Navigating the Metaverse: A roadmap towards the design of Educational Metaverse Applications in Enterprise Context

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Preface

In front of you lies my master's thesis: 'Navigating the Metaverse: A Roadmap towards the Design of Educative Metaverse Applications in an Enterprise Context.' This thesis is a big step for me. It marks the end of my student days and the start of my career. I would like to express the gratitude to the people who have supported me along this journey. Furthermore, I am thankful for the academic and professional progress I've made, as well as the personal growth I've experienced.

First, a big thanks for my university supervisors, Robin Effing and Faiza Bukhsh. They guided me throughout this period and gave me helpful feedback. Robin, you inspired me with the main topic of this thesis: The Metaverse. Without your input, a completely different thesis would have been produced. Faiza, your academic insights and feedback greatly contributed to improving my work, giving it an academic tone.

Next, I want to express my appreciation to SAP, where I had the privilege to conduct my research and had access to inspiring materials. I am especially thankful to my company supervisor, Basak Cinlar, for supporting and mentoring me throughout my internship, helping me develop myself further as a young professional. Also, I'd like to thank you for introducing me to the people who provided important insights for the evaluation of my work. I'd also like to express my gratitude to all my colleagues and fellow interns at the company who offered feedback and listened to my concerns about the thesis.

Lastly, I want to thank my family and friends for all their love and support. Your encouragement pushed me to my limits and enabled me to complete this final milestone of my academic journey.

Fleur Veenman

Enschede, October 2023

Executive Summary

The Metaverse presents innovative use cases for enterprises. These use cases encompass immersive collaboration methods, skill and knowledge acquisition through virtualization and gamification, and the emergence of a metaverse-based economy that offers new business models. The use case of skill and knowledge acquisition within an enterprise context is particularly interesting due to the high demand for alternative e-learning approaches to upskill and reskill employees more effectively, helping them adapt to changing job roles alongside technological advancements. However, the development of educational metaverse applications remains limited. Organizations are in an exploratory phase when it comes to designing these educational metaverse applications. Maturity models offer a proven method to systematically evaluate and enhance specific focus areas for application development in line with organizational objectives. The objective of this master's thesis is to identify key design principles that can serve as focus areas for educational Metaverse applications within an enterprise context and demonstrate the utility of a maturity model for systematically evaluating and benchmarking these key design principles.

The first phase of the research establishes the scientific foundation through a comprehensive literature review of the metaverse, its educational capabilities, and key design principles that facilitate immersive interactions. This phase results in: (i) an overview of educational metaverse capabilities, (ii) an understanding of metaverse applications and their alignment with enterprise goals, and (iii) the identification and conversion of key design principles within the research context.

The second phase involves the initial design and development of the maturity model. Firstly, existing scientific maturity models are systematically evaluated to create the architectural format. Additionally, empirical research, expert interviews, and market analysis are conducted to refine the focus areas. Insights gathered from experts regarding metaverse capabilities and design principles, combined with market research, enable the analysis of the evolution of key design principles, progressing from foundational to optimal stages. For a high-level overview, the model encompasses four primary domains for the classification of key design principles within these domains: Accessibility, Engagement, Usability, and Security & Privacy. These domains, informed by literature and expert insights, contribute to user experiences within the applications. To measure each of the key design principles within these four domains, the model employs a five-level maturity scale that assesses attributes of the key design principles.

In the third phase, the initial model undergoes validation and refinement through a mixed-method approach involving experts' perceptions and case studies. An Excel assessment tool is created to structure assessments of key design principles. Subject-matter experts and pioneering organizations in metaverse application development participate in the validation process. The findings affirm that the metaverse maturity model comprises accurate maturity levels, relevant and comprehensive design principles, and user-friendliness.

The primary strength of this research lies in the introduction of a novel metaverse maturity model, focusing on metaverse application development in enterprise contexts, particularly in an educational setting. The model meets all requirements and is operationalized through an assessment tool. The research process's strength lies in its integration of established scientific knowledge, combining existing frameworks and empirical research from practical contexts.

In summary, this research makes a fourfold contribution:

1. *Academic*: Presents a novel metaverse maturity framework that combines existing frameworks, methodologies, and scientific knowledge to support the development of metaverse applications.
2. *Academic*: Introduces the first maturity framework for assessing applications with metaverse technology features.
3. *Practical*: Offers a maturity model and assessment tool for evaluating current (educational) metaverse applications within focus areas that enable educational capabilities.
4. *Practical*: Provides evaluation results from practitioners, metaverse experts, and organizations, indicating the potential of the proposed maturity model and assessment tool.

Future work can address the model's limitations by incorporating qualitative maturity measures, expanding domains, and conducting ongoing validation through action research. This evolving metaverse maturity model allows organizations to coordinate and synchronize their short- and long-term improvement efforts in (educational) metaverse applications.

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List of abbreviations

Abbreviation	Meaning
AI	Artificial Intelligence
API	Application Programming Interface
AR	Augmented Reality
AVG	Average
BCI	Brain Computer Interface
BTP	Business Technology Platform
CMM	Capability Maturity Model
CX	Customer Experience
DSR	Design Science Research
EG	Enterprise Goal
ERP	Enterprise Resource Planning
FEDS	Framework for evaluation in Design Science
GPS	Global Positioning System
HR	Human Resource
IT	Information Technology
ITU	International Telecommunication Union
KPA	Key Process Area
MAMM	Metaverse Application Maturity Model
MMM	Metaverse Maturity Model
MR	Mixed Reality
NPC	Non-Player Character
PBT	Planned Behavior Theory
RQ	Research Question
SAP	Software Application Provider
SLR	Systematic Literature Review
SQ	Sub-Question
TAM	Technology Acceptance Model
UX	User Experience
VR	Virtual reality
XR	Extended Reality

1
Introduction

This chapter serves as an introduction to the research. In Section 1.1, we provide a description of the rationale behind this research, which includes background information and an examination of the limitations of current practices. Section 1.2 defines the research goals and scope. Section 1.3, introduces the research questions, and Section 1.4, explains the methodology employed throughout the research. Finally, in Section 1.5, we present an overview of the thesis, specifying the specific goals and objectives of each subsequent chapter in this thesis.

1.1 Background

The Metaverse marks a new era in digital engagement, offering immersive and interconnected experiences that surpass the capabilities of conventional digital platforms (Park & Kim, 2022). It augments digital platform capabilities by establishing a dynamic virtual space that coexists with the physical world (Park & Kim, 2022). Recognizing this potential, global enterprises are increasingly investing in exploring the Metaverse, viewing it as a promising domain for business expansion and technological advancement (Hatami et al., 2023). Projections suggest that within the next four years, about 30% of global enterprises will offer products and services compatible with the Metaverse (Rimol, 2022). In total, the Metaverse is anticipated to generate a business value of $5 trillion by 2030 (Hatami et al., 2023). Figure 1, illustrates the specific enterprise goals supported by the intrinsic capabilities of Metaverse applications (ISACA, 2019), which will be further elaborated upon in this thesis.

Figure 1, Enterprise goals supported by the Metaverse (ISACA, 2019)

The fusion of virtual and real-world experiences presents significant opportunities for enterprises to design customized virtual spaces and leverage data-driven insights (Chen et al., 2023). One use-case for such virtual spaces is knowledge and skill acquisition, especially given the challenge to reskill the current workforce to fill skill gaps alongside technical innovations. Conventional instructional approaches in both corporate training and educational contexts, such as e-learning, videos, and textual resources have proven to be ineffective, with comprehension rates ranging between 10% to 20% (Danylec et al., 2022). Despite advancements in online learning practices, digital platforms fall short in conveying the cognitive and emotional dimensions (Al-Adwan et al., 2023). Conversely, experiential learning involving active engagement significantly enhances comprehension, often achieving success rates as high as 75% (Danylec et al., 2022). However, resource constraints hinder active training. The metaverse, holds the promise for personalized learning experiences in virtual spaces, simulating traditional classroom settings, which stimulates active learning (Al-Adwan et al., 2023). However, many organizations struggle to develop educational metaverse applications due to a limited knowledge of their design and its focus areas (Narang, 2023). The existing scientific literature lacks design principles for creating educational Metaverse spaces in enterprise context. When considering the use case of these applications for re- and upskilling of employees within an enterprise context, a structured framework for Metaverse application design, which includes key design principles and clarifications of the capabilities they enable, shows potential for advancing educational Metaverse application development and filling this gap in the literature.

1.2 Research objective and scope

Acknowledging the research gap outlined in Section 1.2, this research is devoted to developing a comprehensive maturity model. The main goal encompasses both theoretical contributions and practical applications. The aim of the maturity model is to streamline the evaluation of key design principles for educational metaverse applications within an enterprise context, assuming appropriate software infrastructure is available. Moreover, it aims to elucidate the distinct value of each design principle in attaining learning objectives, ensuring the framework's relevance in developing metaverse applications for educational purposes. Figure 2, visually illustrates the concrete steps towards achieving this objective, providing a clear roadmap for the research.

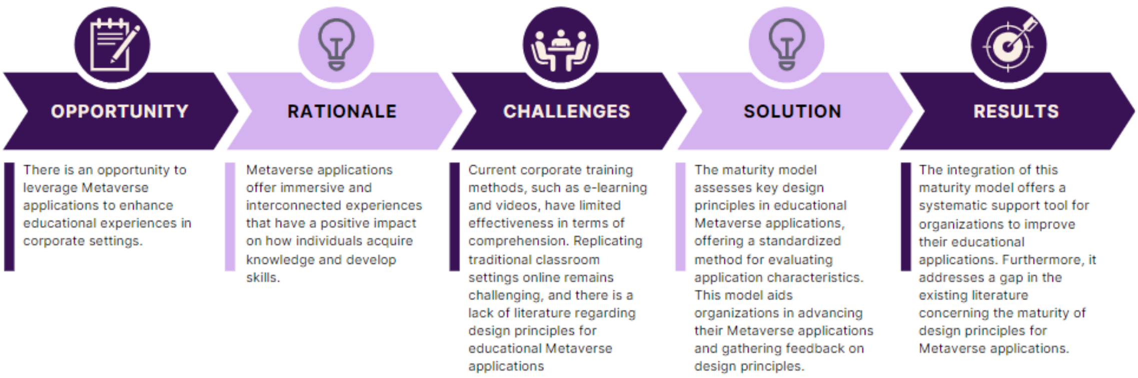

Figure 2, Visual flow towards the research objective

1.3 Research questions

The primary objective of this research question is to design a maturity model that enables the iterative refinement of key design principles for educational Metaverse applications within an enterprise context, surpassing the limitations of conventional e-learning methods. The research question is formulated as follows:

What constitutes a maturity model for enhancing learning initiatives for metaverse applications, enabling stakeholders to assess and advance metaverse application features, thereby leveraging advanced educational capabilities beyond conventional e-learning methods in enterprise contexts?

The RQ is divided into the following sub-questions (SQ):

1. *Evolution of the Metaverse concept:*

   How has the concept of the Metaverse evolved within the broader digital landscape over time?

   This knowledge question explores the evolution of the Metaverse concept and its current state of development. Understanding the current state of the concept is pivotal for making informed decisions regarding the utilization of metaverse applications and to evaluate which key design principles are relevant at this stage for educational practices.

2. *Essential technological components and interactions:*

   What are the essential technological components that comprise the Metaverse, and how do they interact to create immersive learning experiences?

   This knowledge question explores the foundational technological elements that form the core of Metaverse experiences and examines their interactions. Special emphasis is placed on understanding how this convergence enables the potential to develop distinctive immersive (educational) experiences.

3. *Key design principles for Metaverse applications*
   a. What are the key design principles that distinguish educational experiences within metaverse applications from conventional methods?
   b. How do these design elements contribute to a more engaging and effective learning environment?

   This set of knowledge questions aims to identify the key design principles that enhance educational experiences within metaverse applications.

4. *Development of the maturity model:*
   a. What is the most effective structure for a maturity model that guides the advancement of key design principles within metaverse applications?
   b. How can the key design principles align with different stages of this model?

   This knowledge question focuses on formulating the maturity model, presenting a structured framework for evaluating metaverse application features, and enabling the gradual evolution of the key design principles over different stages.

Figure 3, presents the structural framework aligning the SQ with the RQ.

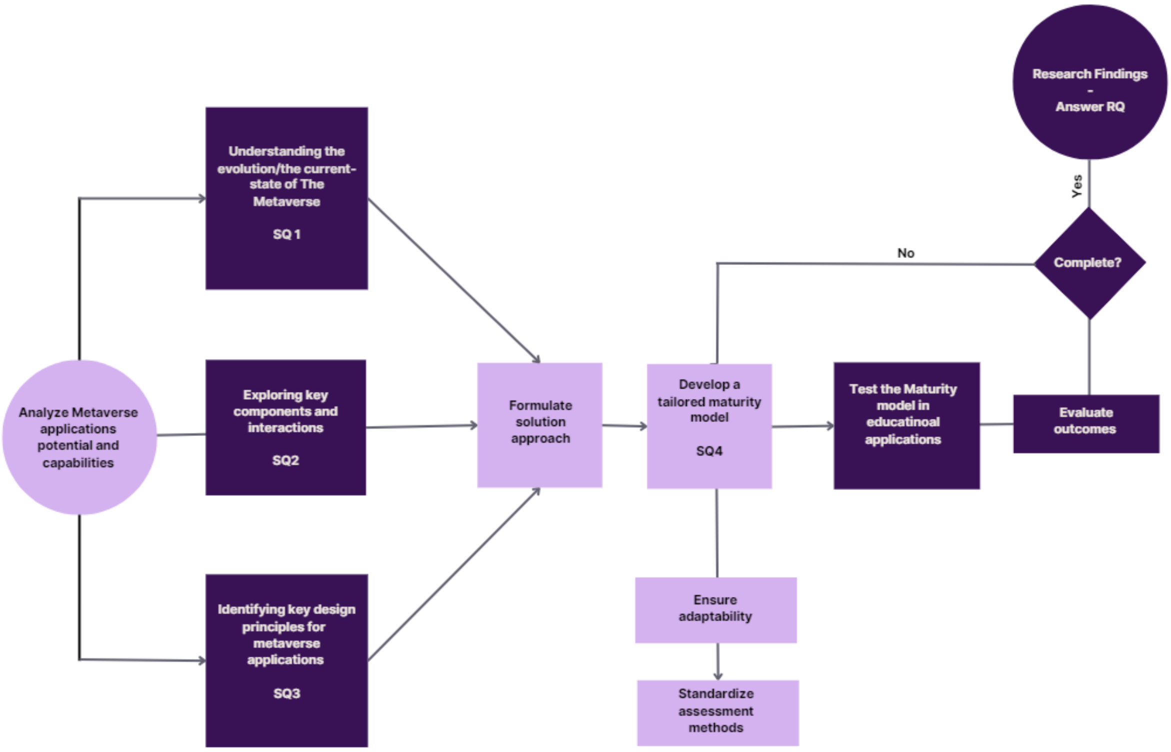

Figure 3, Structural framework towards the Research Objective

1.4 Research Approach and Design

To address the research and sub-questions outlined in Section 1.3, a diverse array of research methodologies is employed throughout the research. The approach utilized a mixed-method strategy, integrating literature reviews, case studies, and interviews to systematically collect data. Each of the methods is shortly elaborated on within this section.

Multivocal literature review.

Given the novelty of the metaverse and the limited availability of white literature an extensive multivocal literature review was initially carried out to assess the current state of the art of the metaverse in literature. This method allowed for the collection of theoretical knowledge concerning the Metaverse, a prerequisite for evaluating its current capabilities, with a specific focus on its evolution and potential for educational purposes. This encompassed a thorough review of articles from both scientific and grey literature. The inclusion of grey literature was necessary due to the lack of organizational knowledge in the available scientific papers. Such information is primarily published by organizations through white papers, websites, and blogs, which, though falling short of scientific standards, offer important practical insights.

Systematic literature review

A systematic literature review was conducted to identify the key design principles specific to Metaverse applications oriented towards learning purposes, emphasizing their applicability within enterprise environments. The objective was to extract essential capabilities and design principles from existing literature. The insights obtained from this review were employed as attributes in the iterative development of a maturity model.

Development of the model

A notable proportion of researchers employ diverse methodologies in constructing maturity models. Nearly half of the studies encompass distinct approaches, while an additional 37% lack specification of any methodology (Pereira & Serrano, 2020), highlighting a lack of established practices in this research domain. Widely recognized methodologies, such as design science research (DSR) and action research, constituted only 15% and 3% of the studies. Nevertheless, there has been a recent increase in the use of design science methodology in maturity model development (Pereira & Serrano, 2020).

Design science involves the creation and analysis of artifacts within a specific context (Wieringa, 2014), wherein the maturity model serves as the artifact aimed at measuring a set of key design principles. The validation process in design science employs a model of the real-world context to simulate realistic conditions. On the other hand, action research entails collaborative problem-solving with practitioners to address real-world issues (Wieringa, 2014). Information systems action research, as defined by (Hult & Lennung, 1980) embodies six key characteristics:

(1) Aims to understand an immediate situation;
(2) Simultaneously assists in practical problem-solving and expands scientific knowledge;
(3) Is collaboratively performed, enhancing the involved parties' competences;
(4) Follows a cyclical process with data feedback;
(5) Primarily focuses on understanding change processes in social systems; and
(6) Operates within an agreed-upon ethical framework.

In the context of maturity model development, action research involves applying a model under development to address a client's problem while conducting research on the social impact and contributing to scientific knowledge. Despite similarities, DSR and action research exhibit significant differences (Iivari & Venable, n.d.). DSR inherently involves artifact design, unlike action research. In action research, the developing artifact is applied to a real-world problem, while DSR permits the use of a model representing the artifact and its context. Action research emphasizes collaboration with practitioners and investigating the social context, which is not a primary focus of DSR. Despite these distinctions, the two methodologies can complement each other, particularly in validating the artifact. The use of a model representing a real-world context in DSR may be considered less robust than action research. However, conducting simulations with a model requires less time compared to solving a real-world problem, enabling multiple experiments and generating stable results. While action research provides a more realistic validation of the artifact, DSR offers a suitable methodology for the early stage of maturity model development, thus chosen for the development of the maturity model. The methodology proposed by (Becker et al., 2009) for developing maturity models is mapped against the design science research engineering cycle of (Wieringa, 2014), as presented in Table 1 for a structured design methodology.

Development of Maturity models	Design cycle
Problem definition	Problem investigation
Comparison of existing models	
Determination of development strategy	Treatment design
Iterative maturity model development	
Evaluation	Treatment validation

Table 1, Research approach

Interviews

In order to validate and test the artifact (Wieringa, 2014), interviews were conducted with subject-matter experts to evaluate the model's input, understandability, ease of use, usefulness, and practicality. Additionally, the model's effectiveness was examined through multiple case studies to validate its applicability in real-life scenarios. These case study sessions were conducted using Microsoft Teams calls and were recorded with participants' consent. During the initial round, questionnaires were administered by an organizational representative claiming familiarity with the requisite information. Subsequently, recommendations were provided based on the findings. Following this, participants were invited to provide feedback on our findings, assessing the Metaverse Application Maturity Model. Analyzing user feedback generated valuable qualitative data that contributed to evaluating and refining the model development process. Figure 4, provides a structural overview of the research design.

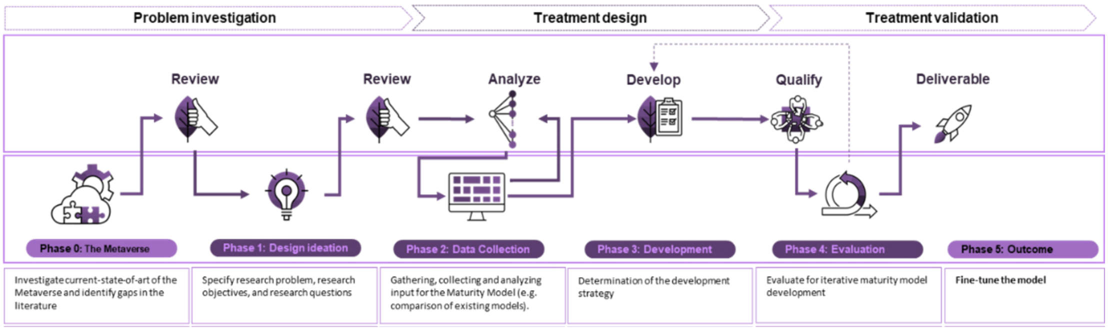

Figure 4, Research Design

1.5 Thesis outline

The thesis is structured into seven chapters, the objectives of each of the chapters is illustrated in Figure 5, outlining a comprehensive research approach divided into three phases: (1) Establishment of Theoretical Foundations in chapters 1 and 2, (2) Formulation and Development of the Maturity Model in Chapter 3, and (3) Assessment and Enhancement of the model in chapters 4 and 5. Final, chapter 6 presents the research outcomes and their implications for practical applications, and a detailed discussion is offered in Chapter 7. This discussion encompasses a review of the research methodology, the resulting MAMM, highlighting its contributions, acknowledging its limitations, and presenting potential future research directions.

