Meta Horizon Workrooms. Image from [www.meta.com](http://www.meta.com).

## 4.4 Microsoft Mesh

Mesh combines both industrial and productivity features, as illustrated in Figure 3.4. It allows creating environments with both premade and custom assets, although they require slightly different licenses. The standard environments that are provided by Microsoft and accessible with a PC are available through a Microsoft Teams [127] meeting by having a standard Teams subscription included in Microsoft Office, or Microsoft 365 as it is known nowadays [128]. Creating custom immersive environments that can be accessed through Meta Quest devices require a Teams Premium subscription [129]. The environments are used to organize Mesh events, and all users entering a Mesh event are required to have the necessary subscription. Both of the aforementioned ways of access can leverage user avatars,

which can also be created through a Teams extension [130]. Mesh events can be created either directly through the Teams calendar [131], or through a separate website provided by Microsoft [132]. In addition to accessing Mesh events through Teams, Microsoft also offers a separate Mesh application through Microsoft Store [133] that provides users another way to access the events. On Meta Quest devices, accessing the events is done through an application from the Meta Quest store [134].

Content creation in Mesh is done with the Mesh toolkit [135], which is a free extension to the Unity development environment [136], provided by Microsoft through the Unity extension registry. Through the toolkit, creators get access to various tools that can be used to for example use real-time web content, enhance avatar interactions with physics, and create logic with custom scripting possibilities [119]. In addition to the custom content creation possibilities, Microsoft also offers tutorials that leverage ready-made scenes to showcase the available features. The custom logic can be created in two ways: either through a customized version of the visual scripting extension for Unity called Mesh Visual Scripting that provides visual building blocks similar to block coding, or with the help of the Microsoft Azure cloud platform, to which the creator can publish custom code built with C# straight from Unity. The latter way also requires an Azure subscription in addition to the standard subscription for Mesh usage [137].

## 4.5 Selection of the implementation platform

From the three analyzed platforms, NVIDIA Omniverse introduced unnecessarily strict hardware requirements for the given steelmaking case. With these require-

ments, Omniverse allowed creating experiences with realistic graphics and physics, which were not needed for this case. Thus, there was no significant justification to explore the platform further, as the added value was thought to be minimal. The second analyzed platform, Meta Horizon Workrooms, was found to not have the necessary features for the prototype development, as it did not allow creating custom environments with 3D objects and self-programmed logics. The third analyzed platform, Microsoft Mesh, was found as the most feasible platform for the given steelmaking case. It allowed using custom 3D objects and implementing self-programmed logics to create dynamic and tailored content with the Unity to be usable on the targeted end devices, Meta Quest VR headsets in this case. Therefore, it was selected as the metaverse platform for the prototype implementation.

# 5 Prototype design and implementation

In this chapter, first the design phase of the prototype will be discussed, including the general design requirements which were present from the beginning. After it, the implementation phase will be covered, including the selection of the used scripting method, placements of the objects and platforms inside the experience, and discussion about the scripting and building infrastructure of Mesh in general.

## 5.1 Designing the prototype

### 5.1.1 Gathering the general design requirements

The requirement gathering was started with the base of having two different steel-making processes to showcase and compare. The first process was based on the traditional Blast Furnace (BF) and Basic Oxygen Furnace (BOF) components to produce steel with CO<sub>2</sub> emissions, and the second one was instead using a Direct Reduction Shaft (DRS) and an Electric arc furnace (EAF), producing steel with virtually zero CO<sub>2</sub> emissions.

The experience was planned to be a marketing and communication tool from the very beginning, which limited its duration to 5-10 minutes, preferably closer to five. A short time limitation then resulted in limiting the possibilities of what can be implemented to the experience. This included for example restrictions for achievement hunting or other concepts that offer commitment for the user. While the experience was planned to be used during exhibition booths or similar areas, it also needed to support spaces of any size, as they could not be specified beforehand. In addition, an average age of the users was not specifiable either, as the only limiting factor for the age of the users was the official age restrictions. For Meta Quest HMDs, the age threshold for using a headset through a Meta account is 13 years, although such a device can be used with parental control from the age of 10 [138]. During the design, the gamification mechanisms included needed to remain within certain limits to also make the experience usable for elderly people, as there was no maximum age restriction. The experience was designed to be accessible while either sitting and standing, and the user could change their position if they wanted to.

Finally, the experience needed to allow another user to connect to the experience, fulfilling one of the key aspects of a metaverse. In this context, the functionality was provided by Mesh, and the other user acted as a steelmaking expert, having virtual notes about the processes. With these notes, anyone was able to act as the expert, explaining the user more about the processes and answering questions. The expert did not have to be physically located in the same area as the user, making it possible for the experience to emphasize the remote possibilities as one of the key aspects.

### 5.1.2 Designing the prototype

After the general requirements had been gathered, the prototype design was started. As mentioned in the previous section, the experience was focused on emphasizing how the new fossil-free process makes it possible to produce steel with virtually zero CO<sub>2</sub> emissions. To give the user a practical idea of how different components within the processes are connected to each other, both processes were showcased in a miniature size. The flow of different substances between the components was also shown to the user. To guide the focus of the user, a lighting system was designed to emphasize the explained phases of the process, while guiding the focus away from the others. This will be explained in more depth during Section 5.2.3. Both of the processes were divided into two subprocesses in practice: iron-making and steelmaking. In both subprocesses, the user was guided through the phases of each subprocess, explaining and showcasing what is happening in the process. The explanation was done in two ways: written text in text boxes and voice over. With each text box, the user was given a button through which the showcase progressed. To ensure engagement throughout the experience, multiple different gamification ideas were considered, as gamification is a factor that can improve learning results for adults also [139]. These include for example having a dramatic storytelling beginning from a pleasant starting point, turning into a more dramatic situation because of the produced CO<sub>2</sub> emissions. The user could then have money or resources to achieve an emission-free outcome in the end.

However, in order to achieve a general presentation of the changes of the fossil-free process without needing to give exact figures or numbers, gamification of the traditional BF process was decided to be focusing on catching the CO<sub>2</sub> molecules

produced by the process components. In the procedure, the user was first given a virtual net, which they could grab and swing around. Both the BF and the BOF then showcased how their real life counterparts produce CO<sub>2</sub> emissions, letting the user grab them with the given net. Both of the emission phases consisted of three subphases. During the first, only a few CO<sub>2</sub> molecules spawned, slowly moving towards the user. During the second subphase, the spawning and moving speed of the molecules was increased to an average speed. Finally, during the last subphase the molecules spawned fast and moved fast towards the user. In each part, both the amount of molecules spawned and the amount captured by the user were tracked. At the end of the third part, the user was shown a percentage of how much they captured. Because both the BF and the BOF CO<sub>2</sub> emissions in the traditional process, the molecule catching game was presented two times. Through this, the user was given a chance to practice the procedure during the first time, and to be more prepared for the task during the second time.

## 5.2 Implementing the prototype

The experience was implemented with the development platform Unity [136], using its version 2022.3.34f1, together with the Mesh Toolkit package for Unity, using its version 5.2414.126 [135] to enable the features of the Mesh platform. Implementations done with Mesh can be integrated into existing Microsoft infrastructures used by organizations, such as those residing in Azure, making it easier for organizations to take Mesh into use.

### 5.2.1 Selecting the scripting method

During the time of implementation, Mesh provided two methods of logic scripting into the experience. The first way was the default for new projects, being called *Mesh Visual Scripting* and providing the scripting functionality through a method similar to visual block coding. Microsoft had built it on top of the existing Visual Scripting package of Unity, removing some of the native functionality but also adding some of their own [140]. Like the native implementation of Unity, Mesh Visual Scripting was available through a Script Machine component, which could be attached into GameObjects. The method offered the creator two different script types, "Embed" and "Graph", which both were targeted for slightly different needs. For example, solutions using the first type were implemented directly inside the Script Machine component and they could reference other GameObjects in the scene, while the second type was only referenced in a Script Machine and unable to contain GameObject references within the implementation.

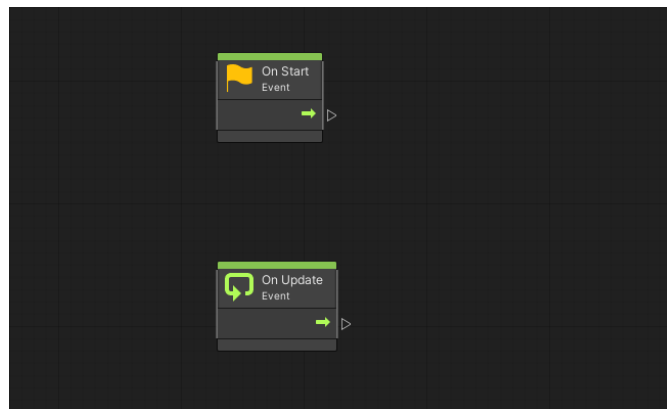


Figure 5.1: The default script nodes of Mesh Visual Scripting.

Both Embed and Graph offered the same default script nodes, "OnStart" and "OnUpdate", which can be seen in Figure 5.1. They established the starting point

of the script for the creator, acting as triggers being executed under certain circumstances; in this case either when the script was enabled (OnStart), or on every frame (OnUpdate). The triggers themselves did not provide any functionality besides acting as triggers, and any additional logic nodes had to be connected to their output for them to be executed when a trigger execution happened. Although the default OnStart and OnUpdate nodes only provided triggers for the mentioned circumstances, Mesh Visual Scripting provided several other triggers that could be used in addition to the default ones or even to completely replace the defaults, as it was not necessary to include them within the script.

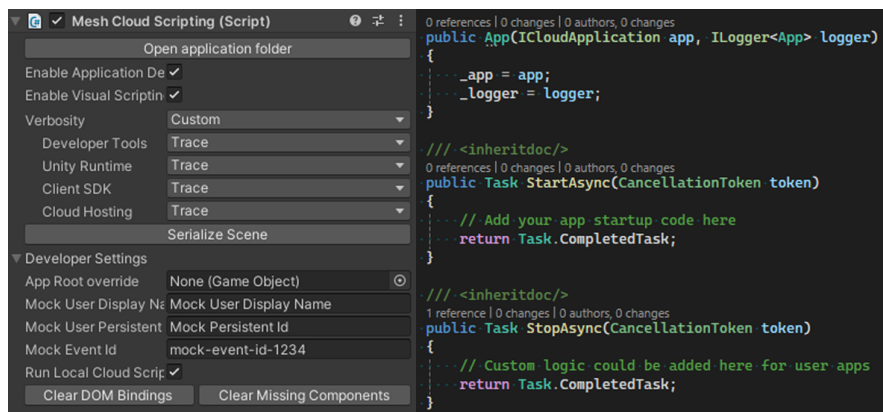


Figure 5.2: The native Cloud Scripting GameObject, and the default C# functions for Cloud Scripting.

While Mesh Visual Scripting only allowed simple logic and physics, the second scripting method called *Cloud Scripting* was closer to the native Unity C# scripting, allowing for example complex logic and calling any .NET application programming interface (API). By adding a separate native GameObject, Microsoft provided a generic C# project template with slightly different default functions compared to Mesh Visual Scripting. Figure 5.2 shows the native GameObject and the default functions of Cloud Scripting. While Cloud Scripting was functioning

through C# code, Microsoft still did not allow mixing Cloud Scripting and the native Unity C# scripting, throwing an error message during runtime.

During the time of implementation in summer 2024, the Cloud scripting method required two different .NET SDK versions for certain parts of the publication process, 6.0 and 7.0. From these, the latter version was deprecated by Microsoft already in May 2024 [141]. Some problems were already noticeable during the local Cloud Scripting testing, as the official documentation implied that both of the versions had to be installed on the local machine [142]. This resulted in confusion when thinking where each version had to be referenced within the project files. In addition, the deprecated version had debugging support only in a specific version of Visual Studio, which was not the latest. Thus, only the Mesh Visual Scripting method was seen as reliable and trustworthy enough for the implementation.

### **5.2.2 Models of the process components and their placements**

When searching the 3D models of the steelmaking components that would be used to showcasing the processes, there were certain requirements in place. First, the models would preferably need to match a certain style, being miniature and simplified versions of their correspondents as mentioned in Section 5.1.2, and somewhat mimicking the appearance shown in a comparison image published by the steel-making company. The comparison image is shown in Figure 5.3.

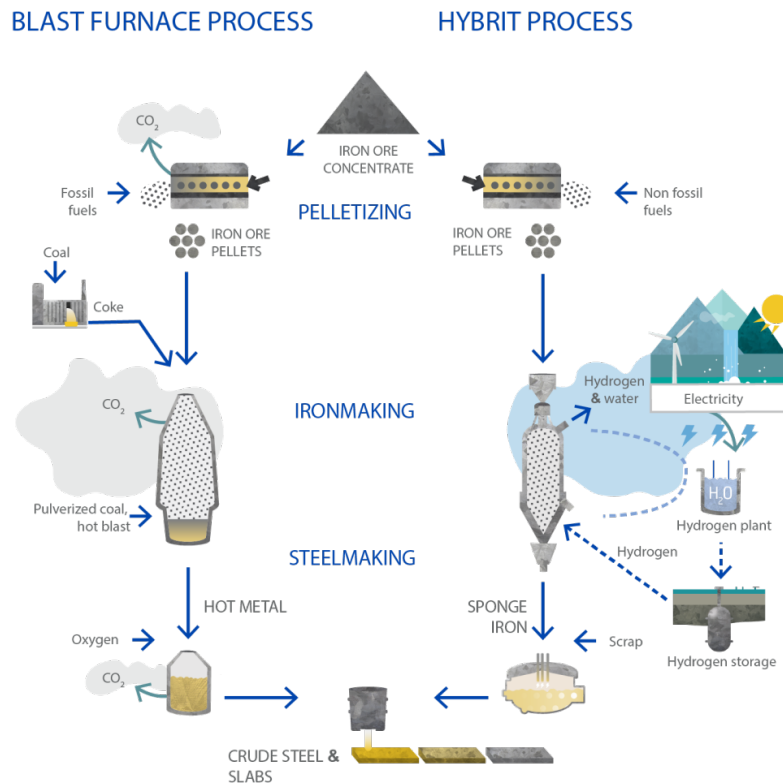


Figure 5.3: A comparison of the traditional and fossil-free steelmaking processes used in the case. Image from [www.hybritdevelopment.se](http://www.hybritdevelopment.se).

There were difficulties in finding models that would both match the desired style and have similarities in their appearances, which led to pondering if they could be self-created. Some of the connections that would be used in the showcase, such as conveyor belts, were found from the Unity Asset Store [143] which reduced the amount of needed models. This ultimately led to self-creating the remaining models with the Blender 3D modeling tool [144], as the development work needed for the model creation was within reasonable limits. A list of the needed 3D models with a description of their purposes and the process they belong to can be seen in Table 5.1.

Table 5.1: A list of the needed 3D models for the steelmaking processes.

<b>Component</b>	<b>Purpose</b>	<b>Process</b>
Iron pellet pile	Provides iron pellets for the BF and the DRS	Both
Coal pile	Supplies coal for the coking plant	Traditional
Coking plant	Supplies coke (processed coal) for the BF	Traditional
Blast furnace (BF)	Melts iron pellets and rips oxygen impurities from them, and creates CO <sub>2</sub> and pig iron	Traditional
Oxygen tower	Supplies the BOF with oxygen	Traditional
Basic oxygen furnace (BOF)	Combines oxygen with pig iron, and creates molten steel and CO <sub>2</sub>	Traditional
Direct reduction shaft (DRS)	Removes oxygen from iron pellets with hydrogen direct reduction and produces water, hydrogen and sponge iron	Fossil-free
Hydrolysis	Breaks water down into oxygen and hydrogen using electricity, and supplies the DRS and the hydrogen storage with hydrogen	Fossil-free
Hydrogen storage	Stores excess hydrogen and supplies the DRS with it	Fossil-free

Table 5.1: A list of the needed components for the steelmaking processes.

Component	Purpose	Process
Electric arc furnace (EAF)	Smelts sponge iron into molten steel	Fossil-free
Scrap metal pile	Supplies the BOF and the EAF with scrap metal	Both
Steel mold storage	Provides molds for the molten steel	Both
Steel slab container	A container for the ready steel slabs	Both

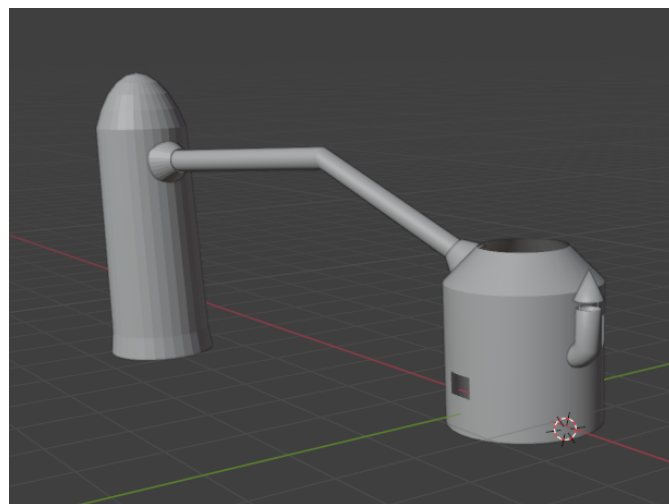


Figure 5.4: Creating the steelmaking models in Blender.

Furthermore, by self-creating the 3D models, their appearance was completely customizable as per the specific needs. Figure 5.4 shows an example of the model creation in Blender. In the experience, the steelmaking processes were shown to the user one at a time, and they were located in different places. In addition to

the process miniatures, the experience included four platforms for each process, on which the user and the expert were standing. Two of them were accessible for the user, and the remaining two for the expert. A meetup with the expert can be seen in Figure 5.5.