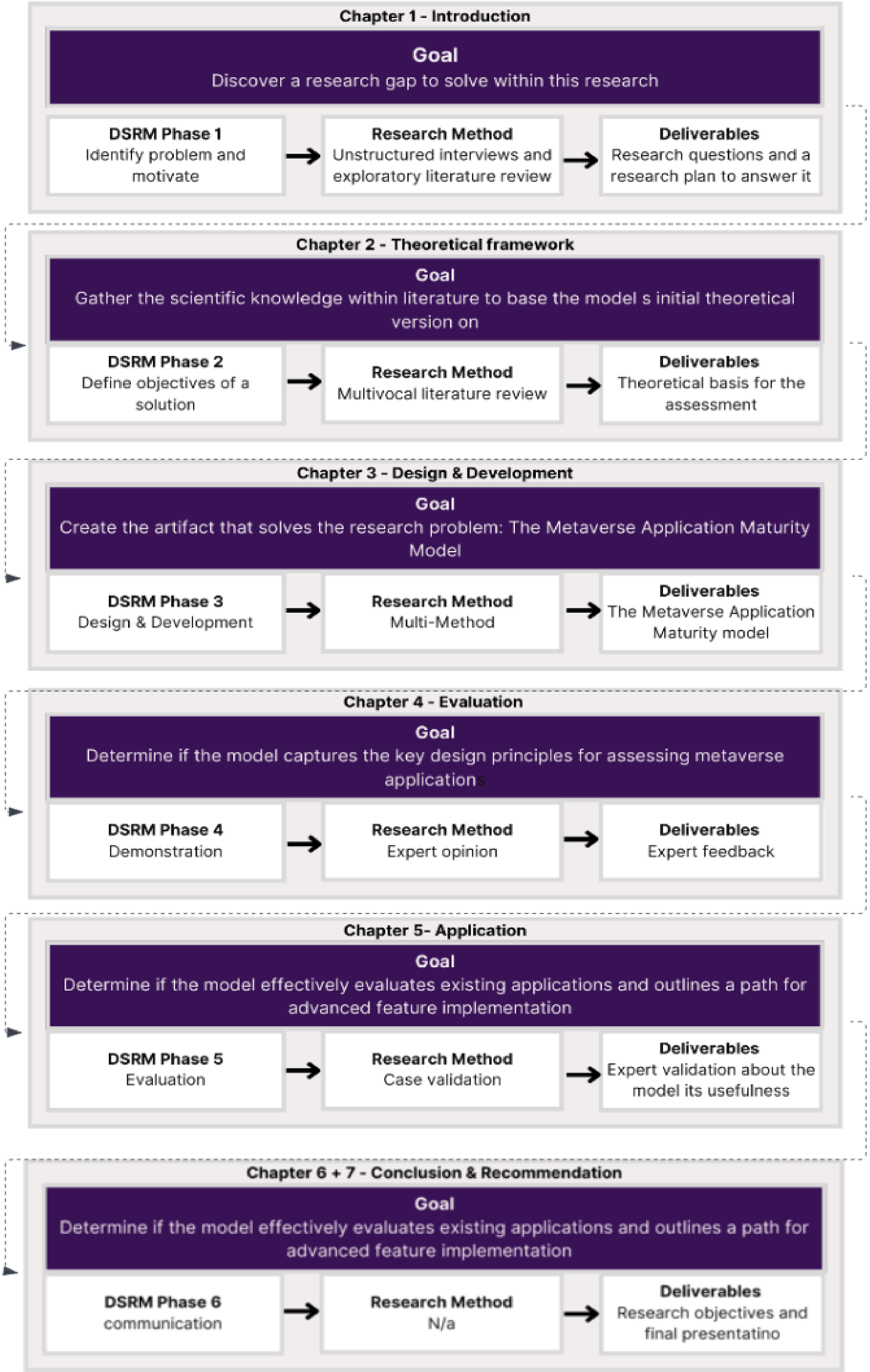

Figure 5, Thesis outline

2

Theoretical background

This chapter comprises the theoretical framework of the research. In Section 2.1, we introduce the concept of the Metaverse, emphasizing the factors that had an impact on its evolution. In Section 2.2, we explore the technological components that underpin the distinctive capabilities of the Metaverse when applied in an enterprise context. Then, in Section 2.3, we outline the application of the Metaverse for educational purposes. Section 2.4 highlights the characteristics of Metaverse learning environments, emphasizing their advantages over conventional e-learning methods. Finally, in Section 2.5, we summarize the findings and establish the connection between Metaverse applications and the achievement of enterprise goals.

2.1 The maturity of the Metaverse

The maturity of the Metaverse is evaluated by examining its stages of development and adoption. Currently, the Metaverse is rapidly evolving due to advancements in technologies like virtual reality, augmented reality, artificial intelligence, and connectivity technologies. However, its application remains limited in this early developmental phase (Dwivedi et al., 2022). Given the absence of a uniform definition for the metaverse at this moment, this section provides clarification on what the metaverse is not and the factors that have driven its evolution, building on the rise of the internet.

What the metaverse is not

Similar to the lack of technical understanding about the internet and social media in 1995, the Metaverse is expected to offer unforeseen opportunities for innovation and monetization. In this rapidly evolving field, providing a definitive and absolute definition of the Metaverse is challenging and limiting. To develop a more nuanced understanding, an approach based on Popper's falsification theory is applied (Wallis, 2008). This approach involves focusing on what the Metaverse is not. It encourages a multidimensional perspective that considers different viewpoints and possibilities, avoiding rigid definitions or assumptions about the Metaverse.

First, The Metaverse is not a static or fixed concept; instead, it is an evolving and dynamic concept as advancements in technologies and use cases continue to emerge. It is a convergence of various technologies that create a virtual space rather than being limited to immersive virtual reality or video games (Ball, 2021).

Secondly, the Metaverse is not confined to a singular platform or technology; it encompasses a broader range of technologies and applications, such as augmented reality, virtual reality, and mixed-reality, converging to create a connected virtual space (Richter & Ehlert, 2023). It is not limited to a specific technology or platform, but rather represents a convergence of technologies that shape a virtual ecosystem (Schöbel & Leimeister, 2023).

Third, the Metaverse is not a standalone or isolated virtual world; instead, it constitutes a connected virtual ecosystem, that spans multiple platforms, devices, and online communities. It is not limited to a specific location but rather constitutes an interconnected network of virtual experiences and interactions accessible from various points in the physical world (Schöbel & Leimeister, 2023).

Furthermore, the Metaverse is not solely for entertainment purposes; it encompasses a wide range of economic, social, and creative activities, including virtual commerce, education, collaboration, and socialization. It is a multi-dimensional virtual space with diverse use cases beyond being a mere entertainment medium.

concluding, the Metaverse is not a static or fixed concept; it is an evolving and dynamic concept that constantly evolves with advancements in technology, changes in user behavior, and shifts in societal norms. Therefore, it cannot be definitively defined or confined to a single interpretation. This foundational understanding of the concept sets the stage to examine the historical development of the web which have led to its evolution.

The evolution of the Metaverse

As human societies evolve, so do their methods of communication and interaction. From early forms of written language to the modern-day internet and social media, the ways in which humans connect and engage with each other have constantly evolved (Zhu, 2022). To better understand the driving forces behind the development of the Metaverse and the movements within it, the historical context of web communication is examined, from web 1.0 towards the Metaverse. This exploration provides insights into the motivations, and the potential impacts of the ongoing development of the Metaverse.

From web 1.0 towards the Metaverse

The International Telecommunications Union (ITU) defines the internet as a source of personal fulfillment, professional development, and value creation (Zhu, 2022). People access the internet through various devices to browse websites, use email services, engage in social networks, and participate in online marketplaces. According to the Vice President of Simulation Technology at NVIDIA, the Metaverse necessitates a distinct infrastructure and protocols compared to the current internet, aiming to empower creators by decentralizing ownership and enabling unrestricted movement through virtual spaces without being restricted to the governance of a single web-space provider (Kindig, 2021). This development is an iteration of the original web, as depicted in Figure 6, illustrating the evolution of the internet, each possessing unique characteristics and capabilities.

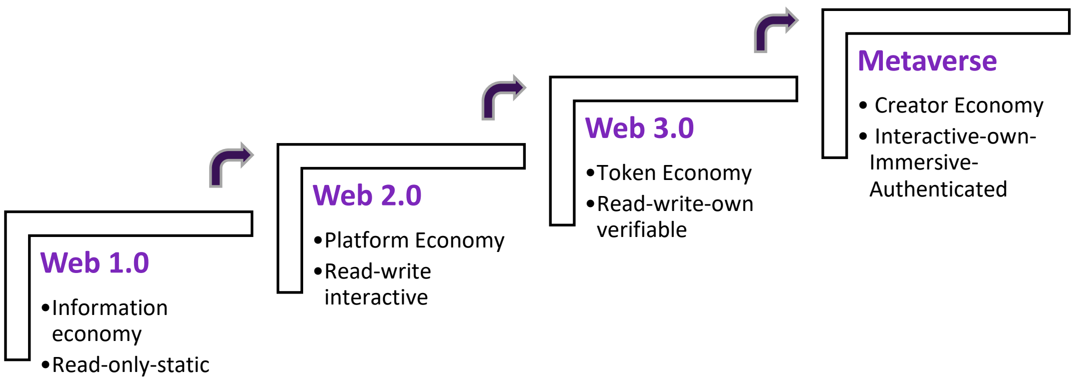

Figure 6, Evolution of the Web.

Initiating with Web 1.0, focused on delivering static content in a read-only format. Web 1.0 served as platform for exchanging knowledge and was not driven by economic motives (Richter & Ehlert, 2023). Conversely, Web 2.0 marked a significant shift in the internet's evolution, emphasizing user-generated content and social interaction, which had economic implications. Web 2.0 is characterized by its centralized structure, where a small number of companies have ownership and control over user data and content on the platform. This centralization has led to significant profits from the flowing data, raising concerns about data privacy and ownership. Responding to these concerns, a new iteration of the internet, Web 3.0, emerged. Web 3.0 aims to decentralize content ownership through distributed ledger technology, empowering both companies and users with more control over their data. This shift towards decentralization seeks to democratize access to information and value creation, utilizing a distributed and open architecture that promotes transparency, privacy, and security.

Although Web 3.0 and the Metaverse share the core idea of decentralization, the two concepts are distinct (Spahn, 2023). Web 3.0 seeks to decentralize content ownership on the traditional web, while the Metaverse goes beyond the concept of decentralized content ownership on the traditional web. It aims to create a new decentralized virtual world not limited to any single app, game, or physical location, allowing for the persistence of digital goods and identities across different platforms. Overall, the Metaverse can be partly described as a Virtual Economy, as illustrated in Figure 6, where digital assets, virtual goods, virtual currencies, and other forms of value are created, exchanged, and managed (Schöbel & Leimeister, 2023). In addition to economic activities, the Metaverse offers a highly interactive environment that goes beyond the read-write functionality of Web 2.0. Users can actively engage with the virtual world, collaborate with others, and participate in various activities such as gaming, socializing, shopping, and learning. This high degree of interactivity allows users to shape their virtual experiences, making the Metaverse a user-driven environment. In this environment, ownership is a key element, as users have control over their digital assets and virtual possessions. Users can own and manage their virtual property, virtual identities, and virtual currencies, often facilitated by blockchain technology or other authenticated systems (Huynh-The, Gadekallu, et al., 2023). This ownership aspect of the Metaverse provides users with control and autonomy over their digital presence and activities within the virtual world.

Concluding, the Metaverse is immersive, providing users with a sense of presence within the virtual world. Unlike Web 1.0, where users could only passively read and consume static information, or Web 2.0, which introduced interactivity and user-generated content (Richter & Ehlert, 2023), the Metaverse allows users to navigate, explore, and interact with the virtual environment as if they were physically present. The Metaverse offers an immersive experience, blurring the lines between the physical and digital space. It goes beyond the traditional models of the web, presenting new opportunities for economic activity, social interaction, and user-driven creativity.

The fact that the Metaverse goes beyond the traditional version of the web also requires different technological building blocks. In Section 2.2, the core technological components are examined.

2.2 Core technological components of the Metaverse

The Metaverse aims to create a virtual space that can interact with the physical world. Achieving this requires the convergence of various technologies. The core components necessary to create this virtual space are displayed in the framework in Figure 7. This framework highlights the core components, including communication and computing infrastructure, technology management, fundamental common technology, virtual reality object connection, and the convergence of virtual reality spaces. All these elements play a role in constructing Metaverse environments, and are further elaborated upon in this section.

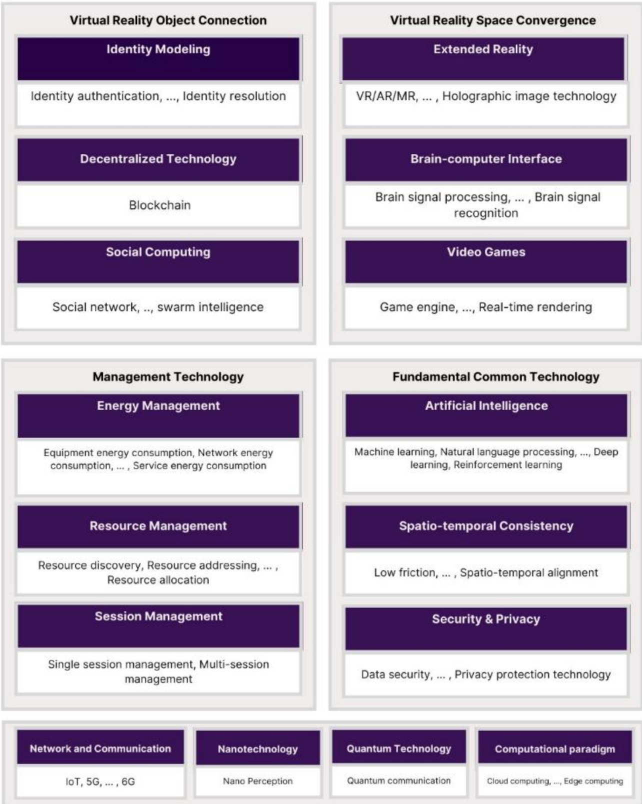

Figure 7, Core components that enable Metaverse interactions (Ning et al. 2021)

Communication and computing infrastructure

The quality of conversations within the Metaverse applications relies on its communication and computing infrastructure (Ning et al., 2021). Currently, the 4G bandwidth falls short in providing a high-quality Metaverse experience (Siniarski et al., 2016). The adoption of 5G holds promise in overcoming these limitations, allowing seamless communication between the physical world and virtual spaces, advancing the Metaverse experience. Looking ahead, the introduction of 6G is expected to broaden the scope of service objects, promoting extensive collaboration and interaction among humans, machines, physical-world entities, and the virtual environment, thereby creating highly advanced Metaverse experiences.

In addition to robust communication, a powerful computing system is required to meet the low-threshold and experience-intensive requirements. Anticipated computing paradigms, such as cloud computing and edge computing, are expected to serve as the primary infrastructure of the Metaverse, driving the development of computing power (Ning et al., 2021). And, although quantum computing, with its immense processing capabilities, holds potential for enhancing the immersive and interactive user experience, it may not be deemed essential for the functionality of Metaverse applications within an enterprise context.

To sum up, the communication and computing infrastructure are fundamental components of the Metaverse framework, playing an indispensable role in realizing the virtual spaces, and a strong communication mechanism with the physical world.

Management of Technology

Efficient management of energy, resources, and sessions is essential for the viability of the Metaverse within an enterprise context. Maintaining a consistent energy supply throughout Metaverse sessions can be maintained by the implementation of energy management technology, which may involve methods such as IoT-based approaches and neural network models. Alongside energy management, effective resource management needs to be in place to efficiently identify and allocate educational resources within the Metaverse environment. This can be accomplished by employing resource search algorithms and cloud resource discovery mechanisms (Ning et al., 2021). Simultaneously, session management technologies focus on effectively handling interactions between resources and users, especially in multi-user sessions, characterized by dynamic elements. Real-time session management enhances user immersion while providing security against potential attacks in 5G wireless network environments, thus playing a critical role in delivering a secure and engaging experience.

To sum up, management of technology has an essential role in ensuring the Metaverse operates efficiently and remains sustainable in the enterprise context. This encompasses critical areas such as energy management, resource allocation, and session orchestration, as highlighted by (Ning et al., 2021).

Fundamental common technologies

The richness of the educational experience within the Metaverse relies on fundamental common technologies, such as AI algorithms, encompassing machine learning, deep learning, and reinforcement learning. These technologies play a role in ensuring secure, social and economic engagement within the virtual space (Huynh-The, Pham, et al., 2023). First, AI holds immense promise within the educational Metaverse, particularly in the development of intelligent Non-Player Character (NPC) tutors, tutees, and peers (Hwang & Chien, 2022). These intelligent NPCs provide educational services involving arbitration, simulation, and decision-making. As a result, integrating analytical technologies within the Metaverse enables the assessment, monitoring, collection, and analysis of learners' data, including their behaviors, emotions, preferences, and performance. By leveraging this data, applications have the potential not only to assist educators in learner evaluations but also to offer personalized resources and services to learners. Second, the use of computer vision and natural language processing allows users to perceive sensory experiences similar to those in the real world while in the virtual environment. Additionally, maintaining spatio-temporal consistency, ensuring accurate and up-to-date data regarding location and time, is critical for seamless mapping between the real world and the virtual space of the Metaverse (Ning et al., 2021). Third, security and privacy are concerns within the Metaverse due to the substantial exchange of personal data in the virtual world. Effective management and coordination of data among companies, along with the optimization of security measures like user access authentication and network situation awareness, are imperative to ensure privacy and security in the Metaverse (Huynh-The, Pham, et al., 2023). The combination of blockchain and AI technologies provides effective solutions for data security, privacy, and interoperability in the Metaverse.

To sum up, the integration of fundamental technologies, such as AI, has the potential to offer distinct educational opportunities. Simultaneously, spatio-temporal technologies blur the boundaries with the physical world, and AI combined with blockchain solutions can address data security, privacy, and interoperability concerns.

Virtual reality object connection

The concept of Virtual Reality Object Connection revolves around identity modeling, decentralized technology, and social computing, bridging the physical and digital worlds (Ning et al., 2021). To enter the Metaverse and build a community, individuals need a unique identity credential, created using identity modeling technology. Understanding and predicting user behaviors and trends through social computing are essential for managing societal interactions within the Metaverse. As mentioned in the discussion of fundamental common technologies, the security and economic stability of the Metaverse heavily rely on blockchain technology. Integrating blockchain technology is instrumental for establishing an efficient economic system within the Metaverse, enabling the recognition of the value of resources and goods, similar to real-world transactions. Without blockchain support, determining resource values and executing economic transactions within the Metaverse would be considerably challenging (Jeon et al., 2022).

To sum up, to ensure individual identification, unique identity credentials are essential. Connecting these assets within the Metaverse using decentralized technologies safeguards achievements and facilitates secure transactions. Furthermore, leveraging social computing to understand and predict behaviors significantly enhances the connection between virtual and real-world objects.

Virtual reality space convergence

To achieve the seamless connection between the physical world and the virtual space of the Metaverse, we rely on an array of technologies such as augmented reality (AR), virtual reality (VR), mixed reality (MR), holographic imaging, and brain-computer interface (BCI) (Ning et al., 2021). These technologies form the fundamental infrastructure for constructing a highly interactive virtual environment.

AR involves merging computer-generated sensory information with the real world in real-time, integrating sound, video, graphics, and GPS data (Tucci & Needle, 2023). Conversely, VR offers a completely immersive experience by immersing users in a simulated reality beyond physical constraints (Milgram et al., 1995). MR combines aspects of AR and VR, enabling the coexistence of physical and digital objects in real-time, as illustrated in Figure 8 (Milgram et al., 1995). This continuum ranges from entirely real objects to entirely virtual ones, with mixed reality environments existing in between.

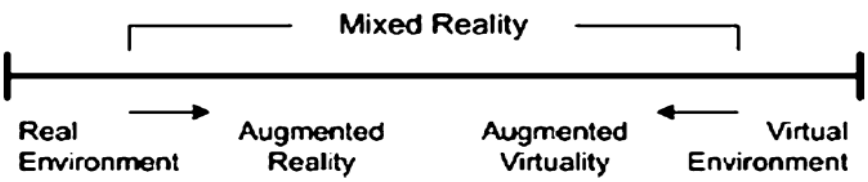

Figure 8, Simplified representation of the Reality-Virtuality Continuum (Milgram et al.1995).

In the future, MR may potentially integrate with BCI technology, allowing users to directly control and interact with virtual objects using their thoughts and brain activity, opening new frontiers for communication. The combination of MR, BCI, and holographic imaging enables immersive interaction with three-dimensional virtual objects. This convergence allows users to interact with virtual environments through brain signals and natural movements and will set the stage for full immersion abilities in Metaverse applications (Songqiang et al., 2023).