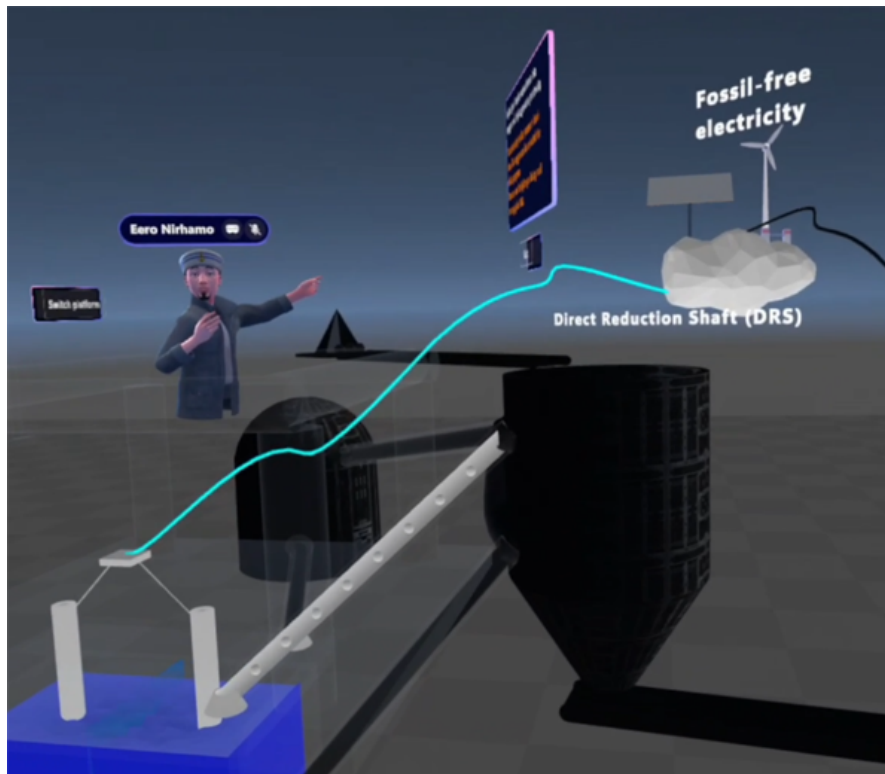


Figure 5.5: A meetup with the expert inside the experience.

As each process was divided into two subprocesses which went through different topics, it was efficient to organize the notes for the expert into two different platforms, both of which were located near the relevant subprocess. The platforms of the user were placed in a way that the user could see the explained process miniature from different angles. Both the miniature and the second user platform were placed diagonally lower from the first user platform, and the second expert platform was located on the same level as the first user platform. Figure 5.6 shows

an overview of the component and user platform locations within the fossil-free process in a 2D view. It also demonstrates the limitations of traditional presentation means compared to a showcase through a metaverse experience, as it is limited in how accurately it corresponds to the real-world process, and it cannot be made as engaging.

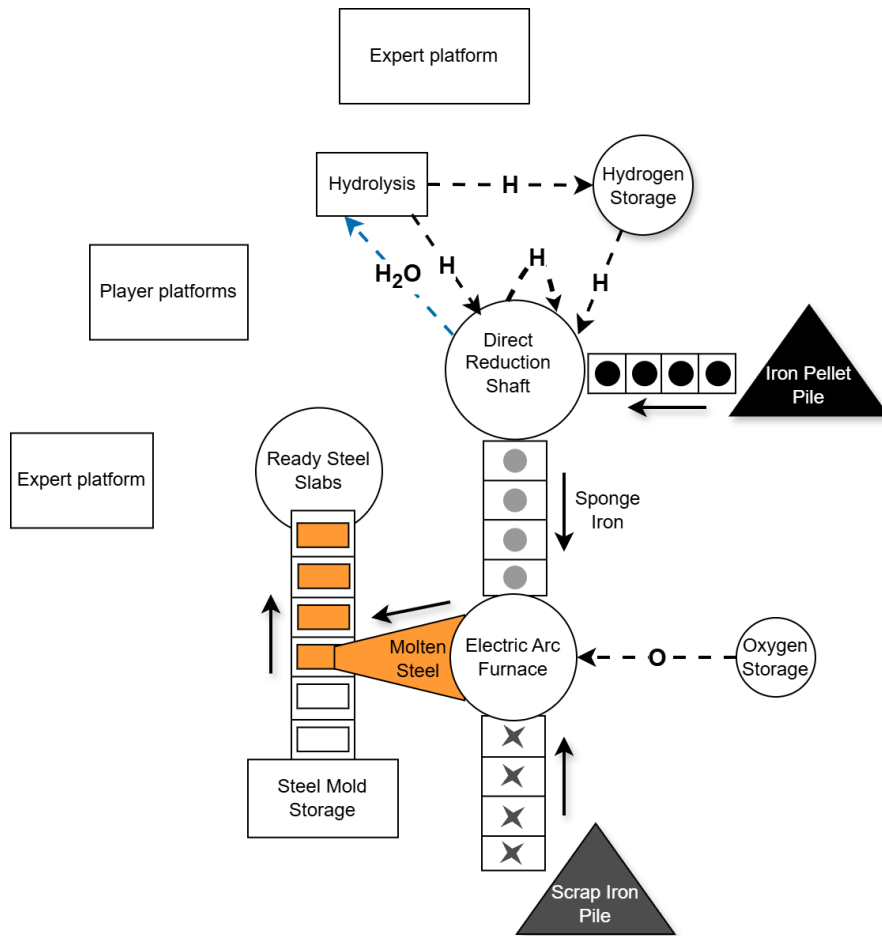


Figure 5.6: A simplified 2D diagram of the fossil-free process.

### 5.2.3 Script organization and functionalities

Variables in Mesh Visual Scripting worked almost the same way as in the Unity counterpart, but according to the Mesh documentation, scene variables were unsupported, although the provided scripting nodes included nodes for managing scene variables also [145]. During the implementation, the showcase of each process was divided into different phases through GameObjects, which acted as folders. The components, which were sometimes constructed from several 3D models, and the logic implemented were placed under these folders based on what phase they belonged to. Through this way, the hierarchy for each of the twenty phases in the showcase was kept organized and easy to find for the creator. The voice overs were generated with a text to speech tool provided by ElevenLabs [146], and the resulted audio files were placed into the folder structure, making them easy to refer from within the scripts.

An important thing for the content creator to note when working with Mesh was that all aspects related to the configuration of the physical controllers and their input was taken care by Mesh without the need of any input from the creator. This meant that when working with Mesh, the content creator did not have to think about using tools like XR Interaction Toolkit [147] or OpenXR [148]. Mesh natively handled the gap between the development environment (Unity in this case) and the VR headset; it took care of configuring the controllers and their input mapping, for example. By doing this, Mesh ensured that the avatars and their hands worked in the environments like they should.

The implementation was originally designed to use a three-step lighting system to guide the focus of the user. First, the components and connections belonging

to the phase under explanation were designed to have an outline similar to the example shown in Figure 5.7. Second, as both of the processes were divided into two subprocesses, steelmaking and ironmaking, the relevant subprocess was lit when its components were being explained. Third, the remaining subprocess that was not being explained at the moment was darkened.

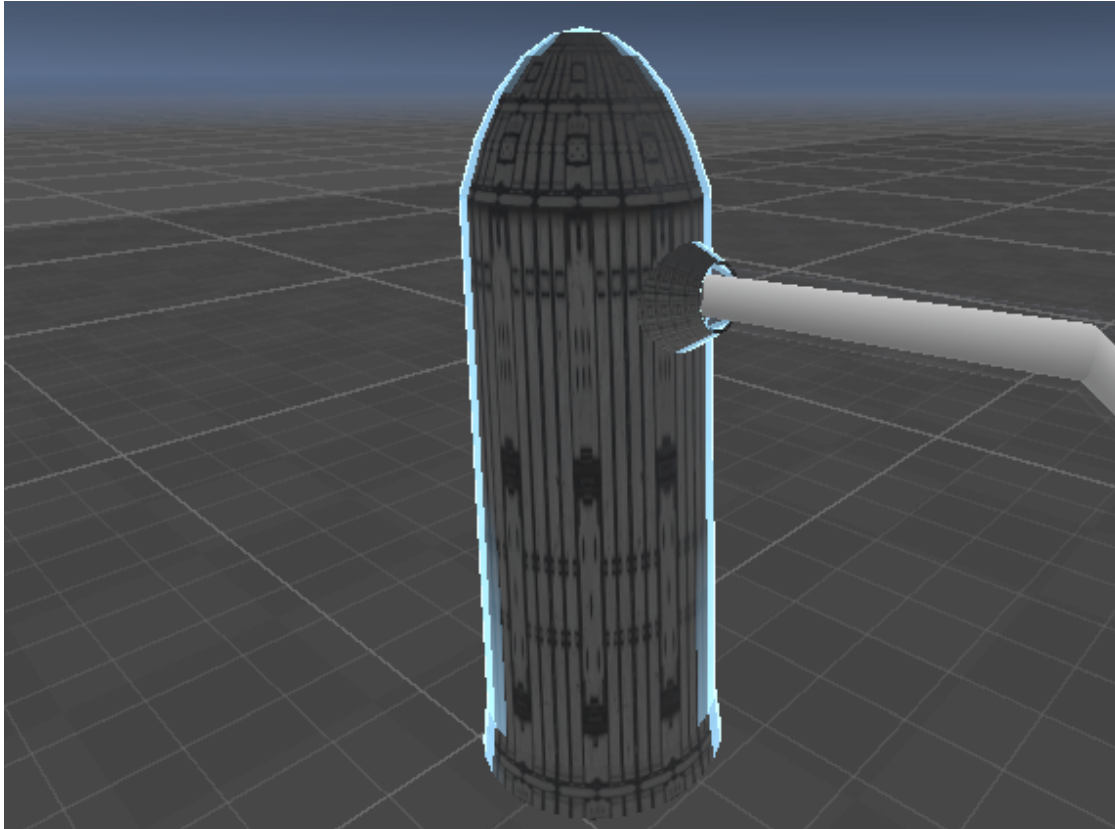


Figure 5.7: An example of what the outline lighting could have looked like.

This turned out to be rather challenging because of the limitations of the Mesh platform. For example, Mesh did not allow using the post-processing functionality of Unity at all, and implementing the outlines by having multiple materials on a single object was seen as impossible with the selected scripting method. Thus, the lighting implemented was narrowed down to only two steps, lit and unlit. In

practice, this was achieved by shaders, which had a variable attached, providing lighting control. An example of the lighting system can be seen in Figure 5.8.

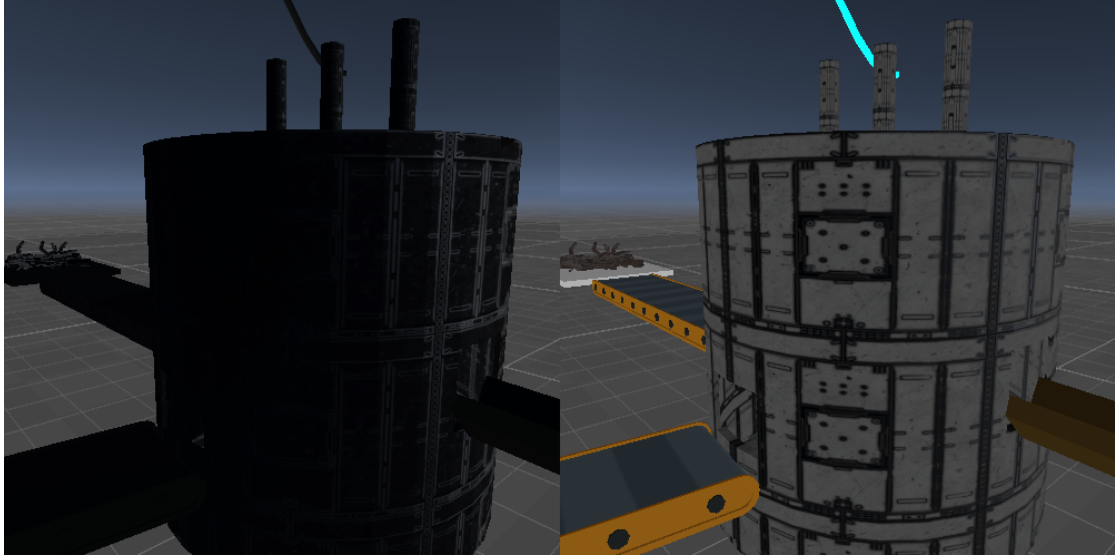


Figure 5.8: Side-to-side preview of the unlit and lit states of different components.

The showcase logic, audio and visuals were controlled by the user with different kinds of buttons which provided functionality for restarting the experience from the beginning, teleportation between the available platforms, and progressing in the current process. An example of these buttons and their positioning can be seen in Figure 5.9.



Figure 5.9: An example of the buttons controlling the experience flow.

The processes were showcased to the user one at a time, which required both of them to have their own collections of the controlling buttons mentioned earlier. The progression button belonging to a certain phase was placed below a text box explaining about the phase, and their positioning can be seen in Figure 5.10. They were placed on the edge of the default user platform in a way where the user could read the text box and see the miniature animations without turning their head. The progression button controlled everything that happened during each phase, whether it was seen or heard. Each of the buttons triggered functions within the corresponding phase `GameObject`, which included all functionality related to the phase.

The progression functionality in the experience was implemented to work in a similar way; when a progression button was pressed, it interrupted any animations and voice overs from the previous phases and started those of the current phase. The text box of the previous phase was also swapped with the current one. The animations varied between different components of the processes; for

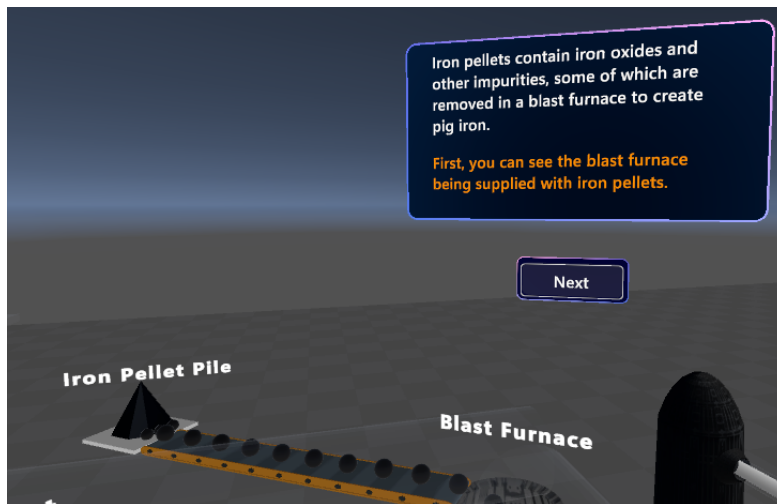


Figure 5.10: An example of a phase in the traditional Blast Furnace process.

example, some of them had glowing red bottoms to indicate heating, and some were spawning moving objects to indicate emissions. Substances moved between the components with conveyor belts when they were solid, and in troughs when they were in liquid form.

```
for (int i = 0; i < co2Array.Length; i++)
{
    if (stage >= 1)
    {
        if (random.NextDouble() < (stage + 1) * 0.001 && !co2Array[i].activeInHierarchy)
        {
            co2Array[i].transform.position = this.transform.position;
            co2Array[i].SetActive(true);

            Vector3 vector3 = new(
                (float)(Mathf.Cos((float)(maxTheta * random.NextDouble()))) * maxRadius * random.NextDouble(),
                (float)(Mathf.Sin((float)(maxTheta * random.NextDouble()))) * maxRadius * random.NextDouble(),
                0);

            Vector3 vectorToProject = target.transform.position - this.transform.position;
            Vector3.ProjectOnPlane(vectorToProject, Vector3.up);
            Quaternion angleAxis =
                Quaternion.AngleAxis(57.29579f * Mathf.Atan2(vectorToProject.x, vectorToProject.z), Vector3.up);

            targetCoordsArray[i] = target.transform.position + angleAxis * vector3;

            co2Array[i].GetComponent<Rigidbody>().velocity =
                Vector3.Normalize(this.transform.position - (target.transform.position + angleAxis * vector3)) * particleSpeed;

            totalSpawned += 1;
        }
        else if (co2Array[i].activeInHierarchy)
        {
            co2Array[i].GetComponent<Rigidbody>().velocity =
                Vector3.Normalize(targetCoordsArray[i] - this.transform.position) * particleSpeed;
            if (Vector3.Magnitude(co2Array[i].transform.position - targetCoordsArray[i]) < 0.1)
            {
                co2Array[i].SetActive(false);
            }
        }
    }
}
```

Figure 5.11: An example of the molecule catching game logic implemented with Cloud Scripting.

During the implementation of the CO<sub>2</sub> molecule catching game, one of the differences between the Cloud Scripting and Mesh Visual Scripting methods introduced difficulties. While it would have been trivial to make the game logic understandable and readable with the Cloud Scripting method, understanding and reading the logic became much harder because the implementation was restricted to only use the Mesh Visual Scripting method. Figure 5.11 presents an alternative implementation using C#, which would be similar to Cloud Scripting if used. The code presented in the Figure is rather easy to read and understand for people with programming knowledge.