This section provided an in-depth exploration of the core technological components and their distinctive characteristics that enable Metaverse experiences. In appendix A, the technological components are synthesized in an architectural overview, illustrating the connection between the Metaverse and the physical world. In Section 2.3 below, the application of the Metaverse within an enterprise context is examined in depth.

2.3 Application of the Metaverse

In the preceding sections, we explored the Metaverse as a dynamic virtual space enabling immersive interactions and meaningful engagements among users. This holds considerable potential in revolutionizing work practices and collaboration, offering innovative opportunities for connection, communication, and cooperation within enterprise contexts. Recent insights from the Work Trend Index reveal a notable surge in interest, particularly among Gen Z and millennials, regarding the integration of the Metaverse into their work routines. Nearly half of individuals within these demographics express a strong desire to incorporate the Metaverse into their work practices within the next two years (Teper, 2022). This section highlights the unique educational capabilities enabled by Metaverse applications and discusses how they can be utilized from an enterprise training and education perspective.

Leveraging Metaverse capabilities in Enterprise Context

Historically, the development of application scenarios and use cases has shown accelerated growth as technologies mature. This historical trend is evident when examining the evolution of internet and mobile connectivity, as outlined in Section 2.1. Currently, the Metaverse and its associated enabling technologies are in an early developmental stage, presenting promising features for advancement. One notable feature is the ability to design tailored virtual spaces. These virtual environments can simulate office setups, serving diverse purposes such as meetings, workshops, and training sessions (Chen et al., 2023). While physical offices support traditional work practices through direct human interaction and collaboration, digital offices utilize internet-based technologies to facilitate remote collaboration and efficient communication, transcending geographical limitations and optimizing information exchange.

Within these virtual spaces, participants can take part in highly customizable and immersive experiences. During meetings, products or services can be visually presented in an interactive and engaging manner. Workshops and training sessions can take place in virtual classrooms or simulated real-world settings, offering hands-on learning and skill development, augmented by the convergence of multiple technologies as discussed in Section 2.2. The integration of Metaverse technologies opens new horizons for engagement and interactivity to enhance the effectiveness of training programs. Two examples are the SAP Business Technology Platform (BTP) Metaverse application and an application that educates employees about phishing tricks.

First, the SAP Business Technology Platform (BTP) Metaverse application is an integrated platform that provides a wide range of services and technologies to support enterprises in their digital transformation. It serves as a comprehensive hub for application development, analytics, database management, and data handling. The SAP Business Technology Metaverse Application demonstrates the diverse features of the BTP within a virtual space. In this virtual space, users can securely and interactively engage with colleagues, closely collaborate, and explore the functionalities of the BTP in a gamified format. Figure 9, illustrates how a human controls their avatar within the metaverse

BTP application. Besides, users can achieve certifications within the Metaverse application, creating additional opportunities for the application provider, in this case, SAP, to generate value through the Metaverse economy. Within this virtual space, users gain practical, hands-on experience. This hands-on approach simplifies the learning and comprehension of the BTP, allowing for the design of personalized learning paths for each user, facilitated by AI assistants within the space.

Figure 9, User Controlling Avatar in the Metaverse BTP application (Bungert, 2022)

Secondly, the "Phishing Pier" application represents an approach to cybersecurity education, enhancing the comprehension of cyber vulnerabilities and threats (Armstrong, 2022). This is achieved by creating a virtual setting where participants find themselves on a pier within a simulated aquatic world. In this environment, virtual fish symbolize potential phishing attempts, mirroring the nature of real-world phishing tactics as they move unpredictably towards participants. Through the utilization of immersive technology and the fusion of education with entertainment, the "Phishing Pier" transforms cybersecurity education into a memorable and impactful experience by offering a tangible and practical understanding of cybersecurity challenges.

In Section 2.4, we provide a description of the distinctive characteristics of Metaverse learning resources to clearly differentiate the Metaverse from conventional learning environments.

2.4 Characteristics of a Metaverse-learning environment

The integration of virtual learning resources in applications holds substantial promise, as discussed in previous Sections. These resources can be categorized into two primary types (Lin et al., 2022): Observational resources and experimental resources. *Observational resources* serve as valuable tools for training and instructing end-users. For instance, In the domain of software education these resources support the visual demonstration of software operations, the implementation and customization methods, and step-by-step guidance for complex tasks. By incorporating these resources, software vendors can effectively communicate information, and create engaging learning experiences for end-users.

Furthermore, *experimental resources* play a role in providing hands-on training and virtual simulations (Lin et al., 2022). Using the context of software education once more, these resources can address actual challenges faced by vendors' partners, such as restricted access to specific equipment, limited entry to real-life customer scenarios, and potential risks associated with software setup or adaptation. Through virtual simulations, learners can acquire practical skills, refine their expertise, and build confidence in their skills. These resources simulate diverse scenarios, enabling learners to engage in activities such as software configuration, troubleshooting issues, and offering customer assistance.

Consider the utilization of Enterprise Resource Planning (ERP) systems. These educational resources can significantly support training users on ERP functionalities. Observational resources can display the intricacies of ERP processes, fostering an understanding of how different modules interconnect and contribute to the overall workflow. Conversely, experimental resources provide an interactive platform for exercises, allowing users to actively participate in ERP tasks and gain hands-on experience within a controlled virtual environment. This section further elaborates on the unique capabilities of Metaverse applications, highlighting how the Metaverse enables personalized learning experiences and surpasses conventional learning methodologies

Metaverse-based learning approach versus conventional learning methodologies

Conventional learning approaches often involve passive engagement, like listening, watching presentations, using online modules, or reading materials. These methods often lead to low comprehension rates, as indicated in Section 1.1. Conversely, the Metaverse offers a highly interactive approach. It utilizes tailored virtual spaces that replicate real-life scenarios and seamlessly integrates learning materials. This enables individuals to immerse themselves fully in their roles and actively engage in practical exercises within the virtual environment. Research has demonstrated that individuals are 47% more likely to complete their courses when engaged in active learning within the Metaverse (Lin et al., 2022), emphasizing the value of personalized learning in maintaining engagement throughout the learning process.

The Metaverse stands out from standalone technologies through the convergence of common technologies and the utilization of virtual space, as discussed in Section 2.2. It provides a more extensive and detailed experience compared to the brief and isolated experiences offered by separate technologies like VR or AR. Metaverse applications can monitor our actions and interactions, assisting in the evaluation of our behavior (Chen et al., 2023). When integrated with common technologies like AI (Hwang & Chien, 2022), the Metaverse can tailor the pace and complexity of content, ensuring each learner progresses according to their specific needs, and recommend alternative learning approaches, such as visual aids, interactive simulations, or gamification. Figure 10, outlines the distinctive features that differentiate the Metaverse learning environment from traditional learning methods (Hwang & Chien, 2022):

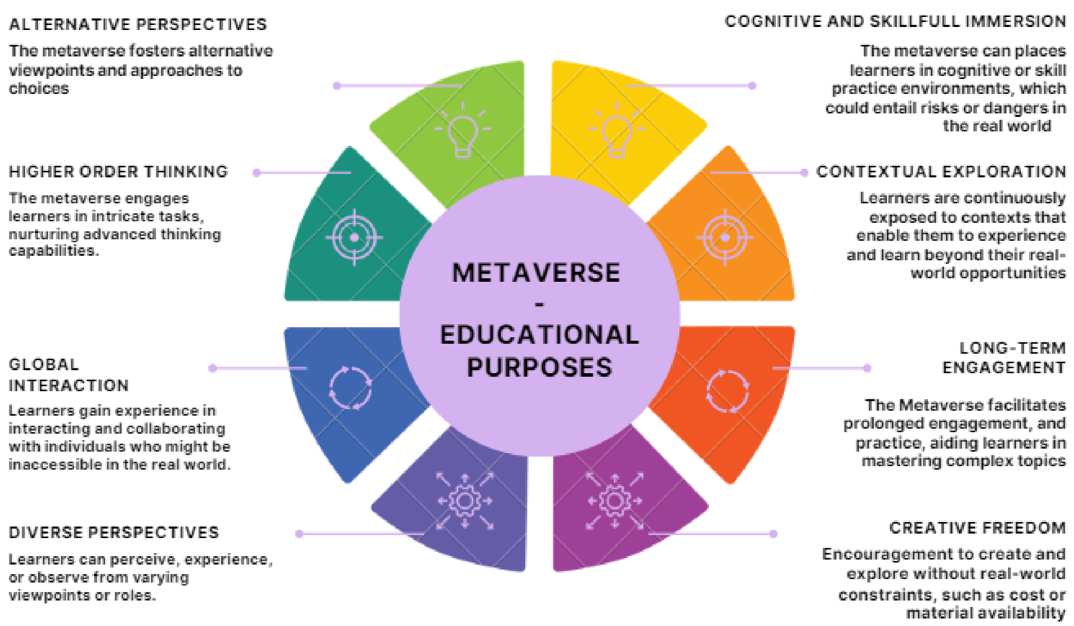

Figure 10, Features of the learning process in the Metaverse

The characteristics identified in the literature studies throughout this chapter have been summarized in Table 2.

Characteristics	Explanation
Immersive interactive experience	(Lin et al., 2022) indicate that learners are more engaged and learn more effectively when immersed in a realistic experience that includes hands-on practice. Thereby, the metaverse education transcends the limitations of traditional web-based training.
Visualization	Leveraging digital technologies, the Metaverse visualizes (e.g. software) concepts that may be challenging to comprehend through conventional means. For example, learners can explore visual representations of complex software architectures or data flow diagrams, aiding in their understanding and problem-solving skills.
Low learning costs and risks	In a business environment, training programs often involve expensive hardware or software set-ups. Metaverse education mitigates these costs by offering virtual simulations and digital environments that replicate real-world scenarios. Learners can engage in hands-on practice without the need for physical infrastructure or the associated risks.
Unrestricted time and space	Metaverse education has no time or location constraints. Training sessions, workshops, and collaborative projects can be conducted virtually, eliminating the need for travel and allowing global teams to work together. Learners can access training materials and resources at their convenience, facilitating continuous learning.
Preventing skill gaps and promoting upskilling	The Metaverse helps identify skill gaps through personalized assessments and can offer targeted training modules to bridge those gaps. Moreover, through the convergence of various technologies, the Metaverse ensures knowledge remains current and relevant.
Personalization	Learners can tailor their training programs to match their specific job roles, career aspirations, and skill requirements. This personalized approach boosts engagement and motivation, leading to more effective learning outcomes.
Promoting collaboration and networking	The Metaverse facilitates virtual meeting spaces where professionals can connect, share ideas, and collaborate on projects. Virtual conferences, seminars, and workshops within the Metaverse create opportunities for networking, knowledge sharing, and industry-wide collaboration.
Gamification of learning	The Metaverse can employ gamification techniques to make the learning process engaging and enjoyable. Through gamified modules and interactive simulations, professionals can enhance their problem-solving abilities, critical thinking skills, and creativity, all while having fun and competing with peers.
Collaborative learning environments	Within the virtual spaces, professionals can participate in collaborative projects and engage in group discussions, stimulating a culture of teamwork and knowledge sharing. Virtual workspaces and social features enable professionals to connect with like-minded individuals, exchange ideas, and form connections within the community.

Table 2, Advantages of learning experiences in the Metaverse vs Traditional Learning Spaces.

In Section 2.5, we provide an analysis of the discussed theory, establishing a relationship between the utilization of Metaverse applications and the Enterprise Goals discussed in Section 1.1.

2.5 Theoretical analysis

The dynamic Metaverse, defined through the lens of Popper's falsification theory in Section 2.1, extends beyond entertainment. It's a connected virtual ecosystem integrating diverse technologies for economic, social, educational, and creative activities, transcending platforms, and devices.
In Section 2.2 is explained how the underlying technological components of the Metaverse interact to create the virtual space and its unique capabilities. Subsequently, in Section 2.3, is described how these capabilities can be effectively utilized in an enterprise context. Considering the advantages outlined in Table 2 from Section 2.4, the utilization of Metaverse applications demonstrates significant potential in advancing education and professional development. By leveraging the Metaverse's capabilities, learners can immerse themselves in dynamic educational environments, achieving a highly adaptable workforce. The integration of Metaverse technologies supports the upskilling of professionals with the latest tools and knowledge. Figure 13 illustrates how the set of characteristics aligns with the enterprise goals described in Section 1.1.

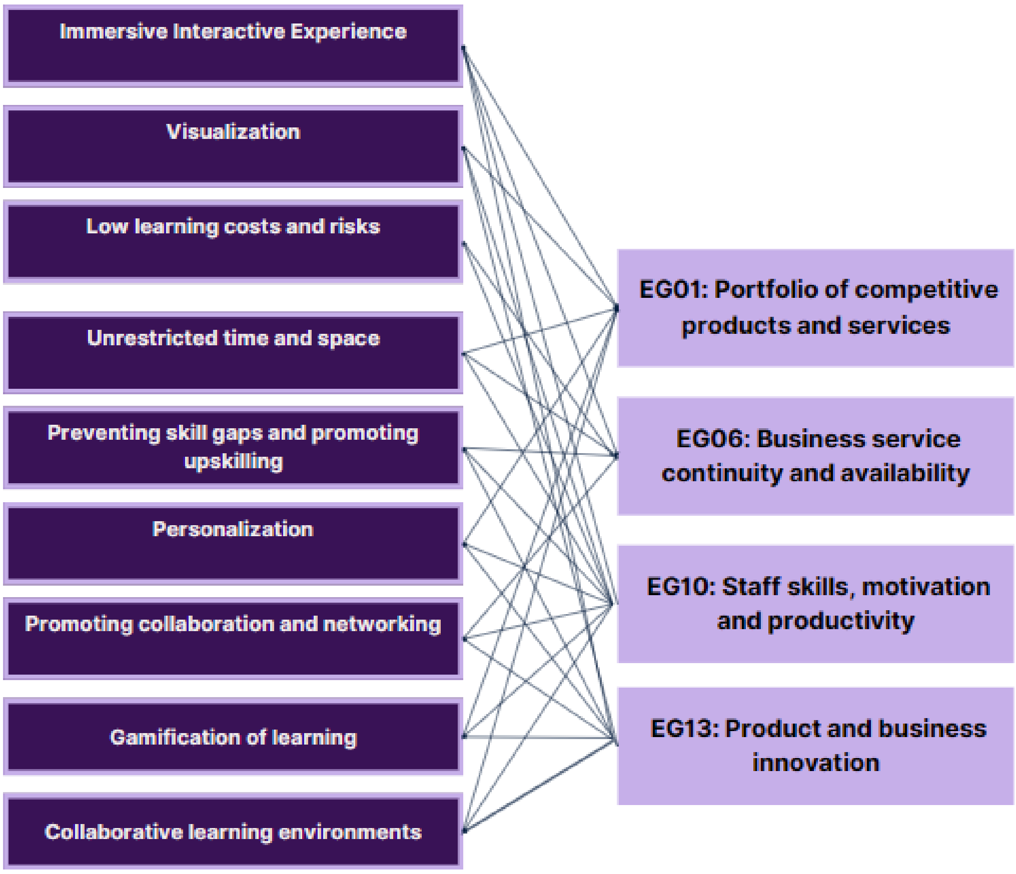

Figure 11, Mapping of metaverse characteristics to Enterprise Goals

The connection between enterprise goals and outlined characteristics is elaborated in Table 3. This table refines how these characteristics drive Metaverse application within an enterprise context.

EG01: Portfolio of Competitive Products and Services	Metaverse education stimulates competitiveness by providing immersive experiences that enhance problem-solving skills and creativity. It allows learners to visualize complex concepts, thereby improving their ability to develop innovative products and services. The cost-effective and low-risk nature of Metaverse education ensures that resources can be directed towards enhancing the organization's portfolio. Additionally, personalized learning paths and collaboration opportunities contribute to the overall skill development of individuals, which in turn boosts organizations' offerings.
EG06: Business Service Continuity and Availability	For business service continuity and availability, the Metaverse, with its immersive characteristics, prepares individuals to handle real-world scenarios effectively. By eliminating the need for physical presence and enabling virtual training, it ensures uninterrupted operations even in challenging circumstances. Moreover, continuous upskilling and collaboration through the Metaverse maintain a skilled and connected workforce, for service continuity.
EG10: Staff Skills, Motivation, and Productivity	Metaverse education motivates employees by offering immersive learning experiences, personalized learning paths, and visualization of complex concepts. These features boost staff skills, motivation, and overall productivity. Collaboration and networking opportunities within the Metaverse generates a sense of community and shared goals, further enhancing staff motivation and engagement. Gamification of learning, adds an element of fun to the learning process, promoting higher levels of motivation and productivity.
EG13: Product and Business Innovation	In the pursuit of product and business innovation, Metaverse education's immersive experiences stimulate creative thinking and problem-solving skills. Visualization of intricate concepts aids in ideation and innovation. Continuous learning and upskilling ensure that the workforce remains at the forefront of industry developments, contributing to innovation efforts. Moreover, personalized learning paths and collaborative projects foster an environment conducive to generating innovative ideas and solutions.

Table 3, Enterprise goals mapped against Metaverse characteristics

In general, Metaverse applications offer a diverse array of features that effectively support various enterprise goals. Their immersive nature, combined with features like visualization, personalization, and gamification, positions them as innovative applications for organizations aiming to expand their portfolios, ensure business continuity, train their workforce, and drive innovation. In Chapter 3, a practical design—the artifact— is defined to evaluate focus areas for the design of educational Metaverse applications.

3

Design & Development

This chapter presents the design and development of the artifact: The Metaverse Application Maturity Model (MAMM). Specifically, Section 3.1 describes types of maturity models, while Section 3.2 focuses on the analysis of existing Metaverse maturity models and frameworks to determine the architectural framework. Section 3.3 explores user-centric viewpoints of Metaverse technology by reviewing relevant research and empirical studies in the literature. In Section 3.4, the key design principles for Metaverse application development are clarified as the focus areas for the maturity model, and in Section 0, the maturity stages of the model are defined. Then, in Section 3.6, the measurement attributes alongside the stages of the maturity levels are determined. Finally, an overview synthesizing the design process is presented in Section 3.7.

3.1 Types of maturity models

Maturity models commonly consist of predefined interest areas, focus areas, and a well-defined maturity scale. The most popular way for assessing maturity is a five-point scale where '5' signifies the highest level of maturity (de Bruin & Rosemann, 2005). Although the fundamental structure remains consistent, variations exist in the type and structure of these models (van Steenbergen et al., 2008). Three basic types can be distinguished: Staged fixed-level, continuous fixed-level, and focus area models. Staged fixed-level models ('a' in Figure 12) have five fixed and generic maturity levels, each corresponding to specific focus areas that must be fulfilled. Continuous fixed-level models ('b' in Figure 12) also have five levels, but each focus area has its own maturity level and defines different levels of capabilities within those areas. Each focus area has a series of development steps that organizations can progress through to achieve higher levels of maturity (van Steenbergen et al., 2008). These continuous fixed-level models provide a more detailed and targeted approach to assessing capabilities and guiding improvement efforts. Focus area models ('c' in Figure 12), on the other hand, feature several specific maturity levels per focus area, not necessarily limited to five.

	1	2	3	4	5
FA 1	X				
FA 2	X				
FA 3		X			
FA 4		X			
…					

a)

	1	2	3	4	5
FA 1	X	X	X	X	X
FA 2	X	X	X	X	X
FA 3	X	X	X	X	X
FA 4	X	X	X	X	X
…					

b)

	1	2	3	4	5	6	7	…
FA 1	X				X			
FA 2		X		X				
FA 3	X		X			X		
FA 4				X			X	
…								

c)

Figure 12, Three types of Architecture Maturity Models (van Steenbergen, van den Berg, and Brinkkemper 2008).

The maturity assessment is determined by combining the maturity levels of all focus areas. These levels, provide a structured framework for assessing capabilities. Fixed level models can be further classified into staged models and continuous models. Staged models require all Key Process Areas (KPAs) to be in place in order to reach a certain maturity level, while continuous models allow for a more flexible improvement path by scoring KPAs at different levels (Proença & Borbinha, 2016). To define the architectural format of the MAMM and complement the literature without duplicating efforts, a comprehensive review of existing Metaverse Models and frameworks is carried out in Section 3.2.

3.2 Existing Metaverse Maturity models and Frameworks

An extensive SLR is conducted encompassing various databases, details of the SLR can be found in Appendix B. The investigation into Metaverse maturity models yielded two academic results and one model from Gartner, evaluating the phases of the Metaverse ecosystem on its journey toward maturity. Given the limited number of results, this Gartner model was included for consideration. Subsequently, a decision was made to review other maturity models relevant to application development and technology adoption, to establish a more robust understanding of the structure and frameworks of maturity models.

The objective of this review was to obtain insights into the structures, assessment methods, and development methodologies that could be utilized to construct the MAMM. In Table 4, the available Metaverse Maturity models are presented.

Model	References
Metaverse Maturity Model (MMM)	(Weinberger & Gross, 2023)
Cross-Reality for extending the Metaverse	(Guan et al., 2023)
Phases of the Metaverse Evolution by Gartner	(Gartner, 2022)

Table 4, Overview of Existing Metaverse Maturity Models

The study employed the maturity model analysis method proposed by (Proença & Borbinha, 2016). This method considers three aspects of creating maturity models: The structure of the model, assessment methods, and support mechanisms.