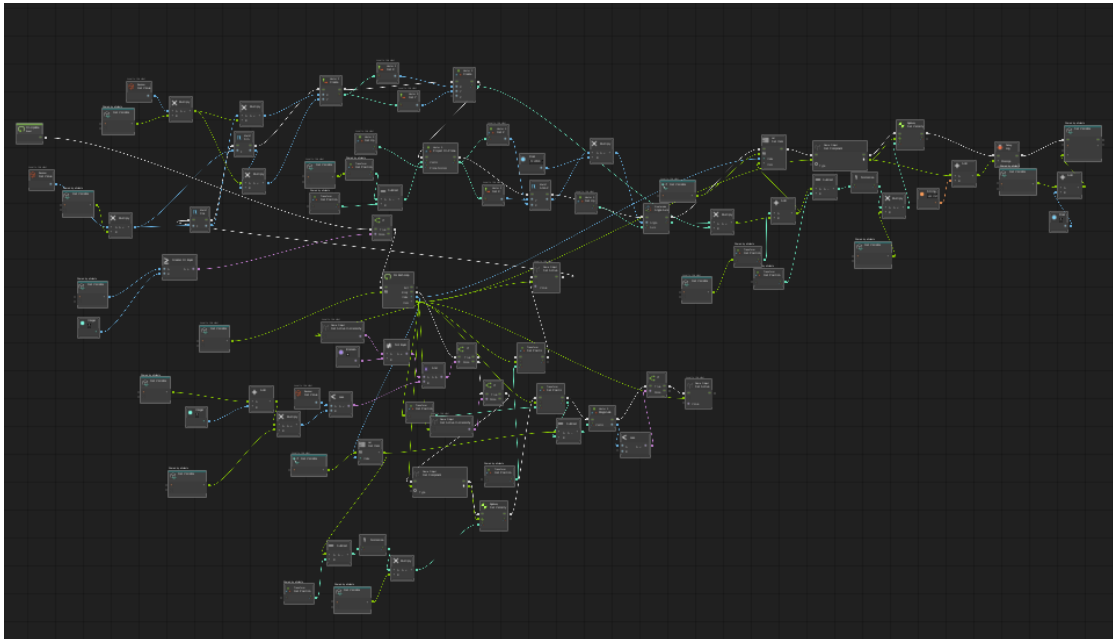


Figure 5.12: A part of the molecule catching game logic implemented with Mesh Visual Scripting.

This was not the case for the actual implementation, which can be seen in Figure 5.12. The method used did not support making calculations or variable operations in a small screen area, because the code blocks were not small and often many of them were required for the task. Thus, the screen area taken grew when the logic complexity was increased. Still, while the Mesh Visual Scripting method was limited to only simple logic, interfaces and physics according to Microsoft [137], the game was implemented successfully with it. The most problematic aspect faced was that the scripting method did not seem to support the instantiating functionality of Unity, meaning that the CO<sub>2</sub> molecule objects targeted towards the user as emissions had to be created as normal GameObjects in the hierarchy. The game occurred in two different phases of the traditional process, which forced the implementation to use two different copies of the related GameObjects, including

the CO<sub>2</sub> models. However, the game logic was only implemented once, as the Visual Scripting package supported separating logic from the actual GameObjects and only referencing the logic in them. This was also possible in Mesh Visual Scripting, which enabled referencing the same logic in two different GameObjects.



Figure 5.13: A player catching CO<sub>2</sub> molecules during the emission phase.

When the phase of the CO<sub>2</sub> molecule catching game started, the user was first instructed on how to grab the net. An example of the game can be seen in Figure 5.13. After this, the three different subphases of the premade CO<sub>2</sub> GameObjects were started, as described in Section 5.1.2. Each of the subphases was 15 seconds long, after which the next one automatically started. There was a collider attached

to the entry point of the net, and as the user was swinging it around during the parts, their score was increased by one every time a molecule hit the entry point. A counter for the total amount of spawned molecules was also present. After the three subphases, the molecules disappeared and new ones stopped spawning, and the user was shown a percentage of how much they managed to catch, calculated with the mentioned score and counter.

#### **5.2.4 Building and uploading a custom project for end devices**

An aspect worth noting during the implementation of any project with Mesh was the fact that it could not be tested on end devices with Mesh features without first building and uploading it through the *Mesh Environments* tool contained in the Mesh Toolkit. In addition, if a public access for the target users was needed, an event had to be created from the Mesh portal. Without an event, the uploaded project was not easily visible in the Mesh application, but it could still be accessed by the creators through customization. An overview of the build and upload process can be seen in Figure 5.14.

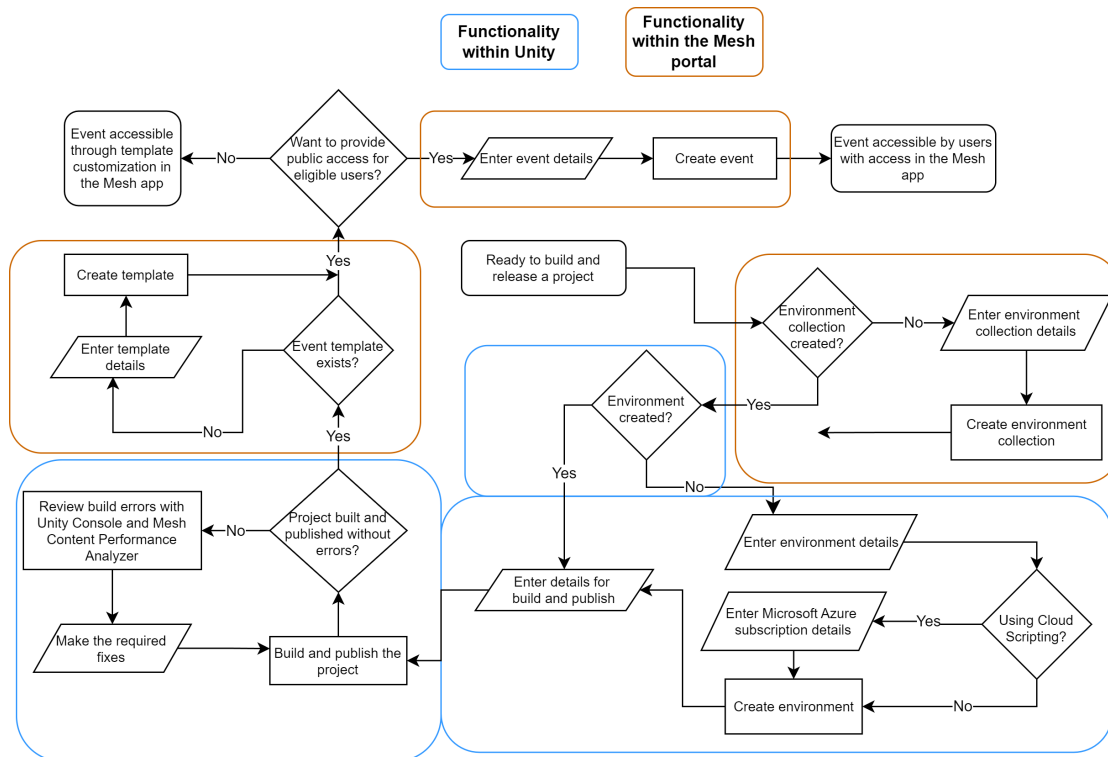
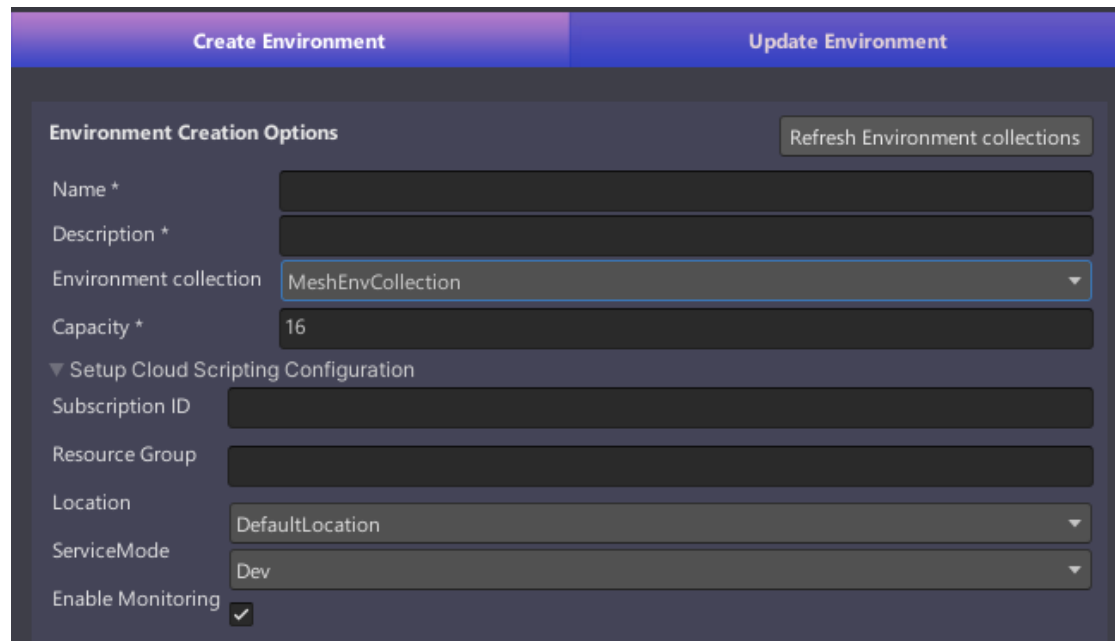


Figure 5.14: An overview of the build and upload process for a Mesh project.

The build and upload process started with the creator having to first create an environment collection through the Mesh portal as instructed by Microsoft [149]. For the collection, the required information consisted of collection name and description, the visibility of the collection which could be either private or public, and the people with access to the collection, specified as either owners or members. In order to give a person access to the collection, they had to be a part of an organization which had a sufficient Microsoft Teams license. The licenses are discussed more in Section 4.4.



The screenshot displays the 'Create Environment' tab of the Mesh Environments tool. The interface is dark-themed and contains the following elements:

- Environment Creation Options:** A section with a 'Refresh Environment collections' button.
- Name \*:** A text input field.
- Description \*:** A text input field.
- Environment collection:** A dropdown menu with 'MeshEnvCollection' selected.
- Capacity \*:** A text input field with '16' entered.
- Setup Cloud Scripting Configuration:** A section with a downward arrow icon.
- Subscription ID:** A text input field.
- Resource Group:** A text input field.
- Location:** A dropdown menu with 'DefaultLocation' selected.
- ServiceMode:** A dropdown menu with 'Dev' selected.
- Enable Monitoring:** A checkbox that is checked.

Figure 5.15: Details required by the Mesh Environments tool when creating an environment.

After the environment collection was created in the Mesh portal, an environment could be created through the *Mesh Environments* tool of the Mesh Toolkit. The information required in the creation can be seen in Figure 5.15, and it consisted of environment name and description, along with the created environment collection and people capacity for the environment. According to Mesh documentation [150], the maximum capacity was 16, which was also the default specified capacity. If the project was using Cloud Scripting, the tool required additional details related to Azure, consisting of Azure subscription ID and resource group, and the server location to which the project would be uploaded to. In addition, Mesh Environments required to specify the service mode, which modified the connection restrictions for the published project, and whether the project would be using the Azure Monitor functionality [151]. All of the information related to Azure could

also be edited through the tool later. If the project was using only Mesh Visual Scripting instead, the information required by Mesh Environments was limited to only the environment name, description, environment collection and the maximum capacity.

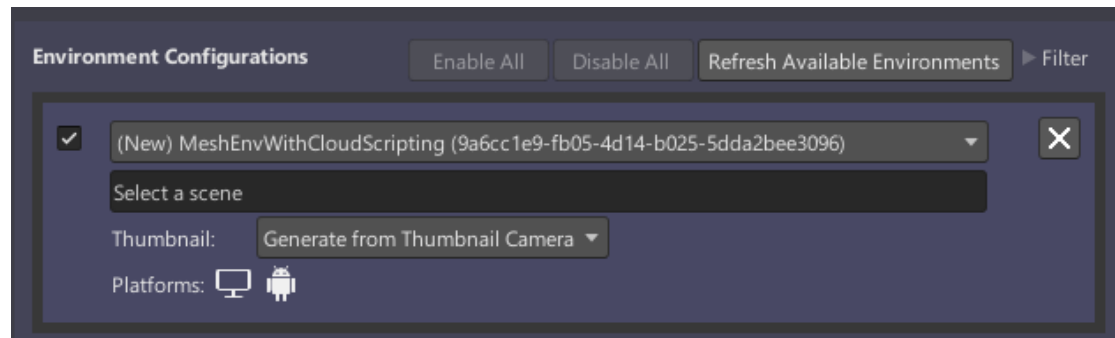


Figure 5.16: Building details required by the Mesh Environments tool after creating the environment.

After the environment was created, Mesh Environments required the creator to specify additional details for the upload, which can be seen in Figure 5.16. This information included specifying the Unity scene that would be uploaded, thumbnail that would be seen by the users connecting into the experience, and platforms on which the users could connect, which included Windows PCs and specific Meta Quest devices. The tool also allowed building for only one of the allowed platforms, although it showed the creator an error message stating that for production environments it was recommended to enable both platforms.

After specifying the remaining information in the Mesh Environments tool, the build and upload procedure could be started. The procedure first compiled and built all the assets in the selected scene, after which they were uploaded to be usable in the Mesh portal. If the project was set to use Cloud Scripting, the infrastructure specified by Microsoft [152] was uploaded to the Azure resource

group specified in Mesh Environments. It is worth noticing that the build process could fail, if for example the Content Performance Analyzer tool of the Mesh toolkit [153] found major performance issues.

When the project was successfully built and uploaded, the next step was to create a template for the environment created before, which could be done in the Mesh portal. The template required a name and an optional description could be specified also. After creating the template, the final step was to create an event in the Mesh portal as instructed by Microsoft [132]. The event required a title that would be shown to the users connecting into the created event, a time and date range during which the event would be available, a room setting that could be either single room with a 24-hour time limit, or a multi-room with a 3-hour time limit. The latter option allowed to create multiple rooms for the same event, allowing the event hosts to broadcast information to the other rooms than the one they were in. In addition, other optional details could be specified, such as a description for the event, specific co-organizers and attendees, and an event image that would override the image specified in Mesh Environments. Once an event was created, it could be connected to on the platforms specified for the project in Unity, as seen in Figure 5.17.

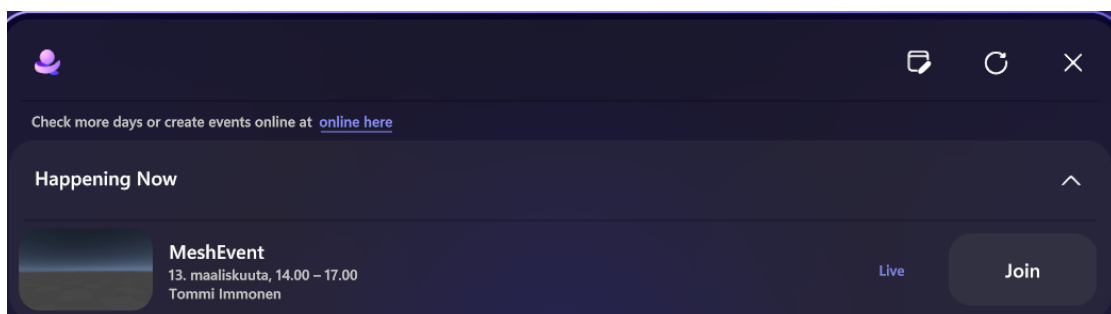


Figure 5.17: A published and visible event in the Mesh application for Windows.

# 6 User feedback survey and testing results

This chapter introduces the user feedback survey created for the experience, which allows gathering systematic feedback from specific target groups. In addition, the test environment is described in detail. The survey answers received are presented and analyzed, along with the observed results from the test sessions.

## 6.1 Test environment and survey description

From the beginning, the experience prototype was designed in a way that would allow it to be testable during several occasions. Through these tests, important and meaningful feedback was collected about the state of the experience, its future development direction, and the relevance of metaverse platforms overall for the organizations of the testers. The tests were organized in a systematically monitored environment during several occasions, and each of the occasions were in a different physical location. In each session, a facilitator first guided the testers on how to use the VR equipment during the experience, and how the experience works overall. The guidance took only a few minutes. Another facilitator recorded the

screen of the VR headset as it was casted, and in the same time wrote notes about both non-verbal and verbal issues and thoughts expressed by the testers. During the test sessions, one of the researchers acted as the remote expert, who was physically located elsewhere, either in another room of the same building or in another town. All of the testers were either affiliated with the maritime industry, or researchers working with the industry. In order to receive written feedback that could be analyzed later in both qualitative and quantitative ways, a survey was needed. In addition to the survey, aspects regarding the physical location of the test session and the spoken feedback received during the tests were observed and noted.

In the survey, the testers were asked 12 different questions, which consisted of background questions and questions about three different key areas; usability, sustainability communication and metaverses in general. There were five different types of questions: single-answer multiple choice questions, general multiple choice questions, questions using the Likert scale, open-ended questions and a dropdown question. A full list of the questions, including their answer options, can be seen in Appendix A. The test results, including the survey results, are presented and analyzed in the next section, which will also go through the questions with more detail. The open-ended question answers are presented by grouping similar answers into general themes, some of which can be seen repeating across different questions. In addition, the observed results are also presented in the section.

## 6.2 Test results

### 6.2.1 Survey answers

The experience was tested in four different sessions by a total of 22 testers. Based on the answers received to the first three background questions, 50 % of the testers were researchers, one was an employee of the steelmaking company for whom the prototype was being developed, and the remaining 46 % were other shipbuilding professionals. The division can be also seen in Figure 6.1.