- The model's *structure* encompasses elements such as the name of the maturity model, its references, the defined maturity levels, and the attributes constituting the model. It also assesses the clarity of the maturity definition and whether the model offers practical recommendations.
- Model *assessment* focuses on the practical application of the maturity model. Evaluating the maturity level within a specific context requires a methodology to calculate these levels. This aspect includes considerations of the assessment process, identification of strengths and weaknesses, emphasis on continuous improvement, and prioritization of areas for enhancement.
- Model *support* encompasses the resources available for implementing and utilizing the maturity model. It takes into account training opportunities, validation support, availability of tools, the model's adaptability to different scenes, its academic or practical origin, and the accessibility of documentation.

To ensure a systematic extraction of attributes, a specific set of variables from (Proença & Borbinha, 2016) was applied for each aspect, these can be found in Appendix B. The findings of the search are presented below:

Model structure

The academic Metaverse maturity models that were analyzed follow a consistent structure, comprising five levels. These models outline the progression of the whole Metaverse ecosystem, starting from fragmented technology usage towards the establishment of a cohesive and independent ecosystem. For each of the attributes, specific improvement recommendations and maturity definitions are provided, enhancing the understanding of their respective developmental stages. For a comprehensive summary of the variables derived from these models, see Table 5.

Maturity Model	Number of levels	Name of the attributes	Number of Attributes	Maturity Definition	Practicality
Metaverse Maturity Model (MMM) (Weinberger & Gross, 2023).	5	Metaverse Core attributes	8	Yes	Practical Recommendation
Cross-reality (Guan et al., 2023)	5	Factors	7	No	Specific recommendation
Gartner (Gartner, 2022)	3	Technologies characteristics	25	Yes	Specific recommendation

Table 5, Analysis of Metaverse Maturity Models – Model Structure

Model assessment

Among the reviewed models, it is notable that the MMM stands out as the only model that provides a clear assessment method. In contrast, the other models do not explicitly specify any assessment methods. For instance, although the evaluation of the Gartner model takes into account technological progression, market emergence, and infrastructure development as indicators of Metaverse maturity, no explicit assessment method is mentioned. For details about the variables associated with each model, see Table 6. This table presents an overview of the variables mapped to the model, allowing for a 'detailed' examination of their respective components.

Maturity Model	Assessment Method	Assessment costs	Strong/Weak Points Identification	Continuous Assessment	Improvement Opportunities Prioritization
Metaverse Maturity Model (MMM) (Weinberger & Gross, 2023)	Yes	?	No	No	Yes
Cross-Reality (Guan et al., 2023)	No	?	No	No	No
Gartner (Gartner, 2022)	No	?	Yes	No	No

Table 6, Analysis of Metaverse Maturity Models – Model Assessment

Model support

The analysis of model support focuses on assessing the level of support offered by the authors or stewards of the maturity model. In the case of the two academic models, they exhibit a lack of strong validation support. On the other hand, the Gartner model demonstrates moderate support, as Gartner emphasizes their industry leadership and collaboration with experts, providing some level of validation. Moreover, all models explicitly mention the evaluation of Metaverse tools and platforms, acknowledging the importance of incorporating these elements. Additionally, the models acknowledge future recommendations, indicating a willingness to adapt and evolve over time. In terms of accessibility, both the MMM and Gartner models are available for free, facilitating wider adoption and usage. However, the cross-reality paper requires a charge, potentially limiting its accessibility. For a comprehensive overview of the variables supporting each model, see Table 8. This table provides a detailed overview.

Maturity Model	Author Support	Training Available	Origin	Accessibility	Tools	Continuity
Metaverse Maturity Model (MMM) (Weinberger & Gross, 2023)	Low	No	Academic	Free	Yes	No
Cross-Reality (Guan et al., 2023)	low	No	Academic	Charged	Yes	No
Gartner (Gartner, 2022)	Medium	No	Practitioner	Free	Yes	No

Table 7, Analysis of Metaverse Maturity Models – Model Support

Following the assessment of the structure of existing Metaverse Maturity Models, the subsequent section focuses on investigating additional factors that potentially influence the adoption and utilization of Metaverse technologies, emphasizing an empirical standpoint that contribute to a deeper understanding of the key design principles involved in the adoption and usage of Metaverse applications by end-users.

3.3 User-centric factors of Metaverse Technology

This section explores user-centric factors in the acceptance of metaverse technology, highlighting factors such as compatibility, usefulness, ease of use, and trialability. These insights are integrated to provide empirical insights into the underlying relationships and influential factors that shape users' adoption of metaverse applications. These theories find support in the theoretical frameworks of the Technology Acceptance Model (TAM) and Planned Behavior Theory (PBT).

Technology Acceptance Model

The TAM is a well-established theory employed to study user acceptance of new technologies. (Toraman, 2022) explores the variables that significantly influence individuals' intentions to adopt Metaverse technology. The TAM considers the following variables: Perceived usefulness, perceived ease of use, and intention to use, which impact the actual adoption of Metaverse applications within an enterprise context. In the context of metaverse technology, perceived usefulness refers to the extent to which individuals believe that using the technology will enhance their learning experiences. On the other hand, perceived ease of use refers to individuals' perceptions of the technology's simplicity, ease of learning and use in the applications. This theory is further complemented by the authors through the Planned Behavior Theory (PBT).

Planned Behavior Theory

In the empirical research by (Toraman, 2022), PBT was combined with the TAM to analyze the factors influencing people's use of metaverse applications. PBT is widely utilized in the study of human behavior, emphasizing the significance of perceived behavioral control and general environmental factors. PBT asserts that the level of control individuals perceive over their behavior is fundamental in an environment. The main variables in PBT encompass attitude towards use, perceived behavioral control and the subjective norm that influence the intention and finally the actual use. Attitude towards use refers to an individual's evaluation of a behavior, influenced by their intention (Toraman, 2022). The attitude towards metaverse technology is a critical factor in determining people's intentions. The relationship between these variables is illustrated in Figure 13.

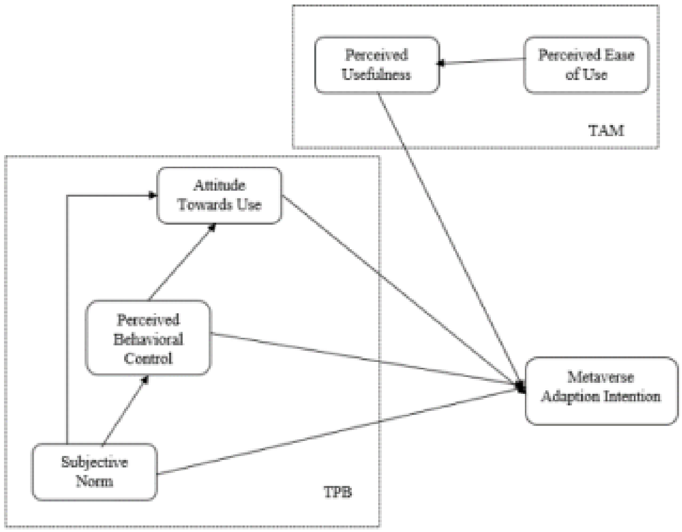

Figure 13 Factors affecting Metaverse Adoption (Toraman 2022)

Research Findings on user acceptance of Metaverse technology

It is important to acknowledge certain limitations in existing research, such as limited active usage and control over Metaverse applications. However, the TAM and PBT provide insights into the factors influencing user intentions and are incorporated for determining the contribution of design principles for the utilization of Metaverse applications. The literature review underscores the significance of evaluating compatibility, usefulness, and ease of use factors as usability and accessibility considerations for users to engage in the Metaverse platform. Also, addressing perceived behavioral control is an essential focus area to enhance the overall user engagement and utility of Metaverse applications (Van et al., 2022).

Key observations included:

I. *Perceived Ease of Use and Perceived Usefulness*: Ease of use holds significant importance for businesses, particularly during the development of Metaverse applications targeting users. Overcoming usability barriers can facilitate better and more accessible user engagement.

II. *Perceived Trialability*: Businesses should carefully select targeted participants for the initial assessment of applications and define the development orientation aligned with the Metaverse to choose the appropriate platform for building their application.

III. *Perceived Compatibility*: Businesses need to evaluate their operational compatibility with the Metaverse platform and consider future directions and user needs. Collaboration within business ecosystems can help in developing a business Metaverse platform for wider use.

Incorporating these empirical statements, Section 3.4 presents the design principles and maturity stages for the MAMM.

3.4 The Design Principles

Maturity model designers typically select input based on the chosen application area. Given the novelty of the Metaverse and the absence of a universally accepted definition of its functioning, key design principles are derived from peer-reviewed scientific papers through a Systematic Literature Review (SLR). The relevance of these principles is validated in the evaluation stage through interviews with subject-matter experts. This method is chosen because researchers in these papers have had the resources to test and evaluate these principles, despite limited practical implementation at this early stage of development.

The research on the key design principles encompassed a review of papers: (Guan et al., 2023), (Narang, 2023), (Lippert et al., 2021), (Rawat & El Alami, 2023), (Setiawan et al., 2022), (Chen et al., 2023), and (Dwivedi et al., 2022). These studies employed various methods including prototype implementation and evaluation, literature reviews, and surveys to understand the principles influencing Metaverse usage. The key design principles identified in the systematic literature review are presented in Appendix B. Collectively, these principles outline the focus areas that should be considered when designing Metaverse applications to ensure functionality, an exceptional user experience, and integration within the enterprise context. A summary of the key design principles is depicted in Figure 14, alongside four main domains, as indicated with revision from subject-matter experts: Privacy & Security, Usability, Accessibility and Engagement.

1. *Privacy & Security*: In the enterprise context, ensuring the privacy and security of data and interactions is critical as emphasized in Section 2.2. Metaverse applications involve user data, and safeguarding it against unauthorized access, data breaches, and cyber threats is of utmost importance.

2. *Usability*: Usability focuses on how easily users can navigate and interact with the metaverse application, which is a critical design consideration as highlighted in Section 3.3. The efficiency and user-friendliness of the usability domain are stimulating employee productivity and the utilization of the metaverse application.
3. *Accessibility:* Accessibility refers to the design and implementation of features and functionalities of the applications that ensure that the application can be efficiently used, scaled, and experienced by users across various devices, places and interaction scenarios.
4. *Engagement:* Engagement drives collaboration, creativity, and productivity, contributing to enterprise goals as described in Section 2.5. Designing metaverse applications with engaging features and user experiences stimulates teamwork and increases employee involvement in virtual workspaces.

Together, these four domains cover a comprehensive spectrum of focus areas for designing metaverse applications in the enterprise context. They address not only the functional aspects but also the human-centric elements taking into account the empirical research from Section 3.3, ensuring that metaverse applications are secure and user-friendly to produce engaging work environments.

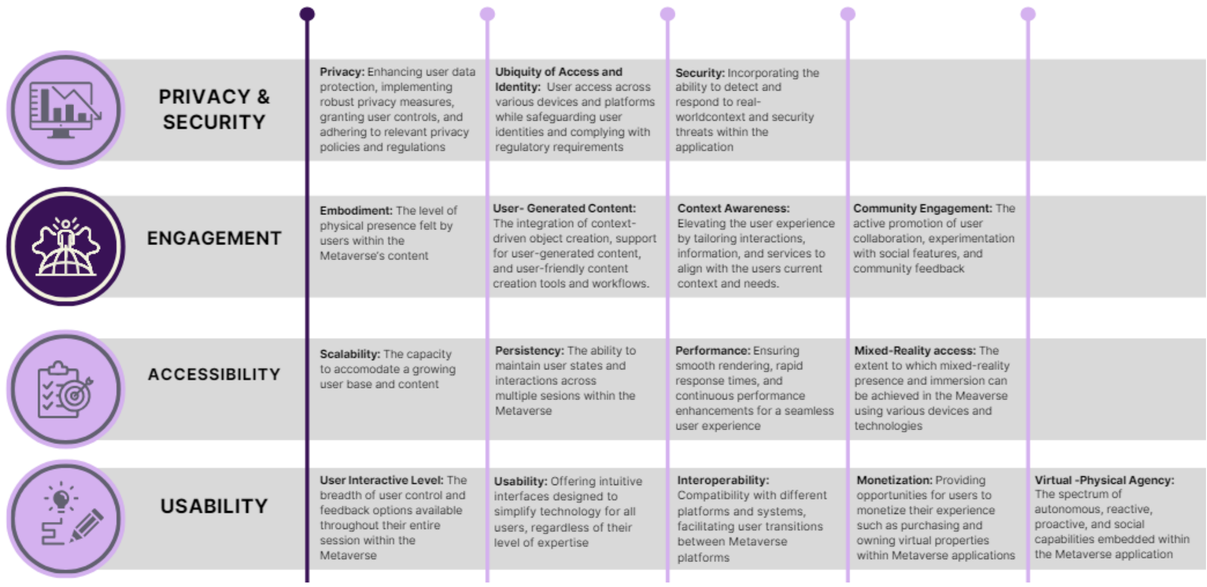

Figure 14, Key design principles educative metaverse application

Next, in Section 3.5, the maturity stages of the MAMM are defined incorporating the key design principles selected in this Section.

3.5 The maturity stages

Building upon the preceding sections, which provided insights on the architectural format of maturity models and key design principles for metaverse applications within enterprise context, this section focuses on defining the maturity levels for the design principles.

Two approaches were being considered: Top-down and bottom-up (de Bruin & Rosemann, 2005). The top-down approach involved defining the maturity stages first and then identifying the appropriate measures aligned with those stages. On the other hand, the bottom-up approach started with the requirements and measures, leading to the definition of maturity stages based on those factors. This top-down approach is particularly useful in new domains lacking well-established maturity indicators and measurements, while the bottom-up approach suits well-established domains. Given the nascent nature of the Metaverse, the top-down approach is deemed most appropriate for defining the maturity stages. This approach allows for a clear establishment of maturity definitions and facilitates the identification of relevant measures corresponding to those definitions. This involves comprehending the context for the application and underlying factors that shape users' attitudes and intentions to determine when an application is in a more mature stage.

Therefore, a five-level framework is designed. It initiates at 'Foundational' and progresses to the optimal stage, 'Full Immersion.' By employing this framework, the key design principles for the applications can be measured and compared in a consistent way. The progression starts with simple functions and moves towards more advanced and immersive features (Becker et al., 2009).

Foundational *Establishing the base*	Basic functionality *Building essentials*	Enhanced features *Elevating experiences*	Advanced *Advanced functionalities*	Full immersion *Optimal experience*
At the "Foundational" level, the focus is on establishing core components of design principles. This phase provides a solid base upon which subsequent levels will build, initiating the essential elements.	Foundational elements are enriched and extended. This level witnesses the emergence of broader functionalities and experiences, enriching users' interactions within Metaverse applications.	Features are enhanced and diversified, offering users a higher level of interactivity. This stage focuses on improving graphics for a more realistic environment, interactions, and user interface for heightened engagement.	Applications offer a range of advanced functionalities. This involves integrating AI, blockchain, advanced physics, and immersive technologies to provide a complex and feature-rich experience.	Applications offer an exceptional realistic immersive experience. This stage marks the optimal convergence of the design principles. Resulting in optimal performance (e.g. AI-driven dynamic interactions, intuitive and customizable interfaces, real-time language translation for global user engagement.)

Figure 15, Maturity levels and their definitions

The levels of "Foundational," "Basic functionality," "Enhanced features," "Advanced," and "Full Immersion," along with their definitions within this context, are presented in Figure 15. These levels are based on several factors that contribute to the maturity of Metaverse applications. Utilizing these levels enables an assessment of strengths and areas for improvement in the focus areas of the applications. This framework empowers stakeholders to evaluate the current state of the focus areas and establish benchmarks for advancement.

It's important to acknowledge that the selection of these levels is somewhat subjective, as the criteria for each design principle may vary depending on specific contexts and evolving technological advancements within the Metaverse field. In Section 3.6, the attributes that serve as measurement indicators of the MAMM are further specified along the stages of maturity.

3.6 The attributes of the MAMM

The identified key design principles included: Embodiment, content generation, virtual-physical agency, scalability, security, monetization, user interactive level, community engagement, mixed-reality access, interoperability, persistency, usability, performance, privacy, ubiquity of access and identity, and context awareness. Incorporating the maturity stages as defined in Section 0, the theoretical knowledge from Chapter 2, and input from experts, the attributes to measure the maturity of each of the key design principles are defined.

The framework containing the attributes is depicted in Table 8. This framework has undergone evaluation and refinement through interviews and case studies with subject matter experts. Details of the evaluation process are further described in Chapter 4, and the cases for application of the model are described in Chapter 5. First, in Section 3.7, an overview of the design process that have led to the MAMM is presented.

Table 8, Maturity stages of the Design Principles and its attributes

Level / Design principle	Foundational	Basic functionality	Enhanced features	Advanced	Full immersion
Embodiment	**Basic avatar representation** - Customizing avatars is unavailable. The avatar selection is limited to pre-set standard options.	**Enhanced avatar customization** - Users have more extensive options to personalize their avatars, including appearance, clothing, and accessories	**Advanced avatar animation** - Avatars exhibit realistic movements and expressions, capturing nuances of human behavior.	**Real-time Facial Tracking** - Avatars accurately mimic the user's facial expressions through advanced tracking technologies.	**Full-Body Tracking and Haptic Feedback** - Users can experience full-body immersion, with haptic feedback devices enabling realistic touch sensations.
Content Generation	**Basic object creation** - Users can create simple objects or modify existing ones within predefined templates.	**Advanced object creation** - Users have more flexibility to create complex objects with custom shapes, textures, and interactions.	**Environment design** - Users can design and build entire virtual environments, including landscapes, structures, and atmospheric effects.	**Procedural generation** - Systems automatically generate dynamic content, leveraging algorithms and user-defined parameters.	**AI-assisted content generation** - Artificial intelligence algorithms assist users in creating and populating virtual worlds with intelligent and context-aware entities.
Virtual-Physical Agency	**Basic Interaction** - Users can perform simple actions within the metaverse, such as object manipulation or basic locomotion.	**Physical object integration** - Users can interact with physical objects in the real world that are digitally connected to the metaverse.	**Real-time physics simulation** - Virtual objects and environments accurately simulate physics, allowing for realistic interactions and dynamics.	**Gesture recognition** - The metaverse can interpret users' real-world gestures and translate them into actions within the virtual environment.	**Real-time environment adaptation** - The metaverse can dynamically adjust the virtual environment based on the user's physical surroundings and context.
Scalability	**Limited concurrent users** - The metaverse supports a small number of simultaneous users, typically within a single instance or environment.	**Moderate concurrent users** - The metaverse can handle a moderate number of users across multiple instances or environments.	**High concurrent users** - The metaverse scales to accommodate a large number of users concurrently engaged in diverse activities.	**Seamless cross-platform integration** - Users can seamlessly transition between different platforms and devices while maintaining their presence and interactions within the metaverse.	**Global-scale infrastructure** - The metaverse leverages distributed networks and robust infrastructure to support a virtually unlimited number of users worldwide.
Security	**Basic user authentication** - Users log in with simple credentials, such as usernames and passwords.	**Two-factor authentication** - Additional security measures, such as SMS verification or biometric authentication, are employed for user access.	**Encrypted communication** - All user interactions and data transmissions within the metaverse are encrypted to protect against eavesdropping and data breaches.	**Content filtering and moderation** - Mechanisms are in place to filter and moderate user-generated content to prevent malicious or inappropriate activities.	**Blockchain-based security** - The metaverse utilizes blockchain technology for enhanced security, decentralized identity management, and transparent transaction records.
Monetization	**In-app purchases** - Users can buy virtual items or services within the metaverse using real-world currency.	**Virtual currency economy** - The metaverse introduces its own virtual currency, enabling users to earn, trade, and purchase items.	**Creator economy** - Users can monetize their own creations and sell them to other users within the metaverse.	**Cross-platform commerce** - Users can engage in economic transactions that span multiple platforms and environments within the metaverse.	**Blockchain-based economy** - The metaverse leverages blockchain technology for secure and transparent transactions, ownership records, and decentralized marketplaces. This addresses opportunities to achieve certifications within the metaverse ecosystem.
User Interactive Level	**Passive observation** - Users can observe the metaverse but have limited interaction or influence over the environment.	**Basic interaction** - Users can perform simple actions such as clicking, selecting, or manipulating objects within the metaverse which enables interactive educational content.	**Cooperative interaction -** Users can collaborate and engage in shared activities with others, fostering teamwork and coordination.	**Social Interaction -** Users can communicate, chat, and engage in social interactions, creating social connections within the metaverse.	**Complex multiplayer interactions -** Users can participate in complex multiplayer experiences, including quests, competitions, or large-scale events
Community Engagement	**Social presence** - Users can see the presence of others within the metaverse but have limited communication options.	**Text-based communication** - Users can exchange text-based messages and engage in chat conversations with others.	**Voice communication** - Users can communicate with others using voice chat, enabling more natural and immediate interactions. This enables vocational trainings.	**Social groups and guilds** - Users can form and join social groups, guilds, or communities within the metaverse.	**Community-driven content and events** - The metaverse empowers communities to organize and host their own events, competitions, and content creation initiatives.