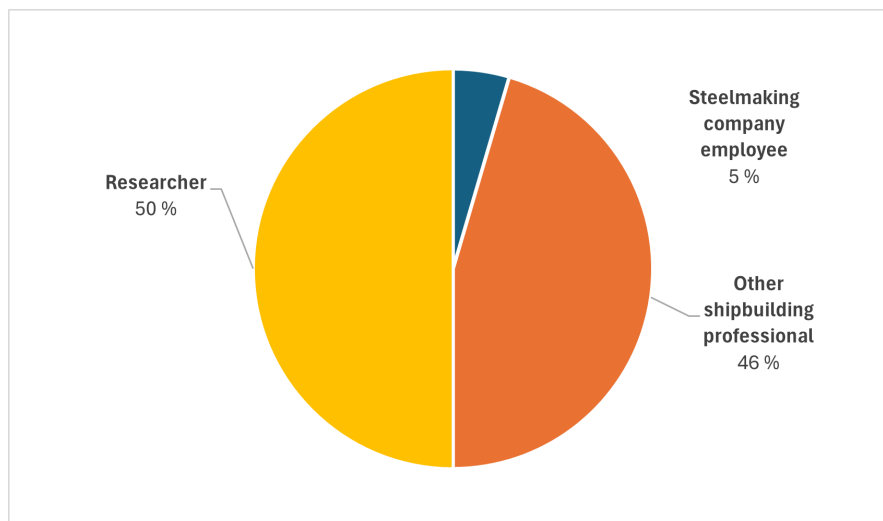


Figure 6.1: The division of tester professions based the survey answers.

Regarding the familiarity of VR among the testers, 23 % of the testers were using VR for the first time, 64 % had used it before under 10 times, and 9 % had used it at least 10 times before. In addition, one tester was using VR weekly. The answers can also be seen in Figure 6.2. The last background question asked whether the respondents had used VR at work. Only 23 % answered that they had, and the remaining 77 % had not.

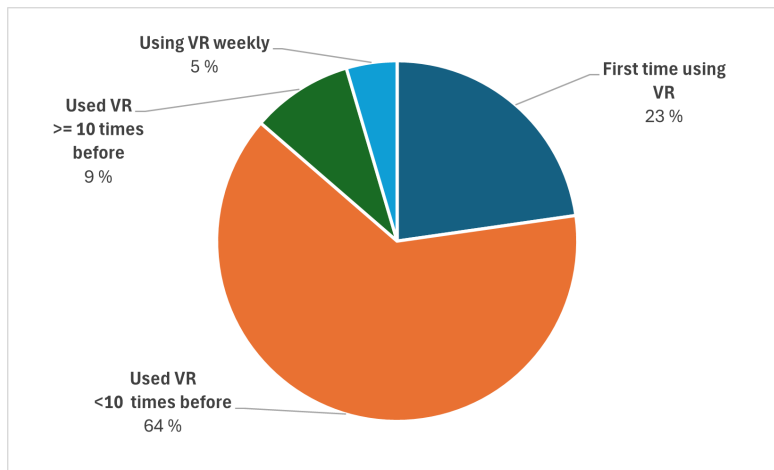


Figure 6.2: The amount of previous VR usage among the testers.

After the background questions, in the fourth question the testers were presented with several statements regarding the usability of the experience, and asked whether they agree or disagree with them. The questions and the answers received to them can be seen in Figure 6.3.

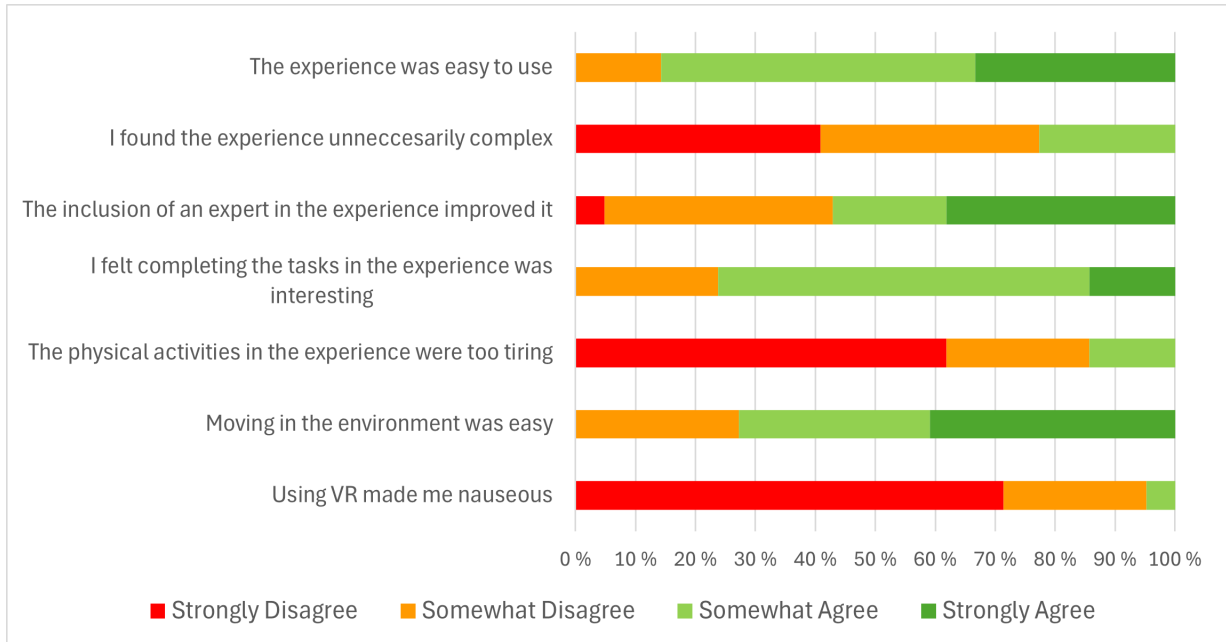


Figure 6.3: Tester answers to the usability-related statements presented.

Based on the answers in Figure 6.3, 86 % of the testers felt that the experience was at least somewhat easy to use, and 77 % of the testers at least partially disagreed that the experience was unnecessarily complex. Regarding the expert who was providing guidance to the tester during the experience, 57 % felt that it improved the experience somehow. In addition to the visualizations of the different phases and progressing between them, the tester was tasked to catch as many CO<sub>2</sub> emissions from certain components of the traditional process, which occurred two times during the experience. 76 % of the testers felt that completing the tasks was at least somewhat interesting, and 86 % at least partially disagreed them being too tiring. This correlates with the reason why gamification aspects were included in the first place as mentioned in Section 5.1.2, positively influencing how the experience feels overall. Finally, 73 % of the testers at least somewhat agreed that moving in the experience was easy, and only one at least somewhat agreed that using VR made them nauseous.

Next after the usability statements, the testers were asked an open-ended question about any major improvements that would make the experience feel better to use. Table 6.1 shows a list of the general themes among the answered improvement suggestions. Most of the suggested improvements were related to changing positioning of objects such as text boxes and buttons, or enabling more flexible movement options to allow better inspecting of the components. Some testers also wrote that they had difficulties grabbing the net because of its hitbox, as it was only grabbable from the narrow handle.

Table 6.1: A list of the general themes among the received improvement suggestions to the fifth survey question.

<b>Theme</b>	<b>Occurrences</b>
<i>Object positioning had problems; some elements required turning or were too close to each other</i>	6
<i>Grabbing and using the net was difficult, partially due to its hitbox</i>	5
<i>More movement freedom for detailed inspection and better molecule catching</i>	3
<i>There could have been more factors helping to guide my focus, such as arrows pointing to the visuals</i>	3
<i>Some concepts were too technical or difficult to understand</i>	2
<i>The environment could look more colorful and appealing or real</i>	2
<i>Communication willingness with the expert can vary through the background and mood of the tester</i>	1

After the usability questions, the survey continued to sustainability-related questions. First there were five statements presented in the sixth question, each with the options to agree or disagree either strongly or partially. The questions and the answers received to them can be seen in Figure 6.4.

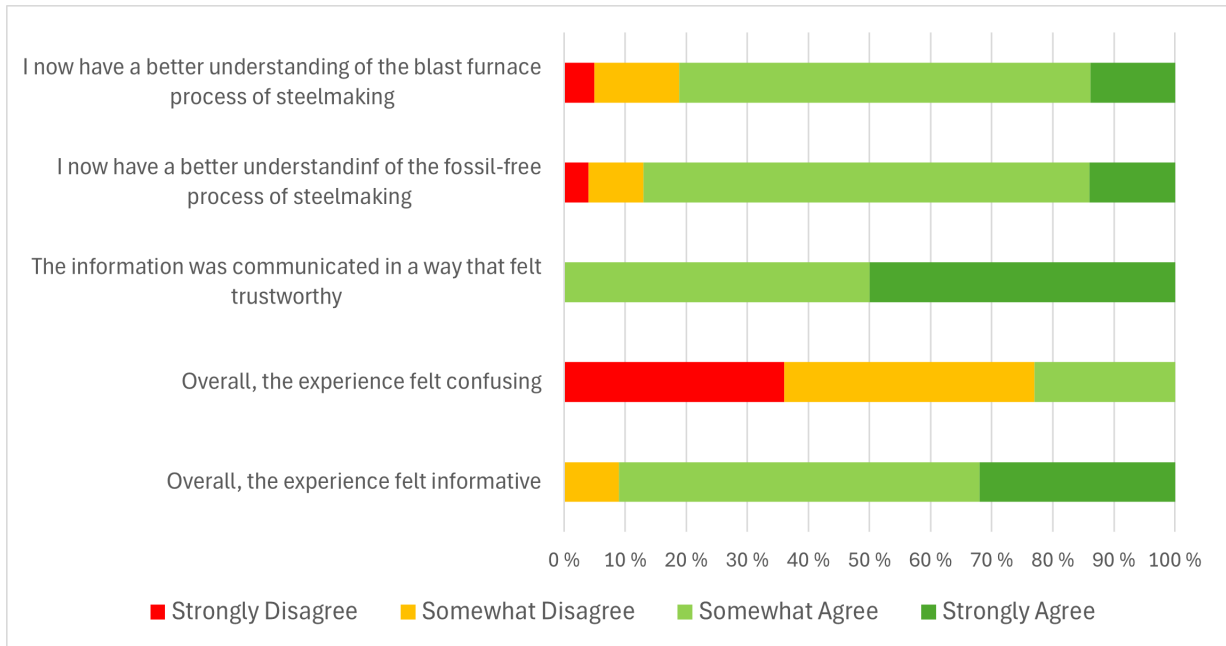


Figure 6.4: Tester answers to the sustainability-related statements presented.

Based on the answers, 82 % of the testers felt that they reached at least somewhat better understanding of the traditional blast furnace process. The amount slightly grew when asking about the fossil-free process, of which 86 % of the testers gained at least somewhat better understanding. In addition, all of the testers at least somewhat agreed that the information was communicated in a way that felt trustworthy. Overall, 77 % of the testers at least partially disagreed that experience felt confusing, and 91 % at least somewhat agreed that the experience felt informative.

Next, there was an open-ended question asking if something should have been communicated better or if the testers felt something was left out completely. Table 6.2 shows a list of the general themes among the communication suggestions received. Most of the answered problems were related to some concepts being too technical or hard to understand, suggesting for example a short comparison

of the processes to be added in the end, or using simpler language. In addition, suggestions about having clearer indicators of where to focus were received, for example arrows pointing to the explained components. Some testers also wrote that the object positioning problems mentioned in the previously covered usability questions affected their understanding, because sometimes they had to move while the explanation was in progress.

Table 6.2: A list of the general themes among the communication suggestions received to the seventh survey question.

<b>Theme</b>	<b>Occurrences</b>
<i>An overview of the key differences between the processes in the end would have been welcome</i>	5
<i>Some concepts were too technical or difficult to understand</i>	4
<i>Object positioning had problems; some elements required turning or were too close to each other</i>	3
<i>Grabbing and using the net was difficult, partially due to its hitbox</i>	2
<i>More movement freedom for detailed inspection and better molecule catching</i>	2
<i>There could have been more factors helping to guide my focus, such as arrows pointing to the visuals</i>	1
<i>The experience does not add enough value yet compared to traditional presentations, it needs more interaction possibilities</i>	1

The last four questions in the survey were related to metaverses. The first of these asked the testers to imagine they wanted to showcase the fossil-free process to someone, and based on that they were asked to rank different presentation methods in the order of preference. The given presentation methods with the answered ranking preferences can be seen in Figure 6.5. The given methods were a combination of popular B2B marketing methods and presentation methods that would be viable in this context.

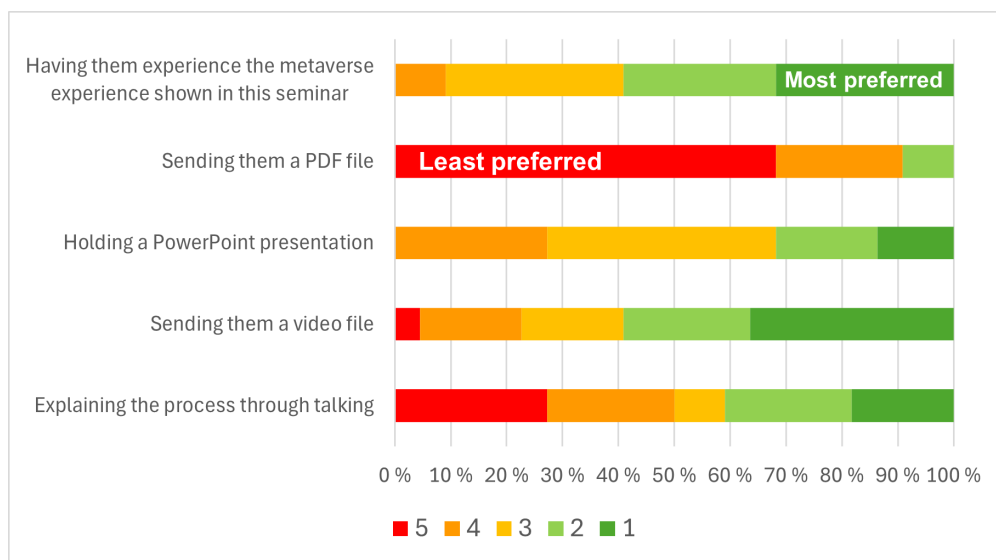


Figure 6.5: The presentation methods given as options and their resulted ranking in the eighth survey question.

Based on the answers, the first place in the ranking in terms of first or second choices received was shared by sending a video file and using the shown metaverse experience as a presentation method. Both of them were chosen either as the first or the second presentation method by 59 % of the testers. The differentiating factor between them was the amount of first choices received. 36 % of the testers

chose sending a video file as their first presentation method, while 32 % chose the shown experience as their first method. The last place in the overall ranking was given to sending a PDF file, which was not chosen as the first presentation method by any of the testers, and only 9 % of the testers selected it as their second method.

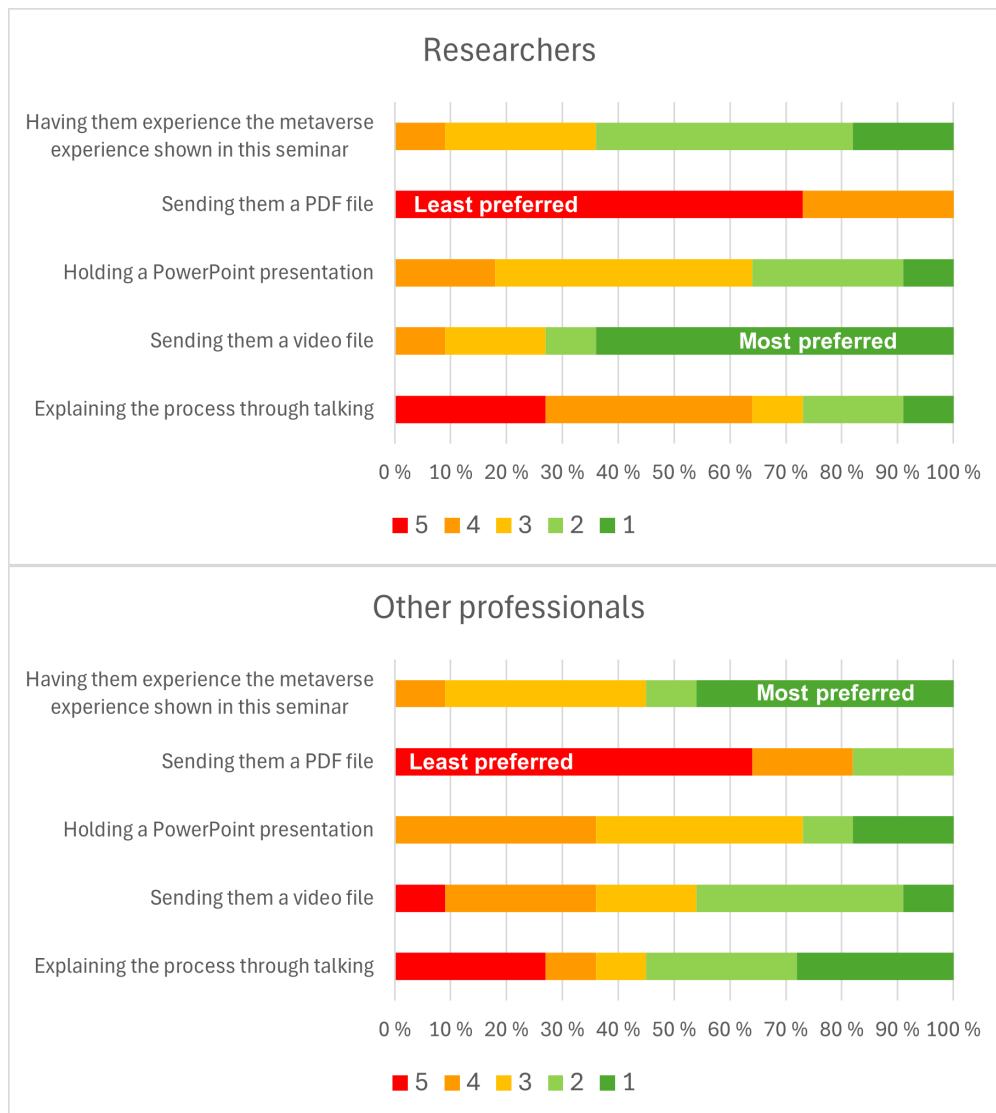


Figure 6.6: The ranking differences based on answerer background in the eighth survey question.