Mixed-Reality access	**Desktop and mobile access** - Users can access the metaverse through traditional desktop computers or mobile devices.	**Virtual reality (VR) headsets** - Users can immerse themselves in the metaverse using VR headsets, enhancing the sense of presence.	**Augmented reality (AR) integration** - Users can overlay virtual elements onto the physical world, blending real and virtual environments.	**Wearable devices** - The metaverse extends to wearable devices, such as smart glasses or haptic suits, enriching the sensory experience.	**Spatial computing** - Users can interact with the metaverse through advanced spatial computing technologies, enabling natural hand gestures, spatial awareness, and object recognition.
Interoperability	**Limited data sharing** - Basic data exchange between metaverse components, allowing for limited integration.	**Standardized protocols** - Common protocols and APIs are established to facilitate interoperability between different metaverse components.	**Cross-platform integration** - Users can seamlessly transition between different metaverse platforms, sharing data and experiences.	**Open metaverse standards** - Industry-wide standards are established to enable interoperability between multiple metaverse ecosystems.	**Universal metaverse integration** - The metaverse achieves a high degree of interoperability, allowing for seamless communication and data exchange across various metaverse domains and platforms.
Persistency	**Basic data retention -** The metaverse retains minimal user data and experiences, with limited capabilities for saving and storing information. User progress may not be preserved between sessions, resulting in a relatively transient experience.	**Partial data persistence -** The metaverse evolves to provide improved data retention capabilities. Users can save and access certain aspects of their experiences and progress, allowing for a partial sense of continuity across sessions. However, the persistency features may still be limited in scope.	**Enhanced data preservation** - The metaverse advances further, offering more comprehensive persistency features. Users can securely store and retrieve a wider range of data, including preferences, achievements, and user-generated content. This allows for a more consistent experience across sessions and platforms.	**Robust data continuity -** The metaverse reaches a highly developed state of persistency. User data and experiences are effectively preserved and seamlessly accessible across different sessions and platforms. Users can confidently expect a persistent and uninterrupted experience, with their progress and interactions consistently maintained.	**Complete data persistence -** In this state, the metaverse achieves the highest level of persistency. User data, experiences, and progress are fully preserved and seamlessly synchronized across all metaverse domains and platforms. The metaverse offers a unified and continuous experience, enabling users to seamlessly transition between different metaverse environments while maintaining their personalized presence and data.
Usability	**Basic interface navigation** - Users can navigate the metaverse through simple menus and buttons.	**Intuitive controls** - User interfaces and controls are designed to be intuitive, reducing the learning curve for new users.	**Customizable user interfaces** - Users can personalize their metaverse interfaces, adapting them to their preferences and workflows.	**Contextual user guidance** - The metaverse provides contextual guidance and tooltips to assist users in understanding features and functionalities.	**Adaptive interfaces** - Interfaces dynamically adapt to individual user preferences and behavior, maximizing usability and efficiency.
Performance	**Basic performance optimization** - The metaverse ensures a baseline level of performance to maintain smooth interactions for most users.	**Enhanced rendering and graphics** - The metaverse incorporates advanced rendering techniques and high-quality graphics to enhance visual fidelity.	**Low latency interactions** - The metaverse minimizes latency to provide real-time responsiveness between user actions and system feedback.	**High-fidelity simulations** - Complex simulations and physics calculations within the metaverse are optimized to maintain high performance.	**Quantum computing optimization** - The metaverse leverages emerging technologies such as quantum computing to achieve unprecedented levels of performance and computational power.
Privacy	**Basic data protection** - The metaverse implements standard privacy measures to safeguard user data and prevent unauthorized access.	**User-controlled privacy Settings** - Users have the ability to manage and customize their privacy settings, granting or restricting access to their personal information.	**Privacy by design** - Privacy considerations are integrated into the metaverse's architecture and development processes from the outset.	**End-to-End encryption** - All user interactions and data transmissions within the metaverse are encrypted, ensuring privacy and confidentiality.	**Self-Sovereign identity and data ownership** - The metaverse adopts decentralized identity systems and empowers users with full control over their digital identities and personal data.
Ubiquity of access and identity	**Device compatibility** - The metaverse supports access from a range of devices, including PCs, smartphones, and tablets.	**Cross-platform integration** - Users can seamlessly access and transition between the metaverse's platforms, maintaining a unified identity and experience.	**Single sign-on** - Users can use a single set of credentials to access multiple metaverse platforms and services.	**Universal identity standards** - The metaverse adopts standardized identity protocols, allowing for interoperability and cross-platform identity management.	**Decentralized identity and portability** - Users have portable and self-sovereign identities that can be utilized across various metaverse ecosystems, promoting user freedom and identity ownership.
Context awareness	**Basic user profile** - The metaverse maintains a user profile with basic information, such as preferences and progress.	**User context tracking** - The metaverse tracks user actions and behavior to provide personalized experiences and recommendations.	**Adaptive environments** - The metaverse adapts its content and interactions based on user context, enhancing immersion and relevance.	**Environmental sensing** - The metaverse incorporates sensors and IoT devices to capture real-world data and integrate it into the virtual environment.	**Cognitive understanding and anticipation** - The metaverse utilizes advanced AI algorithms to understand user intent, anticipate needs, and provide contextually relevant experiences.

3.7 The Design: The Metaverse Application Maturity model

In this section, we synthesize the design process of the MAMM, integrating insights from this chapter. We considered various strategies for developing the MAMM, including designing a completely new model, enhancing existing models, combining multiple models to form a new one, or adapting the structure and content of existing models to suit a new domain (Proença & orbinha, 2016). Ultimately, we decided to adapt the structure and content of existing models to fit the new domain of Metaverse application development. Since existing scientific models followed a continuous-fixed level structure, it was logical to adhere to the same model type, given their proven value, and the time constraints that limited exploration of other structures within this new domain.

To systematically develop the maturity model, we examined various methodologies, methods, and guidelines (Pereira & Serrano, 2020). We employed the design science methodology, following the guidelines proposed by (Becker et al., 2009). These guidelines, aligned with the principles of Design Science Research (DSR), are widely adopted within the scientific community. The design approach involved a mixed-method approach, synthesizing a SLR, analysis of existing maturity models, expert interviews, and market research.

Considered were the educational capabilities enabled by Metaverse applications, as described in Chapter 2, and the user-centric aspects outlined in Section 3.3 to define the focus areas (the key design principles) for the maturity model in Section 3.4. Subsequently, in Section 0, we applied a top-down approach to define the maturity stages alongside the focus areas, as this approach was most applicable in the nascent stage of this research domain.

concluding, the development of the maturity model was an iterative process guided by the analysis of market research and expert interviews. These interviews confirmed the relevance of the attributes in the model. The model's evaluation, the fourth step of the DSR, is detailed in Chapter 4.

4

Evaluation

In this chapter we describe the evaluation process aimed at enhancing the MAMM in maturity levels, understandability, ease of use, usefulness, and practicality. Specifically, Section 4.1, provides an overview of the validation approach, followed by a detailed description of the validation phases in Section 4.2. Further insights regarding the iterative refinement process are presented in Section 0. Section 0 illustrates the practical application of the model, and in Section 4.3, a roadmap is formulated to guide progression towards more mature stages for utilization of the MAMM.

4.1 Validation methodology and approach

The validation approach employed in this research utilizes a mixed-method strategy following the Framework for Evaluation in Design Science (FEDS) (Venable et al., 2016), which encompasses four steps:

1. Explicating the goals of the evaluation
2. Selecting the evaluation strategy/strategies
3. Determining the properties to evaluate
4. Designing the individual evaluation episode(s).

As outlined in Section 1.4, the Design Science Research approach from (Wieringa, 2014) is applied consistently throughout this research. In design science, validation research aims to anticipate the outcomes of implementing the artifact in a real-world problem context. The primary objective of this study is to design a maturity model that facilitates the assessment of key design principles for educational metaverse applications, particularly within an enterprise context. Considering the unique attributes of the artifact, including uncertainties surrounding social and usability aspects, as well as the requirement to establish effectiveness in practical use, the human risk and effectiveness evaluation strategy proposed by (Venable et al., 2016) is employed. Through the application of this strategy, the model has been systematically assessed. In the systematic mapping study on the evaluation and assessment of maturity models, three types of evaluation for maturity models are performed:

1. *Author evaluation*, conducted by the maturity model authors themselves to assess the model's input and compare them with similar models.
2. *Domain expert evaluation*, where experts in the relevant process evaluate the maturity model without involvement in its development. This evaluation typically involves interviews or simulated assignments.
3. *Practical setting evaluation*: Involving implementing the maturity model in real-world scenarios.

The validation encompasses the interaction between the artifact model, namely the MAMM, and case studies representing the problem context. These case studies, presented in chapter 5, are application scenarios for assessing the artifact in real-world contexts. To evaluate these scenarios, expert interviews are conducted with selected participants. By employing these diverse approaches, the validation model ensures a comprehensive and robust assessment of the artifact's effectiveness within real-world contexts.

4.2 Validation phases

In the initial validation episode, expert interviews are conducted with subject-matter experts for the domain expert evaluation. The primary objective of this evaluation is formative in nature, aiming to improve the MAMM and its attributes. The evaluation paradigm is defined as simulated, as the experts envision the implementation of the maturity model in real-world contexts and provide their insights and assessments based on the evaluation criteria. To ensure the reliability and relevance of the findings, interviews are conducted with diverse Metaverse experts. The review of various stakeholders in the Metaverse field is important to ensure the quality and effectiveness of the model. This includes individuals from Metaverse start-ups, developers with expertise in the field, and other related experts. Their input and feedback support the model's understandability, ease of use, usefulness, and practicality.

A summary of the participants involved in the expert evaluation can be found in Table 9. Their participation is particularly important as they provide validation based on their expert knowledge, a process commonly referred to as member checking (Wieringa, 2014). Due to the relative novelty of the Metaverse domain, the availability of approachable experts is limited. Therefore, only a small number of (diverse) experts is interviewed. Detailed notes from the interviews can be found in Appendix C alongside the interview protocol.

Reference	Country	Function role	Interview Date
1.	India	Web Developer at PHYED	29/06/2023
2.	Australia	Inaugural Chair of the World Metaverse Council	13/07/2023
3.	Netherlands	Researcher Educational Technologies	04/07/2023
4.	Netherlands	Editor in Chief at Rocking Reality	04/07/2023
5.	Ireland	Presales Business Technology Consultant	10/07/2023

Table 9, Participants Expert Evaluation

The participants received explicit instructions to concentrate on the aspects they consider themselves experts in. For instance, less technical experts were directed to offer feedback primarily concerning the understandability and ease of use of the model. Conversely, those with greater technical expertise were encouraged to evaluate the model's usefulness, practicality, and overall content. In this Section, the evaluation assessment, the qualitative data analysis of the results and the iterative refinement process is explained in detail.

Evaluation assessment

To conduct a quantitative evaluation of the MAMM, the evaluation template developed by (Salah et al., 2014) is employed. This template encompasses a diverse set of evaluation criteria focusing on the assessment of maturity levels, attributes, and the overall utility of the MAMM. The template comprises a series of statements to be evaluated on a 5-point Likert scale, supplemented with open-ended questions to identify potential areas for improvement.

The interview questions, based on the Maturity Model Domain Expert Evaluation template from (Salah et al., 2014), and the corresponding protocol, are available in Appendix C. The evaluation statements, along with the average scores assigned by the participants, are presented in Table 10.

Maturity Levels *(N= 9)*	*Min.*	*AVG*
The maturity levels are sufficient to represent all maturation stages of the domain *(Sufficiency)*	4	4,0
There is no overlap detected between descriptions of maturity levels *(accuracy)*	3	4,1
Key design principles and Practices		
The design principles and practices are relevant to the Metaverse domain *(Relevance)*	4	4,3
The design principles and practices cover all aspects impacting/involved in the domain *(comprehensiveness)*	3	3,9
The key design principles and practices are clearly distinct *(Mutual exclusion)*	3	3,9
The key design principles and practices are correctly assigned to their respective maturity level *(Accuracy)*	3	3,9
Maturity Model		
Understandability		
The maturity levels are understandable	4	4,3
The assessment guidelines are understandable	4	4,1
The documentation is understandable	3	4,1
Ease of use		
The assessment guidelines are easy to use	3	4,1
Usefulness and practicality		
The maturity model is useful for conducting assessments	3	4,3
The maturity model is practical for use the industry	3	3,9

Table 10, Evaluation assessment by participants

Qualitative data analysis

The data analysis process involved the analysis of information collected from interviews using interview notes. The use of notes instead of full transcripts facilitated faster data analysis due to time constraints, as the notes were filtered to capture the most important information (Garousi et al., 2016). To enhance the reliability and validity of the findings, a peer debriefing process was undertaken. Peer debriefing involves the critical evaluation of the interpretation process by independent scientific peers (Wieringa, 2014). This validation method was selected to ensure an unbiased assessment, as the peer does not possess a bias. The peer possesses experience in qualitative content analysis and was provided with interview questions, notes, and interpretation decisions.

The analysis of the expert interview follows the methodology guided by (Dey, 2005) to derive valid insights from the data. The notes of the interviews are available in Appendix D. The analysis process can be summarized in three steps:

1) *Reading and Annotating*: The notes were thoroughly read, and relevant sections pertaining to the maturity model, open questions, or evaluation criteria were highlighted and annotated.
2) *Categorizing Data*: The data was labeled with appropriate categories.
3) *Corroborating Evidence*: The data was combined based on the identified categories and content, that the comments or responses addressed.

Iterative Refinement

Effective design is an iterative process that thrives on feedback and continuous improvement. Therefore, expert feedback is utilized for the re-evaluation and refinement of the MAMM.

Upon analyzing the outcomes of expert interviews, a notable adaptation was made to the list of key design principles. Expert insights guided the selective sharpening and refining of the attributes at various stages of maturity. In particular, certain key design principles such as "open standards" and "connectedness," initially identified in the literature, were eliminated because experts found them confusing. Furthermore, the distinct levels of the maturity stages were refined based on expert input.

Another outcome was the identification of four distinct domains—Usability, Accessibility, Security, Privacy, and Engagement—to categorize key design principles. These domains were chosen purposefully and correspond to the user-centric factors outlined in Section 3.3. They provide a clear framework emphasizing each key design principle's contribution within its domain.

Application of the model

In order to validate the MAMM, the utilization of scenarios is recognized as a valuable method. NATO defines a scenario as a comprehensive description of various elements such as the environment, means, and objectives associated with application within a defined area (Tetlay, 2010). Scenarios facilitate the evaluation of the design principles under foreseeable and realistic conditions. Nevertheless, it is important to acknowledge that while scenarios are advantageous, they may not cover all possible applications of a key design principle. Therefore, thoughtful construction of scenarios is essential to cover all relevant conditions that a design principle is likely to encounter.

The suggestion to employ scenarios for the assessment and measurement has been previously put forward by (Urwin et al., 2010). These findings contribute to the planning and construction of scenarios using measurement factors. By focusing on the assigned scores for the attributes as measurements and adopting a through-life perspective, organizations can assess how they can meet their needs and effectively balance acquisition and support costs (Tetlay, 2010). It is acknowledged that tailoring content for a broader audience with simplicity necessitates different design principles, compared to tailoring for specific users with more intricate, specialized content. Therefore, three different scenarios are evaluated in Chapter 5.

In Section 4.3, we describe how organizations can progress towards higher stages of maturity through designed roadmaps utilizing the MAMM.

4.3 Advancing through the levels

In order to advance from one level to the next, an approach to incrementally improve the key design principles for each level is described in this section. A general description of what progression to a new level means in terms of functionality for each of the key design principles in the MAMM is provided. Supporting tables are constructed for each of the four key domains, specifying the steps for each of the key design principles to progress towards higher maturity levels.

Level 1 (basic) to Level 2 (foundational)

The progression towards level 2 aims to provide users with more interactive and customizable experiences within the metaverse. The strategy may involve improvements in avatar customization options, enabling basic interactions with objects, introducing text-based communication, and enhancing content creation flexibility. Level 2 aims to establish a foundation for user engagement and interaction.

Level 2 (foundational) to Level 3 (enhanced)

Building upon the basic functionalities in level 2, the goal is to enhance personalization in level 3. The strategy involves introducing advanced avatar animations, voice communication, environment design capabilities, and real-time physics simulations. Additionally, scalability and security measures need to be improved to handle a high number of concurrent users and ensure encrypted communications. Context awareness and mixed-reality access are also emphasized, enabling adaptive experiences and integration with augmented reality.

Level 3 (enhanced) to Level 4 (advanced)

In progressing towards level 4, the application aims to attain an advanced level of performance, privacy, and persistency through the integration of advanced technologies. The strategy involves implementing robust data continuity, low-latency interactions, and edge computing to ensure high-fidelity simulations and seamless cross-platform integration. Security measures need strengthening with content filtering and moderation, as well as end-to-end encryption. Usability requires enhancement with contextual user guidance and customizable interfaces to align with the norms of level 4.

Level 4 (advanced) to Level 5 (full immersion)

To enter level 5 and achieve full immersion in the metaverse application, the strategy revolves around pushing the boundaries of technological capabilities. This involves the incorporating of advanced features such as full-body tracking, haptic feedback, and gesture recognition. Privacy and security are reinforced through blockchain-based solutions. The application evolves to support a global-scale infrastructure, optimize quantum computing, and enable cognitive understanding. Interoperability achieves universal integration, and decentralized networking is adopted. The focus shifts towards adaptive interfaces, decentralized identity, and a blockchain-based economy.

The steps are described in detail for each of the key design principles, categorized by the four domains in Table 11, Table 12, Table 13, and Table 14

Progression / *Foundational Principles*	Level 2	Level 3	Level 4	Level 5
Embodiment: Basic avatar representation - Limited customization options	**Customization:** Provide more diverse appearance options, including clothing and accessories.	**Advanced Animation:** Implement realistic avatar movements and expressions for enhanced human-like behavior.	**Real-time Facial Tracking:** Incorporate advanced tracking for lifelike facial expressions.	**Full-Body Tracking and Haptic Feedback:** Enable users to experience touch sensations and full-body immersion.
User generated content: Basic object creation within templates.	**Advanced Object Creation:** Allow users to build complex objects with custom shapes and textures.	**Environment Design:** Provide tools for creating entire virtual environments with landscapes and structures.	**Procedural Generation:** Develop algorithms for automatic dynamic content creation.	**AI-Assisted Content Generation:** Incorporate AI to assist users in creating intelligent and context-aware virtual entities.
Community engagement: Social presence with limited communication.	**Text-Based Communication:** Enable text-based chat.	**Voice Communication:** Facilitate voice chat for more natural interactions.	**Social Groups and Guilds:** Form and join communities within the metaverse.	**Community-Driven Content and Events:** Empower communities to organize events and content.
Context Awareness: Basic user profile	**User Context Tracking**: Track user behavior for personalized experiences.	**Adaptive Environments**: Modify content based on user context for increased immersion.	**Environmental Sensing**: Incorporate real-world data through sensors and IoT devices.	**Cognitive Understanding and Anticipation**: Utilize advanced AI to understand intent and provide contextually

Table 11, Roadmap for Advancing User Engagement

Progression / *Foundational Principles*	Level 2	Level 3	Level 4	Level 5
User interactive level: Passive observation with limited interaction.	**Basic Interaction:** Enable simple actions like clicking and selecting.	**Cooperative Interaction:** Foster collaboration and shared activities.	**Social Interaction:** Facilitate communication and chat.	**Complex Multiplayer Interactions:** Allow participation in quests, competitions, and events.
Virtual-Physical agency: Basic interaction like object manipulation.	**Physical Object Integration:** Enable interaction with real-world objects connected to the metaverse.	**Real-time Physics Simulation:** Improve physics accuracy for realistic interactions.	**Gesture Recognition:** Translate real-world gestures into virtual actions.	**Real-time Environment Adaptation:** Dynamically adjust the virtual environment based on the user's physical surroundings.
Usability: Basic interface navigation.	**Intuitive Controls:** Design interfaces for easier user adoption.	**Customizable Interfaces:** Allow users to personalize their interfaces.	**Contextual User Guidance:** Provide tooltips and guidance for features.	**Adaptive Interfaces:** Customize interfaces based on user behavior.
Interoperability: Limited data sharing between components.	**Standardized Protocols:** Establish common protocols for interoperability.	**Cross-Platform Integration:** Seamlessly transition between platforms.	**Open Metaverse Standards:** Set industry-wide standards for cross-platform communication.	**Universal Metaverse Integration:** Achieve high-level interoperability between domains.
Monetization: In-app purchases using real-world currency.	**Virtual Currency Economy:** Introduce virtual currency for trading and earning.	**Creator Economy:** Allow users to sell their creations within the metaverse.	**Cross-Platform Commerce:** Enable economic transactions across platforms.	**Blockchain-Based Economy:** Leverage blockchain for secure transactions and decentralized marketplaces.