The order of the methods in the ranking results significantly differed based

on the background of the tester, which can be seen in Figure 6.6. Of those who identified themselves as researchers, 64 % chose sending a video file as their first presentation method, and 9 % selected it as their second method. This influenced the selection of the metaverse experience also, as 18 % of the researchers selected it as their first method, and 45 % of them selected it as their second method. Among the shipbuilding professionals and company employees, 45 % selected the metaverse experience as their first presentation method, and 9 % as their second method. Unlike the researchers, the professionals and employees ranked explaining the fossil-free process through talking on the second place in terms of choosing it as their first or second presentation method. 27 % of them selected it as their most preferred way, and 27 % as their second preferred way.

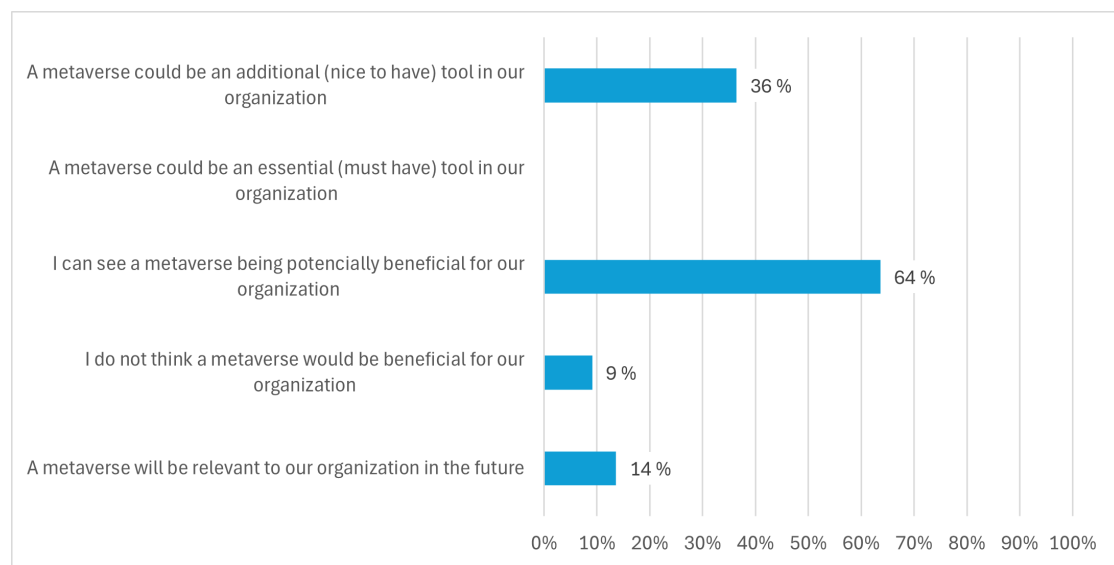


Figure 6.7: How relevant the testers thought metaverses would be for their organizations.

The ninth question was preceded by a short definition of a metaverse. The question asked if the participants felt that metaverses would be relevant to their

organizations, giving multiple statements as answering options. The answering options and the answers received can be seen in Figure 6.7. Based on the answers, 64 % of testers saw a metaverse being potentially beneficial for their organization. Furthermore, 36 % of the testers felt that a metaverse could be an additional tool for their organization.

The question about relevance of metaverses was followed by stating that the experience shown was implemented with Mesh, and the testers were asked if they felt that their organizations could use Mesh or some other metaverse. The answers received can be seen in Figure 6.8. Based on the answers, 82 % of the testers at least somewhat agreed that their organization could use Mesh, and 86 % of the testers at least somewhat agreed that their organization could use some other metaverse.

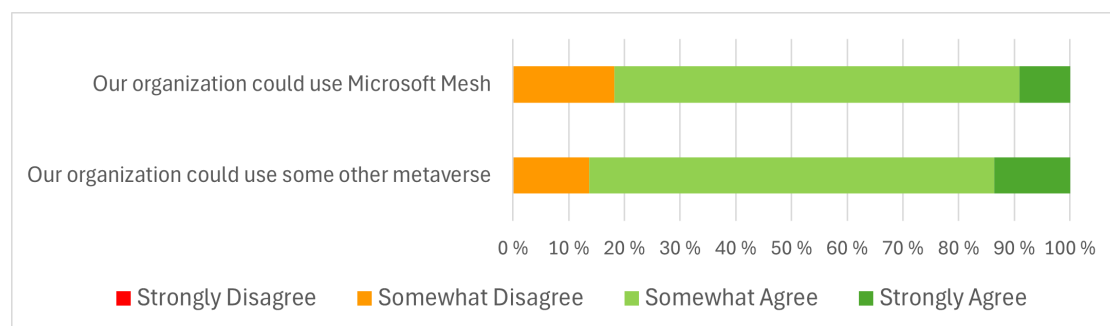


Figure 6.8: How the experience testers felt about their organization using Microsoft Mesh or some other metaverse.

In the end of the survey, the testers were asked two open-ended questions. The first of these asked what major potential issues and benefits the testers saw, if a similar metaverse solution as the presented one would be used at a seminar or an exhibition. Table 6.3 shows a list of the general themes among the benefits and issues mentioned in the answers. The answered issues included the fact that the

experience requires a person to guide the usage of the VR equipment and how the experience works, and that going through the experience is time consuming. In addition, the need to have multiple VR devices to enable multiple testers at the same time, and the lack of more detailed information that the testers could receive through interacting with the components were pointed out. The locations in which the tests took place were noise isolated, which was raised as a concern in the answers as hearing other noises could disturb the tester and break their immersion.

Table 6.3: A list of the general themes among the benefits and issues answered to the seventh survey question.

<b>Theme</b>	<b>Occurrences</b>
<i>An engaging and interesting visual way to explain quite a complex process, gives a forerunner image</i>	9
<i>The testing session needs enough time and resources for several testers</i>	2
<i>The experience does not add enough value yet compared to traditional presentations, it needs more interaction possibilities</i>	2
<i>The environment could look more colorful and appealing or real</i>	2
<i>The session needs a test facilitator to guide with the equipment and how the experience works</i>	1

The last question asked about any other feedback. The received answers consisted of single mentions about the same themes that were covered in the previous

open-ended questions:

- *An overview of the key differences between the processes in the end would have been welcome*
- *Some concepts were too technical or difficult to understand*
- *The environment could look more colorful and appealing or real*
- *Communication willingness with the expert can vary through the background and mood of the tester*

### 6.2.2 Observed results

When observing the test session, sometimes there were practical issues present inside and outside of the experience. Inside the experience, for example difficulties interacting with the grabbable net and issues with object positions were noticed, which both were also written in the survey answers. It was also noticed that the audio heard by the tester inside the experience reacted to physical distance, which in some scenarios affected how well the tester heard the remote expert. Outside of the experience, some testers verbally expressed their opinions about the lack of interaction in the experience, suggesting adding more interaction possibilities. In certain test locations, there was background noise present in the testing scenario, such as people speaking, which affected the testing experience negatively. Some locations also had obstacles such as walls next to the testers, which made physical movement difficult. Regarding the remote expert in the experience, it was observed that some people were more open to discussions with the expert, while others did not leverage the available guidance at all. Most of the individual test

sessions took between 5-10 minutes, but in those cases where the testers discussed with the expert, the time used was up to 15 minutes. Overall, during the observations the testers agreed on the potential of using metaverses instead of traditional presentation methods, while stating that it would require more research and development to achieve the optimal outcome especially regarding the interactions within the experience.

# 7 Discussion and future research

This chapter presents discussion around the suggestions and ideas received through the user feedback survey results. In addition, other potential issues regarding the usage of Mesh as the metaverse platform are discussed. Finally, the chapter presents ideas for future research.

## 7.1 Addressing the ideas and suggestions from the test sessions

During the tests, several areas for possible improvements were identified, which would have made the experience feel better to use. In addition, the experience had some bugs during the first test session, which were fixed for the later ones. This may have affected the ranking opinions in the eighth user feedback survey question. While the background of the tester was identified as one of the factors affecting the ranking, other factors such as stress caused by time restraints may have also affected it. It is also important to note that the ranking results do not provide a definitive comparison of the presentation methods, as the testers were not presented with showcases done with the other presentation methods given as options.

The object positioning was something that was evaluated multiple times during the design. In the original design, the process shown was designed to be on a table, so that it could be seen just by looking forward. This approach was abandoned when the implementation was started, as the implemented size of the components did not make plan possible, and they would have needed to be significantly smaller to fit into the same view. Instead, the design plan was changed so that the subprocesses of a process were positioned within a 45° angle of each other, which minimized the turning required. The risk of text box and the Next button of a phase blocking the view was also acknowledged during the design, which is why they were placed in a corner of the user platform, where the block would be minimal. Unfortunately this was identified to not be enough during the tests, as especially accidental movements sometimes caused the tester to end up in an unwanted position where some objects were either blocking the way or not visible.

Regarding the net interaction, the difficulties in grabbing it when introduced were acknowledged during the test sessions. As in the implementation the net was only grabbable from its narrow handle, a possible solution to the problem could be expanding the hitbox to also include the open grid part of it. Another solution which could improve the experience overall, but result in increased time usage for the experience, would be to implement an introduction inside the experience. The introduction could show the user the same details that were guided by a facilitator during the test sessions, and additionally show how to interact with the net. Adding an introduction to the experience would also give more justification to having a summary of the key takeaways in the end, which was mentioned in the suggestions. The summary could include a practical comparison of the two

processes, helping the testers to gain an improved understanding of both processes, for example by stating why the fossil-free process is a necessary replacement for the traditional process.

There were multiple suggestions of adding more interaction in both the survey answers and the observed test results. Regarding them, the experience was heavily time restrained from the beginning as it was designed to be usable in booths during trade fairs or exhibitions, where time can be very limited. Despite this, already the inclusion of a steelmaking expert led to extending the experience duration significantly in some situations, when the tester had multiple questions to ask or wanted to have a more detailed discussion about the processes. This could also be seen as positive, however, as seeing a user being interested about the experience could help achieve a positive sales outcome. If more interaction possibilities were added, for example other gamification tasks or the possibility to interact with different components to inspect them as suggested, the time consumed would be increased even more often. It is worth noting that although the only implemented gamification mechanism in the experience was within the traditional process, additional gamification mechanisms to the fossil-free process were considered during the design phase, but they were left out due to time restraints. The considered mechanisms centered around presenting the fossil-free process with some connections missing. The user would have been given small grabbable counterparts of them, with visual indicators such as arrows showing where to place them. Placement of the connections would have happened by grabbing the small counterpart, pointing it to the right direction and pressing a trigger from the controllers. The plan included giving the placing opportunity in multiple different phases, and the animations would not be shown before the required connections were placed.

Another suggested improvement that could be added into the experience was the arrows guiding focus to the explained components and connections. While this was mentioned above with the gamification mechanism focusing on object placements, adding it to every phase of both steelmaking processes was not considered during the design. This could also help in gaining a better understanding of the topics covered.

The final suggestion theme received was regarding the visual appearance of the processes; making them look more appealing or real could for example deepen the immersion and give the experience a pleasant visual appearance. However, making the objects look more detailed and real would start to affect the performance after a certain point and it could also have technical limitations in terms of the used rendering pipeline. To avoid this, the objects were created with a simplified appearance while still having small details in the current implementation.

## **7.2 Possible issues from the usage of Mesh**

In addition to the observed issues mentioned in the results in Section 6.2.2, another possible issue comes from the fact that Mesh requires Internet connection with certain network requirements to work, which could be a significant problem in some organizations. As some organizations can have strict network architectures in place, including firewalls and intrusion detection or prevention systems implemented by their IT departments, it is not guaranteed for Mesh to work instantly when its requirements are not acknowledged. In the worst scenario, too strict network requirements can prevent Mesh from working at all, forcing the users to use another network, such as a mobile hotspot.

In Section 5.2.3, it was stated that Mesh does not require any input from the content creator regarding the configuration of physical controllers and related aspects. While this ensured the optimal functionality of Mesh avatars and their hands, it also took some development freedom away from the creator. For example, during the test sessions it was identified that one of the controllers was somewhat redundant. However, because of the native behaviour of Mesh, the controllers were automatically tied to the hands of the avatar. This resulted in not being able to disable the other controller, as it was not possible to get rid of the corresponding avatar hand. In those cases when the controller was just put away, the corresponding hand ended up being in a weird position, which the user could notice.

### **7.3 Future research**

In this thesis, the research was focused on enterprise-targeted metaverses, which are relatively new compared to those targeted for entertainment, as discussed in Section 3.3.3. Some of the entertainment metaverses have existed already for two decades, while the first enterprise-targeted metaverse platforms were launched in 2021. The enterprise-targeted metaverses launched back then, such as NVIDIA Omniverse and Microsoft Mesh, are still under ongoing development, with the potential to develop even further in the future. In addition to following their development, the metaverse industry as a whole should be closely followed in terms of new emerging enterprise platforms, the metaverse industry should be closely followed for new releases, as the options available for conducting independent research are currently quite limited.

Regarding future research of metaverse experiences in a business context, while this thesis conducted research on the potential of metaverses as communication and presentation methods, the research could be expanded by gathering feedback from a larger amount of participants and organizations. In addition, another area of research could be to conduct a definitive comparison of different presentation methods including metaverses as one option, presenting the same content with the given methods and evaluating which achieves the best results.

In terms of the contents of the metaverse experience presented in this thesis, the suggestions discussed in Section 7.1 could be researched more. A future research setting for them could be for example evaluating whether the results achieved with the experience are improved by implementing more gamification or presenting a summary of the topics in the experience. In addition, another future research setting could be to further explore the infrastructural limitations if Microsoft Mesh described in Section 7.2, for example how do different network specifications or intercontinental physical locations affect the experience. Mesh also allows creating multiroom events involving broadcast functionality as stated in [154], which could enable a research setting comparing events created with a single room against the multiroom ones, determining which one of them achieves better results.

The last suggested future research area comes from previous trade fair research. In a study by Sarmiento and Simões [37], the importance of researching the benefits of the interactions and relationship building between company representatives and potential business partners is highlighted. As the interaction between people inside a virtual world is fundamentally different from real-world interaction, there is a need to explore relationship forming through metaverse interaction. This could range from the different modalities of interaction available to the changed dynamics

of sociocultural conditions.

## 8 Conclusion

While the definition of a metaverse varies based on the source, all presented definitions generally refer to a similar idea: a virtual world in which users can interact with each other and the environment. In these virtual worlds, the users are represented by their avatars, which can usually be customized to a certain degree. The first metaverses were created already in the early 2000s, which has led to significant advancements in their development until the present day. These advancements have allowed the metaverse industry to develop to a point where metaverses targeted for industrial and enterprise usage are feasible. In addition, virtual reality devices have been in development for nearly a decade, because of which they are nowadays seen as a revolutionary technology capable of presenting content with a deep immersion. Using these two technologies, immersive metaverse experiences can be created which can significantly improve the understanding about the presented content.

Metaverses naturally enable two-way communication between the users, which is why they can be seen as a solution to the current problem of B2B communication that is described in a study by Graça [36]. While the current B2B communication methods are limited to those employing one-way communication, such as slideshows, pitches and brochures, the study highlights that using two-way

communication between business partners is essential. Furthermore, the need for two-way communication is also identified in the context of sustainability communication by Golob et al. [35]. The study highlights that two-way communication should be emphasized especially when trying to capture the full potential of sustainability communication, while taking into account the overall complexity of communication. Sustainability communication is used nowadays for example in export catalogues, which include PDF files presenting the marketed solutions in a static form. Metaverses have the potential to revolutionize these catalogues among other B2B communications, which was used as motivation in this thesis.

The case study presented in this thesis focused on showcasing differences between two steelmaking processes: a traditional process that produces CO<sub>2</sub> emissions, and a fossil-free process which produces virtually zero CO<sub>2</sub> emissions. Based on these two processes, a standalone enterprise-targeted metaverse experience prototype was created with the Unity development environment, using Microsoft Mesh as the metaverse platform. The experience was developed to be used on Meta Quest VR headsets. The experience was tested during several occasions, in which the testers also answered to a user feedback survey. To evaluate the implemented experience and the testing results, four research questions were formed.

The first research question asks "Can enterprise-targeted metaverse platforms be perceived as commercially feasible nowadays?". In Section 3.3 of this thesis, a categorization for metaverse platforms was introduced. The categorization was created based on known notable platforms, having some similarities with the earlier research presented in the section. The main categories presented in the categorization were entertainment and enterprise, of which the latter was evaluated in more detail to answer this research question. The discussed enterprise platforms were

seen to focus on two different groups: industrial and productivity. Due to this, the enterprise main category of the categorization was further divided into corresponding subcategories to better serve its purpose. The known platforms included six different ones that fell into the enterprise main category, of which three were focused on industrial functionalities, and two on enhancing productivity. In addition, one was focused on both industrial and productivity functionalities. Three of these platforms were selected for further analysis presented in Chapter 4, and they were Meta Horizon Workrooms, Microsoft Mesh, and NVIDIA Omniverse. The purpose of the analysis was to find a suitable platform for implementing the prototype described in Chapter 5, which was then used to evaluate the feasibility of metaverses as a B2B marketing and communication tool.

Each of the three analyzed enterprise metaverse platforms provided different results in terms of their commercial feasibility. The experience received from Meta Horizon Workrooms can be compared to Microsoft Teams, as in practice it provides a similar collaboration experience, as seen previously in Figure 4.1. The added value comes from having immersive virtual meetings in 3D spaces with interactable elements, which can be joined either with a computer or Meta Quest VR headsets. As the Microsoft ecosystem is already popular among enterprises, part of which Teams is, the added value of Horizon Workrooms can be seen as insufficient to justify switching outside of the already adopted Microsoft products. The purpose of enterprise meetings generally is to have discussions with people and collaborate, which can be achieved without using immersive virtual 3D spaces. Especially with the different integrations to Microsoft products that Teams nowadays has, the added value in practice is even lower. The content creation part cannot be evaluated in terms of commercial feasibility, as Horizon Workrooms does not

offer content creation possibilities. For NVIDIA Omniverse, the analysis fell short during this thesis because of its demanding hardware requirements, as explained in Section 4.2, which resulted in the thesis being unable to analyze its commercial feasibility in practice. These requirements could already be an important factor regarding the feasibility for some enterprises, as the development cannot be done on every computer. However, it is clear that some enterprises, such as BMW and Siemens, already recognize the commercial feasibility of Omniverse in industrial context, leading to a partnership with NVIDIA as stated in Sections 1.1 and 3.3.3.

The platform selected for the prototype implementation that was discussed in Section 5, Microsoft Mesh, showed the most promising results in terms of commercial feasibility. As mentioned earlier in this chapter, it provided functionalities for both industrial productivity usage, which was one of the factors providing feasibility. It allowed both having collaborative 3D meetings similar to Horizon Workrooms, even having a Teams integration as described in Section 4.4. For content creation, it provided an extension for Unity, bringing the ability to create metaverse experiences to an already popular development environment. However, it also introduced some problems, such as requiring various different licenses and restricting content creation freedom, which are discussed more with the second research question.

Based on the enterprise-targeted metaverse platforms researched in this thesis, especially industrial metaverse platforms can be seen as commercially feasible since different organizations are already integrating them into their businesses. In terms of productivity metaverses, the commercial feasibility cannot be seen as clearly yet, as they are not as notably used by organizations and might not provide enough added value yet for some organizations.

The second research question asks "What problems do metaverse platforms introduce in an enterprise context?". This thesis researched three different enterprise-targeted platforms, of which the first one, NVIDIA Omniverse was found to have exceptionally demanding requirements for its development hardware as stated in Section 4.2. These requirements included for example the need to have a powerful graphics card, and an extensive amount of memory. Developing with hardware not fulfilling these requirements was not possible. While this could have been justifiable with a different case that would have needed detailed graphics and realistic physics, the design of the steelmaking case in this thesis was not targeting either of them, already because it was developed for standalone VR headsets. The other researched platform that was not selected for the implementation, Meta Horizon Workrooms, did not include necessary functionalities for the given steelmaking case, such as building custom environments with logics. Thus, the development was halted with it also. With Microsoft Mesh, there were some problems already during the development phase.

As described in Section 5.2.3, Microsoft Mesh did not allow using the native development ways of Unity, instead bringing its own ways and forcing developers to use them. In addition to preventing from using the native C# development of Unity, Mesh also introduced difficulties when implementing the lighting system for the experience. It was originally designed to use outlines as shown in Figure 5.7, but because Mesh restricted some of the post-processing functionalities needed, the implemented system ended up using only unlit and lit states for the components, which were shown in Figure 5.8. There was also problems with one of the development methods offered by Mesh, Cloud Scripting, which would have allowed the logic to use written C# code, API calls and more complex logic.

During the research in summer 2024, the Cloud Scripting method required two different versions of the .NET framework, 6.0. and 7.0, from which the latter one was already deprecated by Microsoft in May 2024. This introduced difficulties in trying to manage the different versions and the development environments that supported them, which resulted in not using the Cloud Scripting method. It was also not seen as necessary for the given steelmaking case, as the functionalities could be implemented without it. In addition to the content creation problems, the commercial feasibility could also be affected by the various subscription needs. As described in Section 4.4, the required subscriptions differ based on the desired environment needs. In addition, if the Cloud Scripting development method is used during the development, a Microsoft Azure subscription is needed.

Based on the enterprise-targeted metaverse platforms researched in this thesis, the problems introduced by metaverse platforms in an enterprise context can include significant differences based on the platform. For example, they can be strictly limited to either industrial or productivity usage, causing problems when researching them for the other use case. Furthermore, instead of using widely known native development ways, productivity platforms can be restricted their own methods. In addition, some platforms can also have strict hardware requirements, if they are focused on heavy workloads. Finally, as these platforms are often commercial products, there can be various subscriptions required based on what is needed for the use case.

The third research question is presented as "How easy and efficient it is to create content for and use the researched metaverse platforms, both as a developer and as a user?". As discussed previously in this chapter, this research question cannot be evaluated in terms of NVIDIA Omniverse. Regarding Meta Horizon Workrooms,

while it was not suitable for the given steelmaking case, it can be perceived as suitable for collaboration and enhancing productivity. As these purposes can be seen to target the same user-friendliness and efficiency as joining a regular meeting through Microsoft Outlook or Google calendars, the ease of use of Horizon Workrooms is on a similar level. The platform offered scheduling meetings held in virtual rooms provided by Meta, and the meetings could be scheduled without a need for extensive knowledge through the Workrooms website as mentioned in Section 4.3. Once a meeting was scheduled, it could be synced to Outlook or Google calendars from the Workrooms website, allowing the users to join the meeting through their calendars. While the VR capabilities of Horizon Workrooms required the user to join through a Horizon Workrooms application available for Meta Quest headset, and using a VR headset for the first time can require some practice, it was also possible to join a meeting through a regular computer with the aforementioned calendar integration. After joining, the users had avatars which they could control with platform-specific inputs. Horizon Workrooms cannot be evaluated in terms of content creation, as it did not allow creating custom content.

As previously mentioned with the second research question, Microsoft Mesh introduced several difficulties for the developer, heavily restricting the development capabilities. Still, when creating environments without the need for realistic graphics, API calls or otherwise complex logic, the content creation did not provide notable difficulties and it could be seen as somewhat easy and efficient. In terms of regular usage of the Microsoft Mesh platform, while the process of publishing a developed project to be usable on end devices was somewhat complex as discussed in Section 5.2.4, the parts of the publishing process that happen on the Mesh portal do not require extensive development knowledge and could be learned by a regular

user with instructions. The creation of the environment collection is most likely done by the content creator, because it is followed by tasks that need to be done by the creator in Unity. After this, the regular user would only need to learn the creation of an event template and scheduling an event based on a template, which was not a large workload and could be even compared to creating a regular calendar meeting in Outlook or Google calendars. When an event was created, it could be joined either through a Mesh application that can be downloaded from the Microsoft Store on PCs, or through a Meta Quest VR headset with a separate Mesh application from the Meta Quest store. After joining, the users had avatars which they could control with platform-specific inputs. In the survey results presented in Section 6.2.1, most of the tested at least somewhat agreed that the experience was easy to use. The complexity of the showcased topic was visible in the answers received, but it did not significantly affect the overall positive results.

The last research question asks "Can metaverse platforms be used to gain additional value compared to the existing B2B communication methods?". As discussed previously in this chapter, the answer depends on the use case. When communicating about industrial products, industrial metaverses can be seen to provide enough added value to justify the workload that results from taking them into use. Different organizations have already started leveraging these platforms as previously mentioned, and the added value was also proved in this thesis. In terms of platforms focused on productivity functionalities, the added value may not be that significant yet, as their commercial feasibility is rather questionable, as stated with the first research question. Overall, while the contemporary B2B communication methods described in Sections 2.2 and 2.3 can be seen as acceptable for their purposes, using metaverses for presenting the information, especially if

---

it is complex, is the preferred way as seen in the results of this case study in Section 6.2.1. In addition, they have significant potential in B2B marketing and are expected to fundamentally change the interactions within the industry, as recognized in earlier research [38] [39]. A metaverse experience similar to what was suggested in this thesis allows showcasing the solutions with modern ways such as dynamic content, immersion and gamification, which together can form a deeper interest in the showcased content and improve received understanding. There are still areas where the experience can be improved, which are discussed with more detail in Section 7.1, but as a prototype the experience was a success.

# References

- [1] M. Ball, *The Metaverse: And How It Will Revolutionize Everything*, First edition. New York, NY: Liveright Publishing Corporation, a division of W.W. Norton & Company, 2022, ISBN: 978-1-324-09203-2.
- [2] G. Kumparak. “A Brief History Of Oculus”. (Mar. 26, 2014), [Online]. Available: <https://techcrunch.com/2014/03/26/a-brief-history-of-oculus/> (visited on 10/01/2024).
- [3] S. Parkin, “Who needs the metaverse? meet the people still living on second life”, *The Guardian*, Jun. 10, 2023, ISSN: 0261-3077. [Online]. Available: <https://www.theguardian.com/technology/2023/jun/10/who-needs-the-metaverse-meet-the-people-still-living-on-second-life> (visited on 12/17/2024).
- [4] M. Gatollari. “Who are the two creators of 'roblox,' the wildly popular online game?” (Apr. 19, 2021), [Online]. Available: <https://www.distractionify.com/p/who-are-the-two-creators-of-roblox> (visited on 06/16/2025).

- 
- [5] J. Henningson. “The history of minecraft”. (Oct. 18, 2022), [Online]. Available: <https://www.redbull.com/se-en/history-of-minecraft> (visited on 12/17/2024).
- [6] *Multiplayer minecraft wiki*. [Online]. Available: <https://minecraft.fandom.com/wiki/Multiplayer> (visited on 12/17/2024).
- [7] “Announcing fortnite battle royale”. (Sep. 12, 2017), [Online]. Available: <https://www.fortnite.com/news/announcing-fortnite-battle-royale> (visited on 06/16/2025).
- [8] D. Strickland. “Minecraft has ‘maybe 120 million active players,’ xbox’s phil spencer says”. (Apr. 4, 2023), [Online]. Available: <https://www.tweaktown.com/news/90624/minecraft-has-maybe-120-million-active-players-xboxs-phil-spencer-says/index.html> (visited on 12/17/2024).
- [9] J. Taylor. “How many people play fortnite? player count in 2024 - dexerto”. (Dec. 10, 2024), [Online]. Available: <https://www.dexerto.com/fortnite/how-many-people-play-fortnite-player-count-1666278/> (visited on 12/17/2024).
- [10] “Global roblox games DAU by region 2024 | statista”. (Oct. 2024), [Online]. Available: <https://www.statista.com/statistics/1192586/daily-active-users-global-roblox-region/> (visited on 12/17/2024).
- [11] “SL Live Player Count & Population 2025”. (2025), [Online]. Available: <https://www.playerauctions.com/player-count/sl/> (visited on 06/23/2025).

- 
- [12] A. Kharpal. “Microsoft HoloLens ‘mixed reality’ headset launches in Europe, Australia, New Zealand”. (Oct. 12, 2016), [Online]. Available: <https://www.cnbc.com/2016/10/12/microsoft-hololens-mixed-reality-headset-launches-in-europe-australia-new-zealand.html> (visited on 10/01/2024).
- [13] R. Smith. “HTC Vive Launch Day News & First Impressions”. (Apr. 5, 2016), [Online]. Available: <https://www.anandtech.com/show/10221/htc-vive-launch-day-news-first-impressions> (visited on 04/13/2025).
- [14] Apple. “Apple Vision Pro available in the U.S. on February 2”, Apple Newsroom. (Aug. 1, 2024), [Online]. Available: <https://www.apple.com/newsroom/2024/01/apple-vision-pro-available-in-the-us-on-february-2/> (visited on 04/13/2025).
- [15] “Meta Quest 3: The First Mass-Market Mixed Reality Headset Is Available Now”. (Sep. 27, 2023), [Online]. Available: <https://www.meta.com/blog/quest/meta-quest-3-pre-orders-asgards-wrath-2-bundle-vr-mr-headset-price> (visited on 04/13/2025).
- [16] “NVIDIA Launches Omniverse Design Collaboration and Simulation Platform for Enterprises”. (Apr. 12, 2021), [Online]. Available: <http://nvidia-news.nvidia.com/news/nvidia-launches-omniverse-design-collaboration-and-simulation-platform-for-enterprises> (visited on 10/01/2024).
- [17] A. Sag. “Microsoft’s Mesh Platform For Mixed Reality Puts Microsoft At The Forefront Of XR Collaboration”. (Mar. 3, 2021), [Online]. Available: <https://www.forbes.com/sites/moorinsights/2021/03/03/microsof>

- ts-mesh-platform-for-mixed-reality-puts-microsoft-at-the-fore-front-of-xr-collaboration/ (visited on 10/01/2024).
- [18] “Siemens launches siemens xcelerator an open digital business platform to accelerate digital transformation”. (Jun. 29, 2022), [Online]. Available: <https://press.siemens.com/global/en/pressrelease/siemens-launches-siemens-xcelerator-open-digital-business-platform-accelerate-digital> (visited on 10/01/2024).
- [19] M. Geyer. “BMW group starts global rollout of NVIDIA omniverse”, NVIDIA Blog. (Mar. 21, 2023), [Online]. Available: <https://blogs.nvidia.com/blog/bmw-group-nvidia-omniverse/> (visited on 01/20/2025).
- [20] M. Bhatia and R. Kumar, “Digital Twin and sustainability: A data-driven scientometric exploration”, *Internet of Things*, vol. 32, p. 101 652, Jul. 2025, ISSN: 25426605. DOI: 10.1016/j.iot.2025.101652. [Online]. Available: <https://linkinghub.elsevier.com/retrieve/pii/S2542660525001660> (visited on 06/23/2025).
- [21] University of Turku, *Mixed Reality » SusFlow*. [Online]. Available: <https://tt.utu.fi/ar/research/susflow/> (visited on 04/13/2025).
- [22] Finpro. “Finpro | from export association to finpro”. (Dec. 18, 2010), [Online]. Available: <https://web.archive.org/web/20101218210536/http://www.finpro.fi/en-US/About+Finpro/Our+Story/> (visited on 05/05/2025).
- [23] Finnish Customs, *Free trade*, Free trade - Finnish Customs. [Online]. Available: <https://tulli.fi/about-us/customs-museum/history-of-finnish-customs/free-trade> (visited on 05/05/2025).

- [24] Business Finland, *About us in brief*. [Online]. Available: <https://www.businessfinland.fi/en/for-finnish-customers/about-us/in-brief> (visited on 05/05/2025).
- [25] Viexpo, *History | viexpo*. [Online]. Available: <https://viexpo.fi/en/Viexpo/history/> (visited on 05/05/2025).
- [26] Viexpo, *Expert in export and internationalisation | viexpo*. [Online]. Available: <https://viexpo.fi/en/viexpo/> (visited on 05/15/2025).
- [27] Finland Abroad. “Finpro and tekes uniting as business finland - finland abroad: United kingdom”. (Jan. 3, 2018), [Online]. Available: [https://finlandabroad.fi/web/gbr/current-affairs/-/asset\\_publisher/4ojVRXvbDRVa/content/finpro-ja-tekes-yhdistyvat-business-finland-iksi-vuoden-alus-1/384951](https://finlandabroad.fi/web/gbr/current-affairs/-/asset_publisher/4ojVRXvbDRVa/content/finpro-ja-tekes-yhdistyvat-business-finland-iksi-vuoden-alus-1/384951) (visited on 05/15/2025).
- [28] Team Finland. “Team finland organizations - team finland”. (2025), [Online]. Available: <https://www.team-finland.fi/en/team-finland-organisations> (visited on 05/15/2025).
- [29] Business Finland, *Decarbonized maritime and ports - business finland*. [Online]. Available: <https://www.businessfinland.fi/en/for-finnish-customers/services/programs/ended-programs/decarbonized-maritime-and-ports> (visited on 05/15/2025).
- [30] *Business Finland Media Bank - Maritime solutions*. [Online]. Available: <https://mediabank.businessfinland.fi/1/vhcQV7Lk7C-n/f/ZWv7> (visited on 06/23/2025).