Table 12, Roadmap for improving Usability

Progression / *Foundational Principles*	Level 2	Level 3	Level 4	Level 5
Scalability: Limited concurrent users in a single instance.	**Moderate Concurrent Users:** Handle more users across multiple instances.	**High Concurrent Users:** Scale to accommodate a large number of users concurrently.	**Seamless Cross-Platform Integration:** Allow users to transition between platforms while maintaining presence.	**Global-Scale Infrastructure:** Leverage distributed networks for virtually unlimited users worldwide.
Persistency: Basic data retention with limited preservation.	**Partial Data Persistence:** Allow users to save certain aspects of their experiences.	**Enhanced Data Preservation:** Store preferences, achievements, and user-generated content.	**Robust Data Continuity:** Preserve user data across sessions and platforms.	**Complete Data Persistence:** Fully synchronize experiences across all domains and platforms.
Performance: Basic performance optimization.	**Enhanced Rendering and Graphics:** Improve visual quality.	**Low Latency Interactions:** Minimize delay for real-time responsiveness.	**High-Fidelity Simulations:** Optimize complex simulations.	**Quantum Computing Optimization:** Leverage emerging tech for unprecedented performance.
Mixed-Reality access: Desktop and mobile access.	**Virtual Reality (VR) Headsets:** Enhance immersion with VR.	**Augmented Reality (AR) Integration:** Blend virtual elements with the physical world.	**Wearable Devices:** Extend to smart glasses and haptic suits.	**Spatial Computing:** Enable natural interactions through spatial technologies.

Table 13, Roadmap for enhancing Accessibility

Foundational Principles	Level 2	Level 3	Level 4	Level 5
Security: Basic user authentication.	**Two-Factor Authentication:** Introduce additional security measures for user access.	**Encrypted Communication:** Encrypt user interactions and data transmissions.	**Content Filtering and Moderation:** Implement mechanisms to prevent malicious activities.	**Blockchain-Based Security:** Utilize blockchain for enhanced security, decentralized identity, and transparency.
Privacy: Basic data protection measures.	**User-Controlled Privacy Settings:** Allow users to manage privacy preferences.	**Privacy by Design:** Integrate privacy considerations from the start.	**End-to-End Encryption:** Encrypt all interactions for confidentiality.	**Self-Sovereign Identity:** Give users control over digital identities and data.
Ubiquity of Access and Identity: Device compatibility.	**Cross-Platform Integration:** Access different platforms.	**Single Sign-On:** Use one set of credentials for multiple platforms.	**Universal Identity Standards:** Implement standardized identity protocols.	**Decentralized identity and portability:** Allow users to carry self.

Table 14, Roadmap for Strengthening Security and Privacy

Concluding, progressing from one level to the next entails iterative development, integration of advanced technologies, and addressing user needs at each stage. To streamline the assessment process and provide an effective overview of the results, we have developed an assessment tool. This tool is specifically designed to simplify the evaluation of key design principles and ensure a systematic assessment approach. Further details about the tool can be found in Section 4.4.

4.4 Assessment tool: Functionality and process

The MAMM provides organizations with a systematic framework for assessing their maturity in key design principles specific to Metaverse applications. As mentioned in the previous section, a specialized tool has been developed to effectively collect measurement data. A view of the tool's interface and the provided instructions are available in Appendix E. By leveraging the maturity model and its associated assessment tool, organizations can achieve several objectives:

I. Assess design features of current metaverse applications.
II. Establish a desired maturity level to strive for.
III. Identify discrepancies between the current and desired maturity levels, enabling the development of a roadmap to progress towards the desired level.
IV. Facilitate the comparison of design principles for applications across diverse user target scenarios by utilizing standardized constructs and scales.

The functionalities of the tool are described in this section.

Assessment Process

The tool assesses the key design features based on defined criteria, evaluating each key design principles individually. The assessment process involves the following steps:

I. *Compliance Check*: For each key design principle, the user determines whether the application currently complies with the described criteria or not. If compliance is achieved, it needs to be marked with a "Yes." Otherwise, it needs to be marked with a "No."
II. *Future aim*: If the application does not currently comply with a specific design principle, the tool prompts the user to indicate whether they aim to comply with it in the future for the given application.

Moreover, if the user disagrees with a statement but wishes to provide feedback on the maturity level, a comment box is provided for input. Once the evaluation is completed, the tool automatically calculates the maturity scores for each category. The results, along with the desired maturity levels, are presented in the 'results' tab, functioning as a dashboard presenting the current state of the application, existing gaps, and serving as a starting point for constructing the improvement roadmap. An overview of this tab is detailed in Appendix E.

Score calculation and presentation

Upon completion of the assessment of all key design criteria, the tool automatically computes the overall score and generates an overview of the results. The interface is depicted in Figure 31, available in Appendix D. The assessment tool provides two types of scores:

I. *Completeness Levels*: The tool calculates the completeness of the application in terms of attributes as percentage. For example, if an organization complies with 10 out of 15 attributes in Level 1, the completion level for Level 1 would be 66.7%.

II. *key design principle scores*: Each main principle is assigned a score on a scale from 1 to 5, indicating the applications current level of compliance with that particular design principle. Additionally, the tool calculates and presents the target score that the user aims to attain for each design principle.

Visual Overview of results

In addition to the numerical scores, the assessment tool includes a visual overview that present gaps between the application's current compliance state and the user-defined desired state for each key design principle. The interface of this tab can be found in Figure 32, available in Appendix E. In Chapter 5, the tool is applied in case studies to test the applicability of the MAMM.

5

Application – Case studies

The primary purpose of applying the MAMM in this chapter is summative, aiming to draw conclusive findings for the research. The paradigm employed is naturalistic (Venable et al., 2016), as it examines the performance of the MAMM through the assessment of real-world scenarios. Therefore, we conduct three case studies to effectively assess the MAMM and gather feedback from users regarding the validity and generalizability of the model. Specifically, in Section 5.1, we provide instructions for the case studies, outlining a systematic assessment method. Following this, we present the three cases in Sections 5.2 - 5.4, and conclude with an overall evaluation of the assessment process in Section 5.5.

5.1 Case study instructions

To evaluate the maturity model, interviews were carried out with a diverse set of subject-matter experts who have participated in experiments involving Metaverse applications. The interviewees are detailed in Table 15, and the notes of the interviews are presented in Appendix G.

Meeting	Participant	Case	Country	Function role	Interview Date
Assessment	**1.**	1: Ideation sessions in the Metaverse	Netherlands	Strategic Business and Innovation Developer	24/08/2023
Assessment	**2**	1: Ideation sessions in the Metaverse	Netherlands	Business Development representative	22/08/2023
Assessment	**3**	2: Onboarding Program	Netherlands	Cyber Security Engineer	29/08/2023
Assessment	**4**	2: Onboarding program	Netherlands	Technology & Strategy Consultant	30/08/2023
Assessment	5	3: Business Technology Platform	Ireland	Presales Business Technologies consultant	04/08/2023
Evaluation	**6**	All cases	Netherlands	Industry Value Engineer	31/08/2023

Table 15, Participants Case Studies

The goals of the case study were threefold: Firstly, to test the functionality of the MAMM, demonstrating an application's compliance with attributes of the key design principles; secondly, to evaluate the requirements or evaluation criteria; and thirdly, to assess the recommendations aimed at improving key design principles based on the roadmaps outlined in Section 4.3. An interview protocol, detailed in Appendix E, was employed for systematic assessment. In upcoming sections, the three case studies are described.

5.2 Case 1: Ideation with colleagues

Focus of the application: Broad Audience – Easy content

In this case study, we evaluate an Metaverse application used by a marketing and creative solutions company. They identified a challenge with traditional virtual meetings—lack of creativity and collaboration—and aimed to enhance interaction and engagement during online meetings. The company explored the metaverse concept to provide immersive experiences to its diverse audience easily.

The metaverse application is specifically designed to offer customizable virtual meeting spaces that reflect the company's brand identity. Dynamic 3D models and interactive presentations in the application replace conventional slide decks, encouraging direct interaction with visual content. Real-time collaboration tools facilitate ideation and client interactions. Additionally, breakout rooms are integrated to promote parallel discussions, transforming routine meetings into experiences that effectively spark ideas and facilitate decision-making.

In Figure 16 is presented how such a session could look like. The MAMM is utilized to evaluate the application's features, focusing on user-centric outcomes to refine and further improve the application. The results are presented in this section.

Figure 16, Ideation Session in the Metaverse

Assessment

The case study and its assessment were carried out by participants 1 and 2, details can be found in Appendix G. The evaluation scores for each domain are presented in Table 16. Additionally, Figure 17, offers a visual overview of the scores broken down by each design principle to identify specific gaps with the desired to-be state.

Participant	Engagement		Accessibility		Usability		Security and Privacy	
1	1,0	**3,2**	1,8	**2,8**	2,3	**3,4**	1,7	**2,7**
2	1,7	**3,8**	1,0	**1,8**	2,0	**3,9**	1,0	**2,2**
Average	1,8	**3,5**	1,1	**2,3**	2,2	**3,7**	1,3	**2,5**

Table 16, Scores by domain (Case 1)

(as-is | to-be)


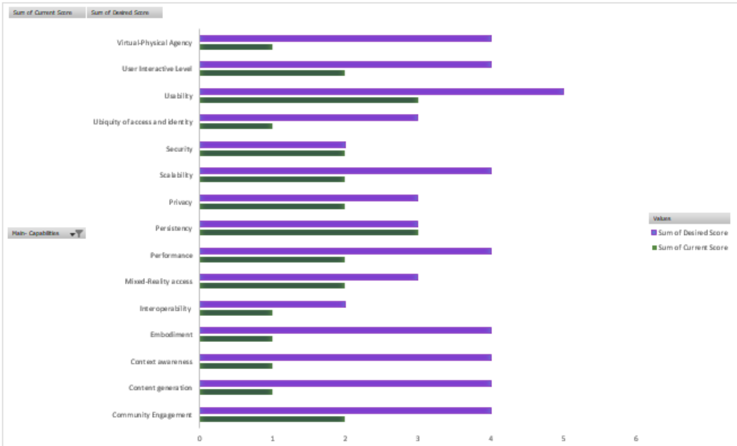

Figure 17, Average Scores broken down for the ideation session (key design principles)

Evaluation and recommendation

The assessment conducted by participants 1 and 2, indicate gaps in the functioning of the application, particularly within the engagement and usability domains. Recommendations for enhancements extend to other domains as well. The prescribed improvement steps are formulated based on the roadmaps described in section 4.3, for each domain:

First, in the user engagement domain, Participant 1 highlighted concerns regarding embodiment: "*Realistic avatars are important for establishing genuine connections. When avatars resemble real people, interactions feel more authentic and relatable".* Therefore, it is recommended to integrate avatars with naturalistic movements and emotive expressions.

Additionally, participant 1 has also raised issues regarding the ubiquity of access principle: *"Ensuring that users present themselves genuinely is important for building trust."* A collaborative effort with animation experts is advised to improve this feature.

In the usability domain, second, the integration of real-time voice chat functionality is recommended, aligning with the feedback from the participants. Furthermore, providing moderation tools contributes to improved usability by ensuring a secure user interface.

Third, in the accessibility domain, the primary step is to enhance scalability. This involves transitioning to a distributed architecture and incorporating intelligent load balancing mechanisms to enhance performance and accommodate a growing participant base for wider adoption. Therefore, efficient resource allocation is needed to meet increased demands from users; see details in Section 2.2.

Lastly, within the data privacy and security domain, granting users control over their data, including the ability to retain specific components of meetings for future reference, is recommended. As the participants feedback highlights, *"If clients struggle to join meetings or if data security is compromised, it undermines the Metaverse's potential".* Following this, and the score outcomes, upgrading security measures through the implementation of two-factor authentication demonstrates a commitment to user privacy, ultimately building more trust and confidence in the application.

Systematically implementing these measures enables the application to achieve a higher maturity level, improving meeting approaches and promoting creativity, interaction, and collaboration.

In the upcoming case in Section 5.3, an onboarding application developed for a diverse employee base within a global service company is assessed using the MAMM. This program aims to effectively onboard employees of various backgrounds and roles.

5.3 Case 2: Onboarding program for a global professional services company

Focus of the application: Targeted audience - easy content

In this case study, we are evaluating a metaverse application developed by a company to onboard new employees. The company identified challenges faced by new hires during the initial stages of onboarding, such as navigating new faces, systems, and surroundings. In response, the global service company designed a metaverse application to streamline the onboarding program and make the transition smoother for incoming employees.

Traditionally, new employee orientation involved workshops or presentations. However, this company has adopted a different approach by developing a metaverse application to welcome new employees. The application provides a platform for various activities, including orientation days. New hires can meet others, attend presentations, and participate in fun collaborative games. The virtual world immerses them in real-life scenarios, enhancing engagement with the training. The goal is to make the experience enjoyable and easy for everyone, regardless of their familiarity with technology or virtual environments. To achieve this, the company has simplified real-life concepts in the Metaverse application, incorporated visuals, interactive elements, and even added game-like features. This has enriched the learning experience, aiding effective knowledge retention and fostering a sense of connection among employees (Armstrong, 2022).

Participants 3 and 4 took part in this onboarding program and assessed the application using the MAMM. The outcomes are presented in this Section, and an improvement plan is described to better meet the needs of its end-users. Figure 18, depicts a scene from the metaverse application used in the onboarding program.

Figure 18, Onboarding Program in the Metaverse

Assessment

The case study and its assessment were carried out by participants 3 and 4, details of the session can be found in Appendix G. The evaluation scores for each domain are presented in Table 17. Additionally, Figure 19, offers a visual overview of the scores broken down by each design principle to identify specific gaps with the desired to-be state.

Participant	Engagement		Accessibility		Usability		Security and Privacy	
3	2,0	**3,0**	1,2	**2,0**	2,3	**4,3**	1,3	**2,0**
4	2,1	**2,8**	1,0	**1,8**	2,0	**3,7**	1,2	**2,4**
AVG	2,1	**2,9**	1,1	**1,9**	2,2	**4,0**	1,3	**2,2**

Table 17, Evaluation of the Metaverse Onboarding Application (Candidate 3 and 4)

(as-is | to-be)

Figure 19, Average Scores broken down for the onboarding application (key design principles)

Evaluation and recommendation

The most significant gap is addressed in the usability domain. Additionally, recommendations for gradual improvements are proposed in the other three domains: security and privacy, engagement, and accessibility. Addressing the key design principles from the improvement roadmaps in Section 4.3, the following advice is described based on input from participants 3 and 4:

In the usability domain, the first priority is addressing the identified gaps. This entails improving navigation and user interface design to make the application more intuitive for new employees. Furthermore, implementing tooltips and on-screen guidance to enhance usability is recommended, as indicated by participant 3: *"A well-structured learning path can significantly enhance the onboarding experience."*

In the security and privacy domain, second, implement stricter access controls and refine user authentication processes. This involves adding multifactor authentication and encryption for sensitive data. Addressing privacy concerns is equally important according to the participants feedback, allowing users to have control over their data and privacy settings, ensuring compliance with data protection regulations.

In the engagement domain, the third priority is focusing on introducing more interactive elements. This encompasses incorporating challenges to keep new hires engaged and motivated during the onboarding experience. Leveraging AI and user data to provide personalized onboarding experiences can significantly improve engagement as suggested by the participants.

Lastly, in the accessibility domain, efforts should be made to expand accessibility features. This involves improving compatibility with assistive technologies and ensuring that the metaverse environment is usable for users across disciplines in the organization. As indicated by participant 3: *"User accessibility should be a top consideration. This involves ensuring that the metaverse environment is accessible to individuals with diverse abilities, including those with disabilities. Implementing features like screen readers, voice commands, and accessible interfaces is essential to provide an inclusive onboarding experience for all employees."*

Furthermore, based on performance metrics, optimizing the application for smoother interactions, faster loading times, and improved overall performance would further enhance the experience. This optimization might require refining server infrastructure, reducing latency, and optimizing rendering processes.

The last case presented in Section 5.4, presents a more complicated scenario. It centers on a software ecosystem and focuses on upscaling partners, ecosystem partners, and resellers of a software vendor with new software developments using a metaverse application that represents the solutions and the architecture of a technology platform in the Metaverse.

5.4 Case 3: Upscaling actors within a software ecosystem

Focus of the applications: Targeted Audience – Niche content

In this case study, we explore training and education within software ecosystems—a network of relevant actors for software vendors and platform owners. A software ecosystem operates as a shared market for software and services, orchestrated through a technological platform (Van Angeren et al., 2013).

The objectives of software vendors and platform owners within these ecosystems are diverse, encompassing financial gains, customer satisfaction, product enhancement, network expansion, and market growth. Achieving these objectives fundamentally relies on collaborations with resellers and strategic allies (Van Angeren et al., 2013). Expansion strategies involve collaborative product innovation with partners and enabling them to develop additional functionalities on the existing platform (Bosch & Avenue, n.d.)

Fundamental actors in the software ecosystem are resellers, ecosystem partners, and partners. Partnerships prove advantageous for vendors by leveraging external expertise and resources, driving innovation and value creation. Resellers primarily focus on distribution and sales, connecting vendors to end users and expanding market reach. While ecosystem partners provide complementary solutions, enhancing the value proposition, and partners engage in co-creation activities (Cinlar 2023). In Figure 21, the relationships are depicted of SAP, a large software vendor, and its ecosystem partners.

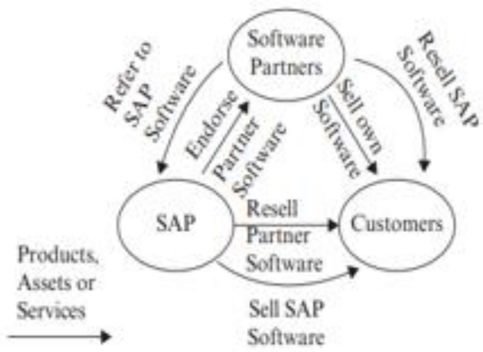

Figure 20, Relationships within the SAP ecosystem (Van Angeren et al. 2013).

Keeping participants informed in the continuously innovating software landscape is a challenge. To address this challenge, SAP introduces a Metaverse application—a virtual replica of their Business Technology Platform (BTP). This application facilitates learning, collaboration, and skill acquisition regarding new platform features for partners, ecosystem partners, and resellers. Figure 22 shows what the application looks like. The conceptual version of the application is assessed using the MAMM. The results are presented in this section, along with a recommendation based on the assessment outcomes.

Figure 21, SAP solutions and Architecture in the Metaverse (Bungert 2023).

Assessment

The case study and the assessment is carried out by participant 5, details of the session can be found in Appendix G. The evaluation scores for each domain are presented in Table 18. Additionally, Figure 22, offers a visual overview of the scores broken down by each design principle to identify specific gaps with the desired to-be state.

Categories	Score	
Engagement	2,3	**3,5**
Accessibility	2,5	**3,0**
Usability	2,4	**3,6**
Security and Privacy	2,7	**3,7**

Table 18, Scores by domain for the BTP application.

(as-is | to-be)

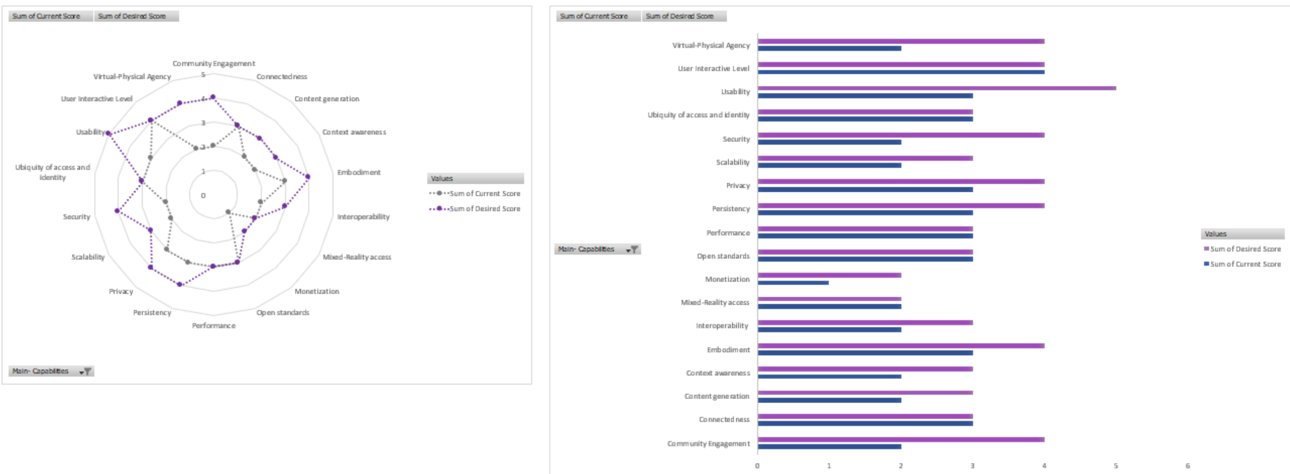

Figure 22, Average scores broken down by the key design criteria for the BTP application

Evaluation and recommendation

Based on the assessment outcomes, we have identified gaps primarily in the engagement and usability domains. Additionally, key design principles that require improvement have been recognized in the security, privacy, and accessibility domains. Therefore, we have formulated recommendations for each of the four core domains, aligning with the assessment from Participant 5, and based on the improvement roadmap outlined in Section 4.5:

In the engagement domain, it is recommended to incorporate immersive scenarios in which avatars can interact with advanced BTP features. This enables users to engage in simulated business processes, such as data analytics workflows and AI integration scenarios. Furthermore, integrating customization options adjusted to users' preferences for a personalized experience is desired, as noted by the participant: *"When users can personalize their avatars, it creates a sense of ownership and identity."* This translates to more natural interactions, establishing a connection with the virtual space. People tend to feel more at ease when communicating through avatars, and this level of personalization enhances engagement and makes the overall experience more relatable.