- [31] Business Finland. “Business finland is publishing a digital brochure to present finnish offering for solutions for decarbonizing industry - business finland”. (Jun. 16, 2024), [Online]. Available: <https://web.archive.org/web/20240616120140/https://www.businessfinland.fi/en/whats-new/news/2022/business-finland-is-publishing-a-digital-brochure-to-present-finnish-offering-for-solutions-for-decarbonizing-industry> (visited on 05/15/2025).
- [32] B. Signitzer and A. Prexl, “Corporate sustainability communications: Aspects of theory and professionalization”, *Journal of Public Relations Research*, vol. 20, no. 1, pp. 1–19, Dec. 25, 2007, ISSN: 1062-726X, 1532-754X. DOI: 10.1080/10627260701726996. [Online]. Available: <http://www.tandfonline.com/doi/abs/10.1080/10627260701726996> (visited on 01/20/2025).
- [33] M. Mäkelä, O. Apostol, and K. Heikkilä, “Pride and fear: Emotions in sustainability”, in *Corporate Social Responsibility: Challenges in Diversity, Accountability and Sustainability*, ser. Management Science - Theory and Applications, B. Escobar-Pérez and M. d. M. Miras-Rodríguez, Eds., New York: Nova Science Publishers, 2018, pp. 121–147.
- [34] D. A. Pitta, M. Weisgal, and P. Lynagh, “Integrating exhibit marketing into integrated marketing communications”, *Journal of Consumer Marketing*, vol. 23, no. 3, pp. 156–166, Apr. 1, 2006, ISSN: 0736-3761. DOI: 10.1108/07363760610663312. [Online]. Available: <https://www.emerald.com/insight/content/doi/10.1108/07363760610663312/full/html> (visited on 01/20/2025).

- [35] U. Golob, K. Podnar, and V. Zabkar, “Sustainability communication”, *International Journal of Advertising*, vol. 42, no. 1, pp. 42–51, Jan. 2, 2023, ISSN: 0265-0487, 1759-3948. DOI: 10.1080/02650487.2022.2144035. [Online]. Available: <https://www.tandfonline.com/doi/full/10.1080/02650487.2022.2144035> (visited on 01/20/2025).
- [36] S. S. Graça, “Forging global b2b relationships through effective communication”, in *Emerging Markets and the Future of the BRIC Nations*, Edward Elgar Publishing, 2015, pp. 127–142.
- [37] M. Sarmiento and C. Simões, “The evolving role of trade fairs in business: A systematic literature review and a research agenda”, *Industrial Marketing Management*, vol. 73, pp. 154–170, Aug. 2018, ISSN: 00198501. DOI: 10.1016/j.indmarman.2018.02.006. [Online]. Available: <https://linkinghub.elsevier.com/retrieve/pii/S0019850118300907> (visited on 01/20/2025).
- [38] Z. Ghali, R. A. Rather, and I. Khan, “Investigating metaverse marketing-enabled consumers social presence, attachment, engagement and (re)visit intentions”, *Journal of Retailing and Consumer Services*, vol. 77, p. 103671, Mar. 2024, ISSN: 09696989. DOI: 10.1016/j.jretconser.2023.103671. [Online]. Available: <https://linkinghub.elsevier.com/retrieve/pii/S0969698923004228> (visited on 11/08/2024).
- [39] B. Bamberger, W. Reinartz, and W. Ulaga, “Navigating the future of b2b marketing: The transformative impact of the industrial metaverse”, *Journal of Business Research*, vol. 188, p. 115057, Feb. 2025, ISSN: 01482963. DOI: 10.1016/j.jbusres.2024.115057. [Online]. Available: <https://linkinghub.elsevier.com/retrieve/pii/S014829632400057> (visited on 11/08/2024).

- inghub.elsevier.com/retrieve/pii/S0148296324005617 (visited on 12/20/2024).
- [40] S. Helle, T. Nyysönen, O. Heimo, L. Sakari, and T. Lehtonen, *Virtual reality applied to interior design reviews in shipbuilding*, In publication process.
- [41] S.-M. Park and Y.-G. Kim, “A Metaverse: Taxonomy, Components, Applications, and Open Challenges”, *IEEE Access*, vol. 10, pp. 4211–4216, 2022, ISSN: 2169-3536. DOI: 10.1109/ACCESS.2021.3140175. (visited on 06/07/2024).
- [42] N. Stephenson, *Snow Crash* (A Bantam Spectra Book). New York: Bantam Books, 1992, ISBN: 978-0-553-08853-3 978-0-553-35192-7.
- [43] T. Huddleston Jr. “This 29-year-old book predicted the ‘metaverse’ — and some of Facebook’s plans are eerily similar”. (Nov. 3, 2021), [Online]. Available: <https://www.cnbc.com/2021/11/03/how-the-1992-sci-fi-novel-snow-crash-predicted-facebooks-metaverse.html> (visited on 06/07/2024).
- [44] *Meta-, prefix meanings, etymology and more / oxford english dictionary*, in *Oxford English Dictionary*. [Online]. Available: [https://www.oed.com/dictionary/meta\\_prefix?tab=etymology](https://www.oed.com/dictionary/meta_prefix?tab=etymology) (visited on 06/07/2024).
- [45] A. Maden and G. N. Yücenur, “Evaluation of sustainable metaverse characteristics using scenario-based fuzzy cognitive map”, *Computers in Human Behavior*, vol. 152, p. 108 090, Mar. 2024, ISSN: 07475632. DOI: 10.1016/j.chb.2023.108090. (visited on 06/07/2024).

- [46] *Metaverse, n. meanings, etymology and more* / *Oxford English Dictionary*. [Online]. Available: [https://www.oed.com/dictionary/metaverse\\_n?tab=meaning\\_and\\_use#130112796](https://www.oed.com/dictionary/metaverse_n?tab=meaning_and_use#130112796) (visited on 06/07/2024).
- [47] S. Spielberg, *Ready Player One*, Action, Adventure, Sci-Fi, Mar. 2018.
- [48] S. G. Weinbaum, *Pygmalion's Spectacles*. Lanham: Start Publishing LLC, 2016, ISBN: 978-1-68299-921-9.
- [49] G. Kao, J. Hong, M. Perusse, and W. Sheng, "The Rise and Fall of Virtual Reality: What It Takes to Create Technological Disruption", in *Turning Silicon into Gold*. Berkeley, CA: Apress, 2020, pp. 133–139, ISBN: 978-1-4842-5628-2 978-1-4842-5629-9. DOI: 10.1007/978-1-4842-5629-9\_19. (visited on 06/12/2024).
- [50] "The Metaverse: Building the Spatial Internet". (2024), [Online]. Available: <https://www.ballmetaversebook.com/> (visited on 06/12/2024).
- [51] W. Gibson, *Neuromancer* (ACE Science Fiction), Nachdr. New York: ACE Books, 1997, ISBN: 978-0-441-56959-5.
- [52] C. Boo and A. Suh, "Developing scales for assessing metaverse characteristics and testing their utility", *Computers in Human Behavior Reports*, vol. 13, p. 100366, Mar. 2024, ISSN: 24519588. DOI: 10.1016/j.chbr.2023.100366. (visited on 07/01/2024).
- [53] J. D. N. Dionisio, W. G. B. Iii, and R. Gilbert, "3D Virtual worlds and the metaverse: Current status and future possibilities", *ACM Computing Surveys*, vol. 45, no. 3, pp. 1–38, Jun. 2013, ISSN: 0360-0300, 1557-7341. DOI: 10.1145/2480741.2480751. (visited on 07/20/2024).

- 
- [54] S. Kim, “The metaverse: The digital earth—the world of rising trends”, *Paju: PlanB Design*, 2021.
- [55] S. Barta, S. Ibáñez-Sánchez, C. Orús, and C. Flavián, “Avatar creation in the metaverse: A focus on event expectations”, *Computers in Human Behavior*, vol. 156, p. 108 192, Jul. 2024, ISSN: 07475632. DOI: 10.1016/j.chb.2024.108192. (visited on 07/09/2024).
- [56] G. Burnett and C. Harvey, “An investigation of the advantages and disadvantages of university students as avatars in virtual learning spaces”, Jul. 2023. (visited on 07/09/2024).
- [57] “Terraria”. (2021), [Online]. Available: <https://terraria.org/> (visited on 05/26/2025).
- [58] J. Holm and E. Mäkinen, “The Value of Currency in World of Warcraft”, *Journal of Internet Social Networking and Virtual Communities*, vol. 2018, pp. 1–13, Jun. 2018, ISSN: 21660794, 21660794. DOI: 10.5171/2018.672253. (visited on 07/22/2024).
- [59] “Marketplace | Decentraland Documentation”. (Jun. 13, 2025), [Online]. Available: <https://docs.decentraland.org/player/market/marketplace/> (visited on 06/16/2025).
- [60] *Ways to Get Robux – Roblox Support*. [Online]. Available: <https://en.help.roblox.com/hc/en-us/articles/203313200-Ways-to-Get-Robux> (visited on 07/22/2024).

- 
- [61] “Blizzard Support - World of Warcraft System Requirements”. (Jan. 2025), [Online]. Available: <https://eu.battle.net/support/en/article/76459> (visited on 07/22/2024).
- [62] C. Davenport. “Across the Metaverse: My trip through VR social platforms”. (Mar. 22, 2024), [Online]. Available: <https://www.spacebar.news/across-the-metaverse/> (visited on 07/22/2024).
- [63] M. Adams. “7 Top Metaverse Coins – Forbes Advisor”. (Jul. 1, 2024), [Online]. Available: <https://www.forbes.com/advisor/investing/cryptocurrency/top-metaverse-coins/> (visited on 07/22/2024).
- [64] G. Lawton. “Metaverse interoperability challenges and impact”. (Mar. 7, 2024), [Online]. Available: <https://www.techtarget.com/searchcio/tip/Metaverse-interoperability-challenges-and-impact> (visited on 07/22/2024).
- [65] “Defining and Building the Metaverse”. (2024), [Online]. Available: <https://initiatives.weforum.org/defining-and-building-the-metaverse/home> (visited on 07/22/2024).
- [66] “Interoperability in the Metaverse”, World Economic Forum, Tech. Rep., Jan. 2024. (visited on 07/22/2024).
- [67] “Types Of Metaverse Explained: A Comprehensive Overview”. (Mar. 8, 2023), [Online]. Available: <https://mudrex.com/learn/types-of-metaverse-explained/> (visited on 10/01/2024).
- [68] T. Bhatt. “Types of Metaverse: An In-Depth Exploration”. (Oct. 11, 2023), [Online]. Available: <https://web.archive.org/web/20240422210301/h>

- <https://www.intelivita.com/blog/types-of-metaverse/> (visited on 10/01/2024).
- [69] S. P. Suryodiningrat, A. Ramadhan, and T. Hirashima, “The Elements of Every Metaverse Types: A Systematic Literature Review”, *TEM Journal*, pp. 771–782, Feb. 2024, ISSN: 2217-8333, 2217-8309. DOI: 10.18421/TEM131-80. (visited on 10/01/2024).
- [70] J. Guo, J. Leng, J. L. Zhao, *et al.*, “Industrial metaverse towards Industry 5.0: Connotation, architecture, enablers, and challenges”, *Journal of Manufacturing Systems*, vol. 76, pp. 25–42, Oct. 2024, ISSN: 02786125. DOI: 10.1016/j.jmsy.2024.07.007. (visited on 10/01/2024).
- [71] J. Wu, K. Lin, D. Lin, Z. Zheng, H. Huang, and Z. Zheng, “Financial Crimes in Web3-Empowered Metaverse: Taxonomy, Countermeasures, and Opportunities”, *IEEE Open Journal of the Computer Society*, vol. 4, pp. 37–49, 2023, ISSN: 2644-1268. DOI: 10.1109/OJCS.2023.3245801. (visited on 10/01/2024).
- [72] *Social media | english meaning - cambridge dictionary*, in *Cambridge Dictionary*, Sep. 25, 2024. [Online]. Available: <https://dictionary.cambridge.org/dictionary/english/social-media> (visited on 10/01/2024).
- [73] “History of the Metaverse Explained | TechTarget”. (Mar. 1, 2024), [Online]. Available: <https://www.techtarget.com/searchcio/tip/History-of-the-metaverse-explained> (visited on 10/01/2024).
- [74] Wowhead. “World of Warcraft Launched Seventeen Years Ago Today on November 23, 2004 - Wowhead News”. (Nov. 23, 2021), [Online]. Available: <https://www.wowhead.com/news/world-of-warcraft-launched-se>

- venteen-years-ago-today-on-november-23-2004-324824 (visited on 06/24/2025).
- [75] T. Curtis. “Seven Years Of World Of Warcraft”. (Nov. 23, 2011), [Online]. Available: <https://www.gamedeveloper.com/business/seven-years-of-i-world-of-warcraft-i-> (visited on 07/21/2024).
- [76] “World of warcraft shatters day-one sales records”. (Dec. 2, 2004), [Online]. Available: <https://www.gamesindustry.biz/world-of-warcraft-shatters-day-one-sales-records> (visited on 07/21/2024).
- [77] D. Takahashi. “The DeanBeat: Epic graphics guru Tim Sweeney foretells how we can create the open Metaverse”. (Dec. 9, 2016), [Online]. Available: <https://venturebeat.com/games/the-deanbeat-epic-boss-tim-sweeney-makes-the-case-for-the-open-metaverse/> (visited on 10/01/2024).
- [78] “Minecraft number of players worldwide 2021”. (Oct. 2021), [Online]. Available: <https://www.statista.com/statistics/680139/minecraft-active-players-worldwide/> (visited on 10/01/2024).
- [79] T. Phillips. “Fortnite earned \$9bn in two years”. (May 18, 2021), [Online]. Available: <https://www.eurogamer.net/fortnite-earned-usd9bn-in-two-years> (visited on 10/01/2024).
- [80] P. Savage. “Valve launch Steam VR beta ahead of their Dev Days event”. (Jan. 14, 2014), [Online]. Available: <https://www.pcgamer.com/valve-launch-steam-vr-beta-ahead-of-their-dev-days-event/> (visited on 10/01/2024).

- [81] *VR chat - LaunchBox games database*. [Online]. Available: <https://gamesdb.launchbox-app.com/games/details/94028-vr-chat> (visited on 06/16/2025).
- [82] R. Schultz. “Another One Bites the Dust: AltspaceVR to Permanently Close on March 10th, 2023”. (Jan. 20, 2023), [Online]. Available: <https://ryanschultz.com/2023/01/20/another-one-bites-the-dust-altspacevr-to-permanently-close-on-march-10th-2023/> (visited on 10/01/2024).
- [83] “Facebook to Acquire Oculus”. (Mar. 25, 2014), [Online]. Available: <https://about.fb.com/news/2014/03/facebook-to-acquire-oculus/> (visited on 10/01/2024).
- [84] A. Kharpal. “Microsoft regains its edge with hologram headset”. (Jan. 22, 2015), [Online]. Available: <https://www.cnbc.com/2015/01/22/hololens-microsofts-augmented-reality-headset.html> (visited on 10/01/2024).
- [85] E. Craig. “The End of AltspaceVR - What it Means for the Metaverse”. (Jan. 23, 2023), [Online]. Available: <https://www.digitalbodies.net/the-end-of-altspacevr-what-it-means-for-the-metaverse/> (visited on 10/01/2024).
- [86] R. Meltz. “The 6 Most Important Things That Happened in Virtual Reality in 2015”. (Dec. 21, 2015), [Online]. Available: <https://www.technologyreview.com/2015/12/21/71925/the-6-most-important-things-that-happened-in-virtual-reality-in-2015/> (visited on 10/01/2024).

- [87] “First Look at the Rift, Shipping Q1 2016 | Meta Quest Blog”. (May 6, 2015), [Online]. Available: <https://www.oculus.com/blog/first-look-at-the-rift-shipping-q1-2016> (visited on 10/01/2024).
- [88] “Rec room on steam”. (Jun. 1, 2016), [Online]. Available: [https://store.steampowered.com/app/471710/Rec\\_Room/](https://store.steampowered.com/app/471710/Rec_Room/) (visited on 10/01/2024).
- [89] “Bigscreen Beta on Steam”. (Apr. 28, 2016), [Online]. Available: [https://store.steampowered.com/app/457550/Bigscreen%5C\\_Beta/](https://store.steampowered.com/app/457550/Bigscreen%5C_Beta/) (visited on 10/01/2024).
- [90] “Steam :: VRChat :: Welcome to VRChat early access!” (Feb. 2, 2017), [Online]. Available: <https://store.steampowered.com/news/app/438100/view/5318144537297818630> (visited on 10/01/2024).
- [91] “Khronos Reveals API Updates & New Working Groups at GDC”. (Feb. 27, 2017), [Online]. Available: <https://www.khronos.org/news/press/khronos-reveals-api-updates-new-workgroups-at-gdc> (visited on 10/01/2024).
- [92] N. Whiting. “The OpenXR Working Group is Here!” (Feb. 27, 2017), [Online]. Available: <https://www.khronos.org/blog/the-openxr-working-group-is-here> (visited on 10/01/2024).
- [93] M. Bastian. “Microsoft kills AltspaceVR and with it a piece of VR history”. (Jan. 23, 2023), [Online]. Available: <https://mixed-news.com/en/microsoft-kills-altspacevr-and-with-it-a-piece-of-vr-history/> (visited on 10/01/2024).

- 
- [94] L. Matney. “Microsoft acquires social virtual reality app AltspaceVR”. (Oct. 3, 2017), [Online]. Available: <https://techcrunch.com/2017/10/03/microsoft-acquires-social-virtual-reality-app-altspacevr/> (visited on 10/01/2024).
- [95] Meta. “Horizon workrooms virtual office and meetings | meta for work”. (2024), [Online]. Available: <https://forwork.meta.com/fi/en/horizon-workrooms/> (visited on 01/20/2025).
- [96] I. Hamilton. “Facebook Launches Horizon Workrooms To Power Remote Work”. (Aug. 18, 2021), [Online]. Available: <https://www.uploadvr.com/facebook-horizon-workrooms-launch/> (visited on 10/01/2024).
- [97] D. Milmo. “Enter the metaverse: The digital future Mark Zuckerberg is steering us toward”. (Oct. 28, 2021), [Online]. Available: <https://www.theguardian.com/technology/2021/oct/28/facebook-mark-zuckerberg-meta-metaverse> (visited on 10/01/2024).
- [98] BBC. “Facebook to create VR world called Horizon”. (Sep. 27, 2019), [Online]. Available: <https://www.bbc.com/news/technology-49851798> (visited on 10/01/2024).
- [99] “Facebook Rebrands Social VR Platform ‘Horizon Worlds’, Offers \$10M To Makers”. (Oct. 2021), [Online]. Available: <https://www.uploadvr.com/facebook-horizon-changes/> (visited on 06/16/2025).
- [100] “HTC VIVE grows XR ecosystem, launches VIVERSE for Business”. (May 17, 2023), [Online]. Available: <https://www.news.viverse.com/post/htc-vive-grows-xr-ecosystem-launches-viverse-for-business> (visited on 12/02/2024).

- [101] “YouTuber finds only 900 daily users in Horizon Worlds — Meta’s \$36B metaverse”. (Aug. 17, 2023), [Online]. Available: <https://protos.com/youtuber-finds-only-900-daily-users-in-horizon-worlds-metas-36b-metaverse/> (visited on 10/01/2024).
- [102] *Decentraland Public Launch*, Jan. 14, 2020. [Online]. Available: <https://decentraland.org/blog/announcements/decentraland-announces-public-launch> (visited on 10/01/2024).
- [103] C. Thompson. “It’s Lonely in the Metaverse: DappRadar Data Suggests Decentraland Has 38 ‘Daily Active’ Users in \$1.3B Ecosystem”. (Oct. 13, 2022), [Online]. Available: <https://www.coindesk.com/web3/2022/10/07/its-lonely-in-the-metaverse-decentralands-38-daily-active-users-in-a-13b-ecosystem/> (visited on 10/01/2024).
- [104] T. Sandbox. “The Sandbox Blog”. (Nov. 13, 2023), [Online]. Available: <https://www.sandbox.game/en/blog/the-sandbox-announces-open-publishing-and-new-100m-sand-game-maker-fund-at-its-first-global-creators-day-held-in-hong-kong/3381/> (visited on 10/01/2024).
- [105] “The Sandbox Hits 5.7 Million Accounts Created”. (Mar. 25, 2024), [Online]. Available: <https://gam3s.gg/news/the-sandbox-hits-5.7-million-accounts-created/> (visited on 10/01/2024).
- [106] “Habbon historia, osa 1 – Suomalainen menestystarina alkaa [Habbo’s history, part 1 - A Finnish success story begins]”. (Jun. 9, 2020), [Online]. Available: <https://kalasaitti.net/article/73> (visited on 10/01/2024).
- [107] “Habbo Collectibles: A Long Term Vision”. (2024), [Online]. Available: <https://collectibles.habbo.com/roadmap/> (visited on 10/01/2024).

- 
- [108] J. Link, “Does Meta’s Horizon Workrooms Deliver? Customers Say Yes . . . and No”, *Wired*, ISSN: 1059-1028. (visited on 10/01/2024).
- [109] C. Daly. “We tested Microsoft Mesh so you don’t have to”. (Feb. 19, 2024), [Online]. Available: <https://www.theitteam.co.nz/blog-posts/we-tested-microsoft-mesh-so-you-dont-have-to> (visited on 10/01/2024).
- [110] T. Milligan. “Meet our Mesh Early Adopters - Microsoft Mesh”. (Jul. 18, 2024), [Online]. Available: <https://learn.microsoft.com/en-us/mesh/develop/mesh-tap-participants> (visited on 10/01/2024).
- [111] “Immersed Inc., a Global Leader in Spatial Computing Software”. (Aug. 9, 2023), [Online]. Available: <https://finance.yahoo.com/news/immersed-inc-global-leader-spatial-120000500.html/> (visited on 10/01/2024).
- [112] K. Y. Lam, L. Yang, A. Alhilal, L.-H. Lee, G. Tyson, and P. Hui, “Human-Avatar Interaction in Metaverse: Framework for Full-Body Interaction”, in *Proceedings of the 4th ACM International Conference on Multimedia in Asia*, Tokyo Japan: ACM, Dec. 2022, pp. 1–7, ISBN: 978-1-4503-9478-9. DOI: 10.1145/3551626.3564936. (visited on 10/11/2024).
- [113] H. Lin, Z. Gan, W. Gan, Z. Qi, Y. Wang, and P. S. Yu, *Interaction in Metaverse: A Survey*, Sep. 2023. arXiv: 2310.13699 [cs]. (visited on 10/11/2024).
- [114] Y. Zhao, J. Jiang, Y. Chen, *et al.*, “Metaverse: Perspectives from graphics, interactions and visualization”, *Visual Informatics*, vol. 6, no. 1, pp. 56–67, Mar. 2022, ISSN: 2468502X. DOI: 10.1016/j.visinf.2022.03.002. (visited on 10/11/2024).

- [115] I. Akin and M. Akn, “Valuation, Accounting Principles, and Classification of Assets in the Metaverse”, *Journal of Metaverse*, vol. 4, no. 1, pp. 43–53, Jun. 2024, ISSN: 2792-0232. DOI: 10.57019/jmv.1412352. (visited on 10/11/2024).
- [116] “Create and customize your avatar in Meta Horizon Worlds | Meta Store”. (2025), [Online]. Available: <https://www.meta.com/en-gb/help/quest/1615817045293118/> (visited on 06/16/2025).
- [117] “Create a new world in Meta Horizon Worlds | Meta Store”. (2025), [Online]. Available: <https://developers.meta.com/horizon-worlds/learn/documentation/vr-creation/getting-started/create-a-new-world-in-horizon/> (visited on 06/16/2025).
- [118] T. Milligan, Q. Wen, and A. Turner. “Personalize your avatars - Microsoft Mesh”. (Jun. 19, 2024), [Online]. Available: <https://learn.microsoft.com/en-us/mesh/user-guide/avatars> (visited on 10/11/2024).
- [119] “Mesh Development overview - Microsoft Mesh”. (Aug. 9, 2024), [Online]. Available: <https://learn.microsoft.com/en-us/mesh/develop/development-overview> (visited on 10/11/2024).
- [120] A. Pekmic. “How to change character in fortnite - equipping skins in four steps - VideoGamer”. (Oct. 1, 2024), [Online]. Available: <https://www.videogamer.com/guides/how-to-change-character-in-fortnite/> (visited on 06/16/2025).
- [121] E. Games. “Create - Fortnite”. (2025), [Online]. Available: <http://www.fortnite.com/create?lang=en-US> (visited on 06/16/2025).

- [122] T. Nyysönen, O. Heimo, S. Helle, T. Lehtonen, T. Mäkilä, and J. Jauhiainen, “Anonymous Collaboration in Metaverse”, in *14th International Conference on Applied Human Factors and Ergonomics (AHFE 2023)*, 2023. DOI: 10.54941/ahfe1003937. (visited on 10/11/2024).
- [123] NVIDIA. “Omniverse platform for OpenUSD | NVIDIA”. (2025), [Online]. Available: <https://www.nvidia.com/en-us/omniverse/> (visited on 02/13/2025).
- [124] NVIDIA. “Legacy tools for omniverse launcher | NVIDIA developer”. (2025), [Online]. Available: <https://developer.nvidia.com/omniverse/legacy-tools> (visited on 02/13/2025).
- [125] NVIDIA. “Technical requirements omniverse materials and rendering”. (Jun. 2, 2025), [Online]. Available: <https://docs.omniverse.nvidia.com/materials-and-rendering/latest/common/technical-requirements.html> (visited on 02/13/2025).
- [126] Meta. “Meta quest MR, VR headsets and accessories”. (2024), [Online]. Available: <https://www.meta.com/fi/en/quest/> (visited on 11/08/2024).
- [127] “Video conferencing, meetings, calling | microsoft teams”. (2025), [Online]. Available: <https://www.microsoft.com/en-us/microsoft-teams/group-chat-software> (visited on 06/19/2025).
- [128] “Microsoft 365”. (2025), [Online]. Available: <https://www.office.com/> (visited on 06/19/2025).

- [129] Microsoft. “Introducing microsoft mesh | connect like never before”. (2024), [Online]. Available: <https://www.microsoft.com/en-us/microsoft-teams/microsoft-mesh> (visited on 11/08/2024).
- [130] Microsoft. “Join a meeting as an avatar in microsoft teams - microsoft support”. (2025), [Online]. Available: <https://support.microsoft.com/en-us/office/join-a-meeting-as-an-avatar-in-microsoft-teams-5384e7b7-30c7-4bcb-8065-0c9e830cc8ad> (visited on 02/13/2025).
- [131] Microsoft. “Schedule a meeting in microsoft teams - microsoft support”. (2025), [Online]. Available: <https://support.microsoft.com/en-us/office/schedule-a-meeting-in-microsoft-teams-943507a9-8583-4c58-b5d2-8ec8265e04e5> (visited on 02/13/2025).
- [132] T. Milligan, S. Kerawala, V. Tieto, and Q. Wen. “Create event in mesh on web - microsoft mesh | microsoft learn”. (Oct. 29, 2024), [Online]. Available: <https://learn.microsoft.com/en-us/mesh/events-guide/create-event-mesh-portal> (visited on 02/13/2025).
- [133] Microsoft. “Microsoft mesh - free download and install on windows | microsoft store”. (Jul. 9, 2023), [Online]. Available: <https://apps.microsoft.com/detail/9nlxzj1fdbd7?hl=en-US&gl=US> (visited on 02/13/2025).
- [134] Meta. “Microsoft mesh on meta quest | quest VR games | meta store”. (Jan. 25, 2024), [Online]. Available: <https://www.meta.com/en-gb/experiences/microsoft-mesh/6750166401689690/> (visited on 02/13/2025).
- [135] *Microsoft/mesh-toolkit-unity*, original-date: 2023-07-18T14:53:10Z, Dec. 11, 2024. [Online]. Available: <https://github.com/microsoft/Mesh-Toolkit-Unity> (visited on 01/20/2025).

- [136] Unity Technologies. “Unity real-time development platform | 3d, 2d, VR & AR engine”. (2024), [Online]. Available: <https://unity.com> (visited on 03/13/2025).
- [137] T. Milligan, V. Tieto, Q. Wen, and A. Turner. “Mesh scripting overview - microsoft mesh | microsoft learn”. (Mar. 16, 2024), [Online]. Available: <https://learn.microsoft.com/en-us/mesh/develop/script-your-scene-logic/mesh-scripting-overview> (visited on 02/13/2025).
- [138] Meta. “Meta quest safety information for parents and children | meta | meta store”. (2024), [Online]. Available: <https://www.meta.com/fi/en/quest/parent-info/> (visited on 12/09/2024).
- [139] W. Elsayah, “Exploring the effectiveness of gamification in adult education: A learner-centric qualitative case study in a dubai training context”, *International Journal of Educational Research Open*, vol. 9, p. 100 465, Dec. 2025, ISSN: 26663740. DOI: 10.1016/j.ijedro.2025.100465. [Online]. Available: <https://linkinghub.elsevier.com/retrieve/pii/S2666374025000317> (visited on 06/23/2025).
- [140] “System - microsoft mesh | microsoft learn”. (Oct. 14, 2024), [Online]. Available: <https://learn.microsoft.com/en-us/mesh/develop/script-your-scene-logic/visual-scripting/visual-scripting-allowlist/system> (visited on 02/13/2025).
- [141] “.NET and .NET core official support policy”. (2025), [Online]. Available: <https://dotnet.microsoft.com/en-us/platform/support/policy/dotnet-core> (visited on 02/13/2025).

- 
- [142] . “Prepare for your first mesh cloud scripting project - microsoft mesh | microsoft learn”. (Jun. 28, 2024), [Online]. Available: <https://learn.microsoft.com/en-us/mesh/develop/script-your-scene-logic/cloud-scripting/cloud-scripting-prepare-for-your-project> (visited on 02/13/2025).
- [143] Unity Technologies. “The best assets for game making | unity asset store”. (2023), [Online]. Available: <https://assetstore.unity.com/> (visited on 05/26/2025).
- [144] “Blender.org - home of the blender project - free and open 3d creation software”. (2025), [Online]. Available: <https://www.blender.org/> (visited on 05/26/2025).
- [145] V. Tieto and M. Bushbeck. “Mesh visual scripting best practices for networking - microsoft mesh | microsoft learn”. (May 8, 2024), [Online]. Available: <https://learn.microsoft.com/en-us/mesh/develop/script-your-scene-logic/visual-scripting/best-practices/visual-scripting-best-practices-networking> (visited on 02/13/2025).
- [146] “Free text to speech & AI voice generator”, ElevenLabs. (Mar. 10, 2025), [Online]. Available: <https://elevenlabs.io> (visited on 03/13/2025).
- [147] Unity Technologies. “XR interaction toolkit | XR interaction toolkit | 3.0.8”. (2025), [Online]. Available: <https://docs.unity3d.com/Packages/com.unity.xr.interaction.toolkit@3.0/manual/index.html> (visited on 04/14/2025).

- 
- [148] Unity Technologies. “OpenXR plugin | OpenXR plugin | 1.14.2”. (2025), [Online]. Available: <https://docs.unity3d.com/Packages/com.unity.xr.openxr@1.14/manual/index.html> (visited on 04/14/2025).
- [149] T. Milligan, C. Moya, and V. Tieto. “Manage mesh collections - microsoft mesh”. (Aug. 29, 2024), [Online]. Available: <https://learn.microsoft.com/en-us/mesh/setup/content/manage-mesh-on-web> (visited on 03/13/2025).
- [150] V. Tieto, T. Milligan, Q. Wen, and A. Turner. “Build and publish your environment - microsoft mesh”. (Aug. 9, 2024), [Online]. Available: <https://learn.microsoft.com/en-us/mesh/develop/make-your-environment-available/build-and-publish-your-environment> (visited on 03/13/2025).
- [151] B. Wren, A. Maxwell, H. Hunter, R. Boucher Jr., and M. Woitaszek. “Azure monitor overview - azure monitor”. (Sep. 11, 2024), [Online]. Available: <https://learn.microsoft.com/en-us/azure/azure-monitor/overview> (visited on 03/13/2025).
- [152] V. Tieto, T. Milligan, Q. Wen, and A. Turner. “Mesh cloud scripting infrastructure and management - microsoft mesh”. (Aug. 6, 2024), [Online]. Available: <https://learn.microsoft.com/en-us/mesh/develop/script-your-scene-logic/cloud-scripting/cloud-scripting-setup-infrastructure> (visited on 03/13/2025).
- [153] C. Micka, V. Tieto, Q. Wen, and A. Turner. “Content performance analyzer - microsoft mesh”. (May 31, 2024), [Online]. Available: <https://learn.mi>

`crosoft.com/en-us/mesh/develop/debug-and-optimize-performance/cpa` (visited on 03/13/2025).

- [154] “Events overview - microsoft mesh | microsoft learn”. (Apr. 9, 2024), [Online]. Available: <https://learn.microsoft.com/en-us/mesh/events-guide/events-overview> (visited on 06/19/2025).

# Appendix A User feedback survey questions

## Background information

### 1. What is your profession?

- Employee of the company
- Other shipbuilding professional
- Researcher
- Other, please specify

### 2. How experienced are you with virtual reality (VR)?

- This is my first time using it
- I have used it a few ( $<10$ ) times before
- I have used it many ( $\geq 10$ ) times before
- I use it monthly
- I use it weekly

**3. Have you used VR at work?** Yes No**Usability questions****4. To what extent do you agree/disagree with the following statements?**

Statement	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
The experience was easy to use	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I found the experience unnecessarily complex	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The inclusion of an expert in the experience improved it	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I felt completing the tasks in the experience was interesting	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

<b>Statement</b>	<b>Strongly Disagree</b>	<b>Somewhat Disagree</b>	<b>Somewhat Agree</b>	<b>Strongly Agree</b>
The physical activities in the experience were too tiring	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Moving in the environment was easy	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Using VR made me nauseous	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

**5. Open-ended question: What do you feel are the major things to improve to make the experience feel better to use?**

## Sustainability communication questions

6. To what extent do you agree/disagree with the following statements?

Statement	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
I now have a better understanding of the blast furnace process of steelmaking	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I now have a better understanding of the fossil-free process of steelmaking	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The information was communicated in a way that felt trustworthy	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Overall, the experience felt confusing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Overall, the experience felt informative	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

**Open-ended question: 7. Was there something you felt should have been communicated better, or something you wanted to know but was left out completely?**

### **Practicality questions**

**8. Imagine you wanted to showcase the presented fossil-free process to someone. Which of the following methods would you prefer? Please rank them in the order of your preference, 1 being the most preferred.**

Having them experience the metaverse experience shown in this seminar

Sending them a PDF file

Holding a PowerPoint presentation

Sending them a video file

Explaining the process through talking

**9. A metaverse is a kind of virtual reality where users can interact with the environment and each other, especially through communication. How relevant do you feel metaverses will be to your organization? You can choose multiple options.**

- A metaverse will be relevant to our organization in the future
- I do not think a metaverse would be beneficial for our organization
- I can see a metaverse being potentially beneficial for our organization
- A metaverse could be an essential (must have) tool in our organization

- A metaverse could be an additional (nice to have) tool in our organization

**10. The experience was implemented on the Microsoft Mesh metaverse.**

**To what extent do you agree/disagree with the following statements?**

Statement	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
Our organization could use Microsoft Mesh	○	○	○	○
Our organization could use some other metaverse	○	○	○	○

**11. Open-ended question: If a similar metaverse solution as ours is used at a seminar or exhibition, what are the major potential issues and benefits that you see?**

**12. Open-ended question: Do you have any other feedback?**