In the usability domain, the desire for more personalized content is highlighted by the participant that suggests: *"...an introduction of interactive dashboards or virtual project rooms that cater to specific personal workflows."* Therefore, it is recommended to implement streamlined workflows that mirror real BTP processes, along with providing contextual guidance, tooltips, and predictive assistance. By offering features that provide recommendations based on user interactions, users can perform complex actions more easily.

In the privacy and security domain, robust user authentication measures are desired to ensure the secure storage of user data. Moreover, role-based access controls within the metaverse, tying authentication to users' roles and profiles within BTP, could bridge the gap in this domain. This allows users to manage the visibility of their activities and interactions based on the confidentiality needs of organizations.

In the Accessibility Domain, it is important to investigate and enhance compatibility with assistive technologies like screen readers. Additionally, consider providing alternative representations of visual content, such as audio descriptions, to showcase complex BTP workflows and make the application more accessible to a diverse user base.

By gradually implementing these advancements, the integration of BTP within the metaverse can achieve a higher level of engagement, accessibility, usability, security, and privacy, aligning with the broader goals of the BTP.

5.5 Overall evaluation of the expert-interviews - The focus areas

Experts in the field emphasize that the process of creating applications within the metaverse dimension is time-intensive. It requires the gradual integration of metaverse usage into our professional lives to develop more mature applications. However, participants show enthusiasm for integrating improvement options within the applications. Through the evaluation of the key design principles using the MAMM, a thorough application revision is conducted. This resulted in a significant amount of feedback and specific improvement areas for each of the tested applications. Overall, the reflections reveal that social aspects take center focus in the Metaverse environment. The absence of physical presence alters group dynamics, distinguishing these interactions from those in the physical world. As the metaverse becomes an integral part of work, its impact is promising and has the potential to bridge the physical distance between remote employees, as mentioned by an expert. *"The metaverse's potential for remote work is immense. It brings remote employees closer together, providing a sense of collaboration despite physical distance."* However, utilizing the metaverse poses challenges. Some users find virtual reality experiences uncomfortable, especially during longer meetings. The fatigue experienced during sessions could impact its suitability for longer meetings. Therefore, both usability and mixed-reality access of current applications are important focus areas.

Additionally, many discussions revolved around embodiment. *The Metaverse is like complete immersion in another world, a virtual one*. However, it's essential to remember that, while casual conversations flow easily, for critical decisions, physical presence matters according to a participant: *"When big deals are involved, chatting as a cartoon avatar isn't ideal".* Therefore, Realistic avatars deepen connections, However, it's important to acknowledge that this contradicts with privacy concerns as indicated by another expert: *"using 3D scans to create avatars that resemble real people raises reflections on identity principles and representation in this virtual space, giving rise to privacy concerns".*

Also, striking the right balance between data collection and gaining user trust presents a significant security challenge. As pointed out by an expert: *"It all depends on what information you share and what you can do in the metaverse."* People stress the focus area of maintaining security and privacy in the metaverse applications.

Furthermore, the focus area of performance from the application is pointed out for attention, raising questions about effectiveness for meaningful conversations through technical limitations, which, in turn, impacts the focus area of community engagement. In general, participants find metaverse sessions intriguing, supported by a quote from an expert: *"It excels in brainstorming due to its unique engagement and immersive environment."* Primary concerns revolve around interaction, improved usability, realism, and security principles. Ensuring the platform is easily accessible, feels realistic, and ensures comfortable interaction are critical focus areas to consider during the development process toward more mature applications. The MAMM framework offers a useful framework to evaluate and enhance user preferences in this regard. In Appendix H, a general guide towards a design strategy for metaverse applications is formulated building on the research findings.

6

Conclusion

This chapter marks the conclusion of the research, as it addresses the initial research questions established at the outset of the master's thesis:

What constitutes a maturity model for enhancing learning initiatives for metaverse applications, enabling stakeholders to assess and advance metaverse application features, thereby leveraging advanced educational capabilities beyond conventional e-learning methods in enterprise contexts?

To explore this main research question in more detail, the thesis divided it into four specific sub-questions, which are discussed in sections 6.1 through 6.4. Then, section 6.5 provides the final answer to the research question, and section 0 - 6.7 discusses the contributions to both research and practical applications.

6.1 Understanding the evolution of the Metaverse

In this section we answer sub-question 1: How has the concept of the Metaverse evolved within the broader digital landscape over time?

The concept of the Metaverse builds upon previous iterations of the web, extending the internet's capabilities with immersive offerings that blur the boundaries between the physical world and the digital space. Currently, the Metaverse is rapidly expanding, driven by technological advancements in fields such as virtual reality, augmented reality, artificial intelligence, and connectivity technologies. However, it remains in its early developmental phase, primarily centered around individual applications and platforms, rather than an integrated and cohesive virtual world.

At present, there is no universally accepted definition of the Metaverse. Therefore, we applied an approach based on Popper's falsification theory, which focuses on what the Metaverse is not. This approach creates a multidimensional perspective of the concept's current state of art. In Figure 23, is depicted what the Metaverse is NOT:

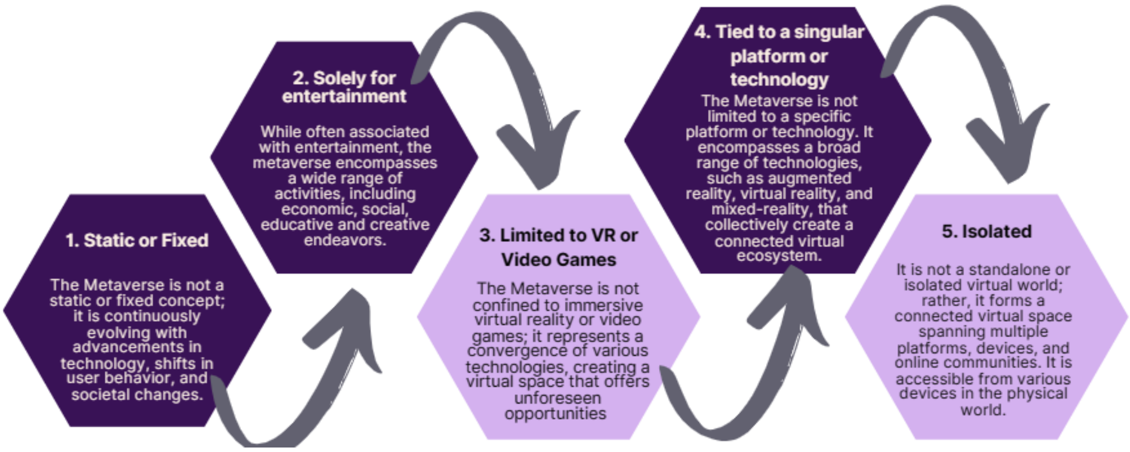

Figure 23, Summary of findings RQ1

Concluding, the Metaverse represents a dynamic concept that has evolved significantly within the broader digital landscape. It offers new opportunities for economic activity, social interaction, and user-driven creativity while constantly adapting to emerging technologies and user needs.

6.2 Exploring key components and interactions:

In this section we answer sub-question 2: *What are the essential technological components that comprise the Metaverse, and how do they interact to create distinct user experiences?*

A summary of the five identified core components and its function is depicted in Figure 24:

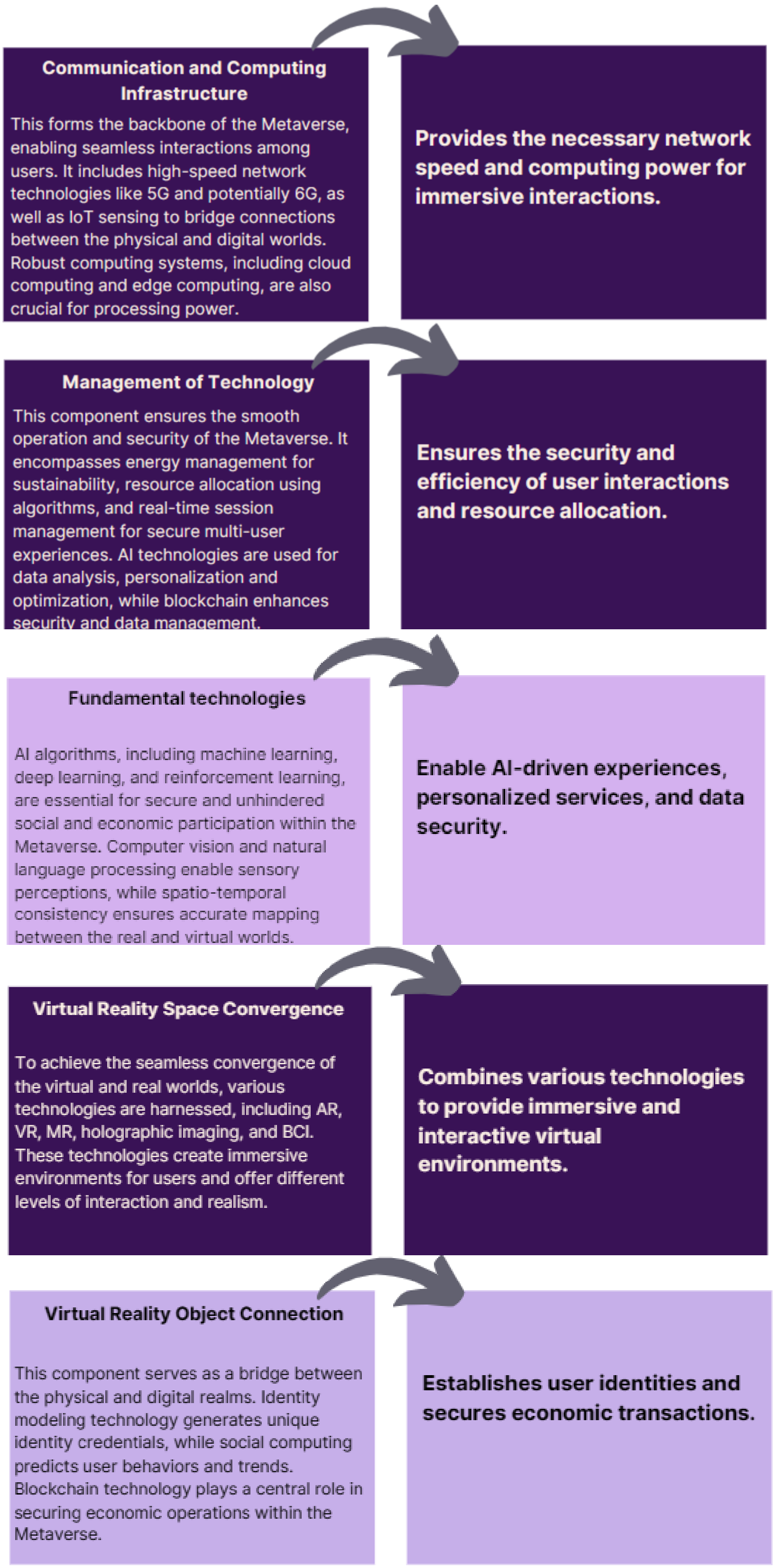

Figure 24, Summary findings RQ2

The combination of these technological components facilitates the principle of connecting the physical and digital worlds, resulting in a wide range of applications and experiences for users.

6.3 Identifying key design principles for metaverse applications

In this section, the third set of knowledge questions is answered, which focused on the key design principles that enhance educational experiences within metaverse applications:

I. What are the key design principles that distinguish educational experiences within metaverse applications from conventional methods?

II. How do these design elements contribute to a more engaging and effective learning environment?

The key design principles and their functioning that distinguish educational experiences from conventional methods are depicted in Figure 25:

EMBODIMENT
Metaverse applications enable learners to immerse themselves in cognitive or skill practice environments through personalized avatars or virtual representations. This embodiment allows learners to break free from real-world constraints, fostering engagement and a sense of presence.

USER GENERATED CONTENT
Learners are encouraged to create and explore within the Metaverse, transcending the boundaries of real-world limitations. This principle empowers learners to generate diverse and immersive content, fostering a dynamic learning environment.

CONTEXT AWARENESS
Context awareness personalizes the learning experience, presenting content in relevant and meaningful ways, fostering higher-order thinking and engagement.

COMMUNITY ENGAGEMENT
Robust community engagement principles foster social connections, collaboration, and shared experiences, enriching the educational challenge.

SCALABILITY
The Metaverse accommodates a vast number of learners and experiences simultaneously, addressing geographical constraints and creating a global, interconnected learning ecosystem.

PERSISTENCY
Persistency ensures a consistent learning experience across sessions and platforms, eliminating frustration and fostering continuous engagement.

PERFORMANCE
Optimized performance ensures smooth and responsive interactions, fostering a productive learning environment.

MIXED-REALITY ACCESS
Learners access the Metaverse through diverse devices, experiencing varied contexts seamlessly, regardless of location or device.

USABILITY
User-friendly interfaces democratize access to advanced educational content, making the Metaverse welcoming for learners of varying technical expertise.

MONETIZATION
Monetization stimulates users to earn credentials by receiving valuable rewards. This stimulates engagements and thrives competitiveness

USER-INTERACTIVE LEVEL
Flexible engagement options allow learners to choose their level of involvement, aligning with their preferences and accommodating varied learning styles.

INTERROPERABILITY
Interoperability within Metaverse applications ensures connectivity between platforms, content, and infrastructure, facilitating cross-disciplinary learning experiences.

VIRTUAL-PHYSICAL AGENCY
Learners gain a sense of control and engagement as they seamlessly navigate and interact with both virtual and physical elements. This blurring of boundaries encourages long-term engagement and hands-on experiences.

SECURITY
Robust security measures safeguard learner data and interactions, fostering trust and sustained engagement.

PRIVACY
Privacy measures grant learners control over their personal data, cultivating trust and confidence in engagement.

UBIQUITY OF ACCESS AND IDENTITY
Ubiquity of access allows learners to engage from a range of devices and platforms, ensuring equal opportunities for engagement. Consistent identity maintenance facilitates a cohesive learning journey.

Figure 25, Summary findings RQ3-I

To answer question II, an overview of how these identified design principles contribute to a more engaging and effective learning environment is presented in Figure 26:

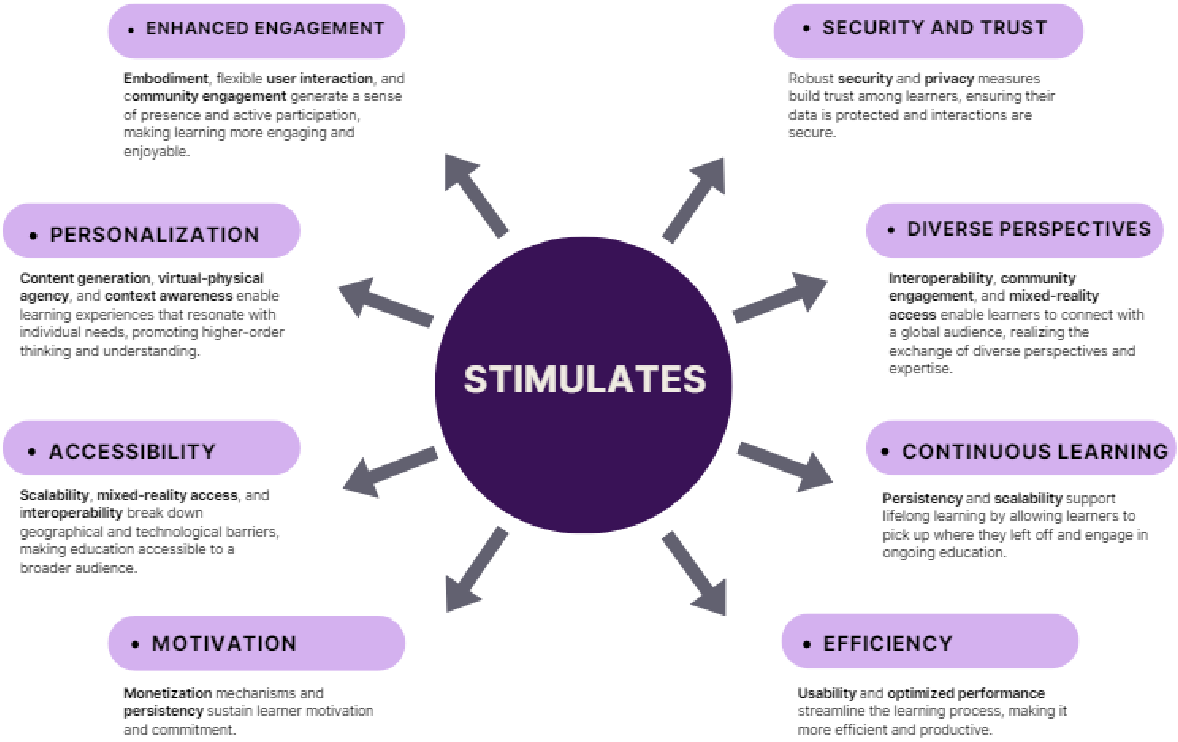

Figure 26, Summary findings RQ3-II

These design principles work together to build a learning environment within metaverse applications that's engaging, tailored to individuals, easy to access, highly motivating, secure, and stimulates collaboration and continuous growth of the users. This approach contrasts with conventional online learning platforms, where learners often passively consume content without active engagement or immersive interaction.

6.4 Developing the Maturity Model

The fourth set of sub-questions focused on the development of the maturity model, referred to as the MAMM, to systematically assess key design principles within Metaverse applications. These questions were:

I. What is the most effective structure for a maturity model that guides the advancement of key design principles within metaverse applications?
II. How can the key design principles align with different stages of this model?

To answer subquestion I: The most effective structure for a maturity model that guides the advancement of key design principles within Metaverse applications is a continuous-fixed level structure. This structure offers a clear progression path with predefined maturity levels. The maturity model consists of predefined maturity levels that represent the stages of development for the focus areas, which are the key design principles of Metaverse applications.

The proposed five-level framework, ranging from "Foundational" to "Full Immersion," serves as a structured roadmap for monitoring the development of design principles in Metaverse applications within an enterprise context. Each level signifies a distinct stage in the evolution of these principles and presents an attribute of the key design principle, providing a means to assess and benchmark the maturity of the key design principles.

To answer sub-question II, attributes are defined for each of the key design principles that serve as focus areas. These attributes align the level of development of the principle with the predefined maturity stages of the MAMM, serving as measurement indicators for assessing the maturity level of the key design principles. While the specific criteria for each design principle may vary depending on the context and evolving technology trends in the Metaverse field, this standardized framework serves as a tool for assessing and benchmarking the progress of the design principles in Metaverse applications. It enables stakeholders to set clear improvement goals toward higher stages of maturity. As Metaverse maturity evolves, this framework can easily adapt to reflect changes, ensuring ongoing relevance.

6.5 The main research question

In this Section the main research question is answered:

What constitutes a maturity model for enhancing learning initiatives for metaverse applications, enabling stakeholders to assess and advance metaverse application features, thereby leveraging advanced educational capabilities beyond conventional e-learning methods in enterprise contexts?

A maturity model for enhancing learning initiatives in Metaverse applications within enterprise contexts comprises a structured framework designed to systematically assess and advance focus areas that enable educational capabilities. This model empowers stakeholders, including organizations and developers, to evaluate the current state of their Metaverse applications, identify areas for improvement, and strategically progress toward more advanced educational capabilities. At its core, this maturity model defines distinct maturity levels, ranging from foundational stages to the optimal stage of functioning, creating a clear progression path.

The focus areas consist of key design principles that enable educational capabilities within the applications. Emphasizing the importance of meeting learners' needs, ease of use, and practicality to ensure a positive user experience, the incorporation of four key domains from a user-centric perspective covers these criteria: Engagement, usability, accessibility, and security & privacy.

To assess its functionality, specific attributes for each focus area that align with the maturity levels are included as measurement indicators in the maturity model. These attributes help organizations determine the maturity level at which their application functions within the focus areas, thus eliminating discussions regarding the level of a key design principle. Score quantification is facilitated by a provided assessment tool with an automatic scoring mechanism, allowing users to indicate compliance with the attributes for each focus area. Additionally, the model includes a roadmap that outlines the steps for progressing toward higher levels of maturity. It offers recommendations and best practices for improving the focus areas within Metaverse applications, breaking down the process into specific steps to enhance these focus areas. Lastly, general descriptions and a broad range of focus areas make the model adaptable to various Metaverse applications and different organizational objectives.

6.6 Contribution to Practice

The practical contributions of this research are twofold. Firstly, it introduces a maturity model and assessment tool tailored for evaluating educative metaverse applications in an enterprise context. Secondly, it presents an evaluation conducted in collaboration with practitioners, synthesizing insights from subject-matter experts across various disciplines and organizations. This underscores the potential of the proposed MAMM, assessment method, and the accompanying roadmap for enhancing the metaverse applications.

Practitioners can readily deploy the MAMM and its associated assessment tool. The model provides a structured framework comprising key domains, essential design principles, and comprehensive explanations that can be customized to specific needs. It also incorporates a hierarchy of maturity levels for evaluating these key design principles through its belonging attributes. The assessment tool serves as a practical guide for conducting these assessments effectively. Subsequent to the assessment process, this research offers practical recommendations for improving key design principles and developing a roadmap to advance across different maturity levels within each domain.

This maturity model addresses a gap in existing research practices. As there only exist one scientific maturity model, and this one is centered around the broader metaverse ecosystem and may not be suitable for businesses seeking to develop metaverse-like applications. The evaluation results of the maturity model and roadmap are highly encouraging. Subject-matter experts, who are the intended end-users of the model, consistently assigned high scores to all evaluation criteria. Furthermore, organizations participating in case studies, representing the ultimate beneficiaries of this model, also awarded high ratings across the same evaluation criteria. These ratings strongly indicate that the MAMM is user-friendly, valuable, and readily applicable in real-world scenarios.

6.7 Contribution to Research

The research makes a dual contribution to the existing scientific knowledge base. Firstly, it introduces an innovative approach to maturity model development, synthesizing established frameworks and methodologies to create a novel maturity model adjusted to a previously unexplored domain. This initiative was driven by the lack of maturity models dedicated to the assessment of metaverse applications, with the only existing model primarily designed for evaluating the maturity of the virtual meta worlds. The aim of this new maturity model is to offer a more pragmatic solution for assessing metaverse applications, particularly in enterprise educational contexts. To support the development of educational metaverse applications, the research conducted a systematic literature review, identifying key design criteria, and an examination of how these criteria contribute to learning experiences within metaverse applications. These criteria underwent validation within the academic community, providing valuable guidance for future metaverse application research. Additionally, the study delved into research methodologies, methods, and guidelines employed by academics when crafting IT maturity models. This research effort builds upon existing frameworks for maturity model development. It aligns with the consensus among researchers that advancing maturity model research necessitates leveraging existing knowledge.

The development of the MAMM relied on well-established and peer-reviewed methodologies, including the Design Science Methodology (Wieringa, 2014), Kitchenham's systematic literature review method (Kitchenham, 2007), qualitative content analysis guidelines (Dey, 2005), an evaluation template for maturity models (Salah et al., 2014), and a framework for evaluation in Design Science (Venable et al., 2016). Beyond methodological foundations, this research distinguishes itself by not merely proposing a new model but by conducting a comparative analysis of existing models. The outcome is a complementary model that addresses a critical gap in the current literature.

Reflecting on the research's contribution to theory development, it aligns with Gregor's classification as a Type II (Gregor, 2006): Explanation study. It offers an understanding of the metaverse, its current state, its application within enterprise context, the educational potential that metaverse applications offer, their advantages over traditional e-learning methods, and the design principles, and its attributes underpinning characteristics of metaverse applications. While this research focuses on explaining current applications of the metaverse rather than making predictions, it enriches the scientific literature. The second contribution of this research lies in the creation of a unique maturity model. Both the metaverse and innovative methods for enhancing employee skills to bridge the technology-knowledge gap have gained substantial attention in recent years. This research stands as merges these two fields within the metaverse domain, attracting interest from industry stakeholders.

7
Discussion

This chapter presents the research outcomes and constraints. Section 7.1, discusses the research methodology, followed by Section 7.2, which focuses on the application of the MAMM. Section 7.3 presents the practical implications of the study, and Section 7.4 discusses implications for further research. Finally, the chapter concludes with Section 7.5, addressing research limitations and outlining potential directions for future research.

7.1 Reflection on the chosen research methodology

The present study adopted an approach that builds on established methodologies, methods, and guidelines to create a maturity model. This methodological choice emphasizes the importance of correctly and validly implementing these methodologies and methods, rather than introducing a novel, untested approach.

The development of the Metaverse Application Maturity model followed the Design Science Research methodology, which aims to assess the maturity model within a contextual framework. This methodology proved effective in generating meaningful insights within a real-world context.

The research employed a top-down approach to construct the maturity model, beginning with proposing definitions for maturity stages and subsequently identifying measures that align with these definitions. This approach was favored due to the nascent nature of the metaverse field, where mature applications are scarce. However, it's worth noting that this approach does have limitations, as a bottom-up approach, starting with collecting measures from practical applications, would ensure that the defined measures have real-world relevance. As the metaverse field matures, it may become more feasible to employ a bottom-up approach, such as a Delphi study, to refine the model further.

To address methodological limitations, the research adopted a mixed-method development strategy, combining elements from various methods. A systematic literature review was conducted to build upon existing knowledge and connect knowledge, while expert interviews gathered novel insights from practical metaverse applications. This blended approach provided a solid foundation by integrating insights from both academic literature and empirical research.

The resulting maturity model underwent evaluation using a mixed-method evaluation strategy. Expert evaluations served as a straightforward means to simulate real-world conditions and gather feedback for model improvement. However, this method only involved a small stakeholder group and may lack real-world authenticity. Case studies, on the other hand, provided a more naturalistic approach, simulating practical conditions for organizations as functional beneficiaries. This combination of expert evaluations and case studies addressed each method's limitations, offering a well-rounded evaluation strategy.

The case studies revealed the model's applicability but also highlighted the immaturity of the metaverse in many instances. This drawback is inherent to case study research in a relatively new field, as organizations may not yet fully utilize metaverse applications. Despite these challenges, case studies remained a valid choice, as they replicated real-world contexts. Assessing organizations even before they fully implement all key design principles within their metaverse applications was deemed valuable for both the organizations themselves and the model's evaluation.

The selected methodology aligned with the available time and resources at the start of the research. While Action Research might have been an alternative, it typically requires investments, resources, and suitable participating organizations, and more time. Given the novelty of the maturity model, securing these resources and organizations willing to invest would have been challenging. Therefore, Design Science Research emerged as the most viable choice. However, the next step in validating the model and its real-world effects could involve applying it in technical action research with an organization like SAP, and a team of experienced metaverse experts who would utilize the model in a real-world context as part of an application improvement project. This would allow for an in-depth exploration of its real-world effects and validation. Here the researcher would then observe and validate the model's effects within a real-world context.

7.2 Reflection on the Metaverse Application Maturity Model

The research introduced the Metaverse Application Maturity Model, which underwent evaluation by 10 subject-matter experts and was subsequently applied in three case studies involving five participants. Throughout both rounds of assessment, the maturity model consistently received high ratings across the scientifically grounded evaluation criteria. Each criterion received an average rating within the range of 3.0 to 5.0 on a 5-point scale. These ratings affirm that the maturity model aligns effectively with the research's design objectives. However, upon conducting a critical analysis of the model, several discussion points arose for further consideration.

It's important to emphasize that not all key design principles proved relevant in the three case studies. Nevertheless, every one of these principles underwent thorough evaluation and was included based on consultation with subject matter experts. For example, the monetization principle may not find practical use in an onboarding program or ideation session, but it holds substantial value within the context of the SAP BTP application. In this particular case, it serves as an additional business model, enabling the organization to capitalize on certificates purchased as proof of achievement. Moreover, as examined in literature studies it also sustains motivation and commitment for learners. However, in scenarios where monetization doesn't apply, its absence can significantly impact the score in the engagement domain, potentially resulting in a score of zero for that specific principle. In such situations, it becomes possible to exclude this principle from the final calculation of the domain score. However, it's important to note that this also affects the benchmarking process when comparing with competing applications that do include monetization options.

Another point of discussion arises from varying interpretations of the metaverse, leading to widespread confusion. The definition of the metaverse varies depending on the context, and in this early stage, there isn't a uniform or universally accepted definition. In industrial settings, it's primarily referred to simulating digital twins to test products or replicate machines to examine their technical characteristics. This usage fundamentally differs from the concept of the web 3.0 metaverse, which serves as a decentralized economy and finds its exploration in retail industries, where consumers interact with each other in the metaverse, as described in Chapter 2. These varying interpretations significantly impact how users perceive the metaverse and its meaning. Distinguishing between these terms can be challenging, as different individuals may have contrasting understandings of what the metaverse entails. This complexity also intersects with the understanding of metaverse applications where is referred to in this research, particularly used purely for educational purposes within an enterprise context.

Furthermore, these differing interpretations have a direct impact on the way key design principles are understood and applied. For instance, when discussing "persistency" within the broader Metaverse ecosystem, it typically refers to the ability to transfer avatars to different virtual landscapes, allowing users to move between various organizations or locations seamlessly. However, in this context, "persistency" means enabling users to pick up where they left off in their learning journey, with their progress and performance data stored and readily accessible. Therefore, each key design principle is thoroughly elaborated upon to avoid misinterpretation, which would affect the quality of the results.

Furthermore, when it comes to interpreting features of applications, users often interact with these elements without realizing the advancement of the underlying technology. Therefore, our research intentionally incorporates specific attributes for each design principle, complete with detailed descriptions and related maturity stage. This approach helps minimize debates about the functionality or significance of these key design principles within the application. We base this decision on the fact that the key design principles in the model describe "what" needs to be done, rather than "how" it should be done. For instance, educational metaverse applications focus on "what" users can experience, while the "how" concerns the underlying technology infrastructure. Take embodiment, for instance: Can users customize their avatars, yes or no? This question doesn't delve into how the development features should be integrated; it simply addresses whether the application offers customization or not.

Another point of discussion within the model is the subjectivity involved in assessing processes. It's important to recognize that subjectivity is a common characteristic of maturity models and only becomes a limitation when participants struggle to align their viewpoints. One advantage of a maturity assessment is that it brings together participants with different perspectives, encouraging discussions about current options and plans for future improvements.

The variance in assessments and the presence of subjectivity became evident in the first two case studies, where two participants evaluated the same key design principles of the same applications. It was rare for participants to assign the same maturity level, with deviations typically limited to less than one maturity level. There is a potential for the model to become more objective, which could enhance its usability and place greater emphasis on improvement.

Maturity models, as a general rule, come with inherent limitations, as highlighted in the literature: they tend to oversimplify reality, focus on a single path to maturity while neglecting alternative approaches, and their applicability may be constrained by internal factors such as technology, as well as external factors like market conditions. In the literature review, we addressed a lack of foundational knowledge by conducting a comprehensive literature review on the Metaverse. We avoided redundancy by comparing existing maturity models, and we ensured transparency in the development process by introducing a multi-method development and evaluation strategy.

Another limitation of the model is linked to participant profiles. To assess all key design principles of the MAMM with the right level of expertise, participants need to come from multiple disciplines, professional backgrounds, and different organizational roles, such as cybersecurity engineers and CX experts. Forming a multidisciplinary team with a diverse set of experts may be challenging within an organization due to time constraints or resource limitations needed to generate the best assessment.

Lastly, a limitation arises from the selection of key design principles. We refined the selection to 16 key design principles after expert evaluations. This selection process means that the model does not cover the entire spectrum of design principles. Some key design principles that are not covered may still have the potential to impact the learning experience. Key design principles frequently evolve due to new technologies and innovations in the evolving metaverse field. Disruptive innovations could even influence entire domains within the model. To ensure the proposed maturity model remains relevant and valuable, we recommend periodic revisions, allowing organizations to incorporate the latest developments in metaverse applications for optimal educational experiences.

7.3 Implications for practical application

The findings of this research have significant implications for practitioners in the field. They can now conduct assessments of metaverse application maturity, taking into account various key design principles and the corresponding maturity levels associated with these principles, as well as their impact on learning experiences. Traditionally, business and IT have operated as distinct realms, with technical experts harnessing metaverse technologies to create opportunities, while the business side remains largely unaware of these potential applications. Likewise, businesses have often underestimated the metaverse's capacity to educate employees or engage with actors within a metaverse ecosystem, thereby adding substantial business value. The MAMM bridges the discrepancie between IT's technical expertise and the business objectives, merging them within a unified maturity model.

Regarding maturity levels, it is imperative to note that a certain level of metaverse maturity must be achieved before effectively implementing the key design principles. Attempting to assess these principles without a well-defined application context would limit the model's applicability. However, the model still offers valuable insights by highlighting which key design principles are absent or not yet integrated into the application, thus aiding in the prioritization of initiatives. Consequently, we believe that this model can serve organizations at various stages of metaverse application development – from those ready to enhance existing applications to those in the early phases of preparation.

Last: What would motivate organizations beyond the scope of this project to adopt the proposed maturity model? We believe that any metaverse practitioner can readily employ this model. During our evaluation, all participants unanimously found the maturity model to be comprehensible and user-friendly, regardless of their prior experience or knowledge of the metaverse. Furthermore, it became evident that organizations already incorporating metaverse functionalities in their applications are sometimes unaware of these focus areas or their full potential. In such cases, the maturity model can be instrumental in maximizing the benefits of existing applications. In conclusion, we are confident that this maturity model offers a tool applicable to organizations with and to practitioners of diverse backgrounds and expertise within the metaverse landscape.

7.4 Implications for research

The findings arising from this study have the potential to influence future research and opens new avenues of inquiry. The initial set of research questions focuses on future investigations into the existing metaverse application maturity model:

1. What is the relationship between Metaverse application maturity and educational outcomes?
2. Does a high maturity level for key design principles lead to increased utilization of metaverse applications by end-users?
3. How does the metaverse application maturity model perform in practice (execute his question with action research)?
4. What level of metaverse application maturity is necessary for beneficial outcomes within an organization, that are significant?
5. What objective measures can be identified to assess the key design principles of the metaverse application maturity model?

Addressing these research questions will provide empirical evidence that could assist practitioners in evaluating the applicability of the maturity model within their specific organizational contexts. Moreover, the presence of a more substantial body of empirical data is important for understanding the implications of maturity levels for organizations.

Subsequently, the following set of research questions focuses on metaverse application maturity as a whole:

1. What is the impact of key design principles on the efficiency of the learning experience?
2. What are the limitations of current practices, and at what point is the adoption of a key design principle feasible?
3. What is the effect of the maturity model on metaverse applications used for educational purposes within enterprise contexts?

Addressing these research questions will provide empirical evidence regarding the full potential, benefits, and impact of the model. The prospects, based on current literature, are promising, and accumulating more empirical data can help determine whether these prospects can be realized in practice.

7.5 Research limitations and future work

The MAMM, is developed through a comprehensive approach involving literature review, expert interviews, and case studies. It is important to acknowledge the limitations associated with these methods, including the potential for overlooking specific sources, potential biases or influence from experts and case study participants, and the possibility of misinterpreting qualitative data (Wieringa, 2014).

The systematic literature review of the Metaverse, its application, the key design principles, and the development of maturity models was conducted with the goal of being as thorough and inclusive as possible. Multiple data sources were consulted exhaustively, yet it remains possible that some sources were omitted or that subsequent research has emerged that could have impacted the present study.

Regarding the experts involved in the evaluation and the participants in the case studies, there is a potential for bias or unconscious influence during the research process. While these experts tend to rate evaluation criteria statements lower than other participants on average, potentially leading to a more critical evaluation. Additionally, both experts and participants may tend to moderate their criticism to maintain a positive tone in an interview setting.

To mitigate potential researcher bias towards positive results, steps were taken to ensure objectivity. A peer-reviewed template from (Salah et al., 2009) was employed for evaluation criteria and questions. Furthermore, an independent researcher was engaged to validate qualitative content analysis through peer debriefing. Establishing the generalizability of the maturity model and research findings requires an argument that extends the sample population's characteristics to the broader population (Wieringa, 2014).The expert interviews included a diverse group with a scientific research background, while the case study participants acknowledge their understanding of the topic. Feedback from both evaluations indicated that the MAMM was user-friendly, valuable, and practical, suggesting that these findings could be generalized to organizations that focus on metaverse application development. The presence of key design principles in widely used Metaverse applications supports this claim.

The MAMM introduces a novel Metaverse maturity scale derived from lesser-known models and suggests recommendations for enhancing key design principles towards higher maturity stages. These aspects are particularly valuable for organizations with relatively mature Metaverse applications and the technical capabilities to implement these insights. The study presented successful use cases of Metaverse applications in enterprise context, indicating the model's adaptability to organizations.

Future research should focus on addressing current model limitations. Objectivity could be enhanced by quantifying measures, such as assessing the percentage of key design principles adhering to specific standards or assigning maturity scores to objective application constructs. The protocol for selecting assessment participants should be refined to encompass a multidisciplinary team such that all key design principles can be assessed with expertise. Additionally, the domains, which were introduced later in the research, could be further reviewed, expanded, or refined to create a more comprehensive model. To include more domains and key design principles, a similar development procedure as used in this study can be applied. The MAMM should be applied to a wider range of organizations, preferably through action research with organizations seeking to implement or improve their Metaverse applications. This approach would allow for the practical study and validation of the maturity model. Lastly, future work should involve periodic revisions to keep the model current, as the Metaverse and its capabilities continue to evolve rapidly.

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Appendices:

Appendix A: Architectural overview Metaverse

A three-layer architecture, as depicted in Figure 27, is proposed to integrate the concepts discussed in Section 2.2. The architecture comprises the following layers:

Infrastructure: This layer constitutes the foundational infrastructure, encompassing the communication and computing infrastructure that facilitates seamless connections.

Interactivity: This layer constitutes the foundational infrastructure, encompassing the communication and computing infrastructure that facilitates seamless connections.

Ecosystem: The ecosystem layer adopts a broader perspective, encompassing the various elements that constitute the virtual space of the Metaverse.

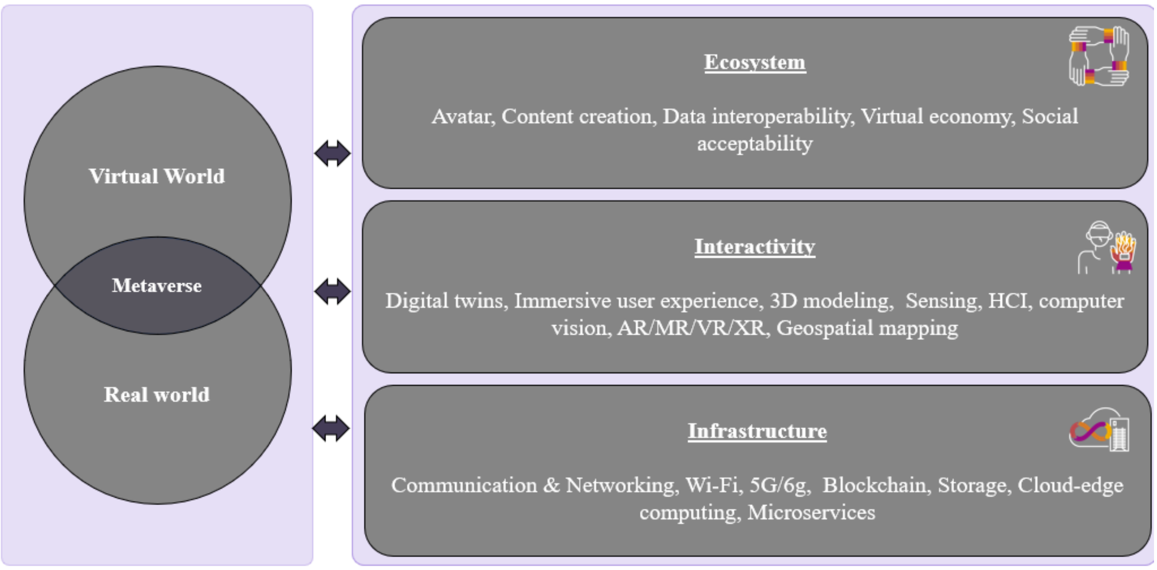

Figure 27, Architectural overview of the "Metaverse Ecosystem".

These layers are visually represented as overlapping circles in Figure 27, symbolizing the convergence of the real world and the virtual world. This depiction illustrates that the Metaverse is not a standalone entity but is deeply entwined with the real world, influencing and being influenced by it. While the architectural overview may not cover the entire spectrum, this three-layer architecture is designed to facilitate understanding through a visual presentation of the Metaverse's key components.

Appendix B: Systematic literature review

To explore the primary Metaverse Maturity Models and key design principles for metaverse applications, an analysis of existing literature was conducted using a systematic literature review approach. This method, introduced by (Kitchenham, 2007), enabled the systematic identification, assessment, and dissection of all research regarding metaverse maturity models and key application design principles. The research methodology encompassed three key phases: planning, execution, and reporting. This process allowed for finely tailoring the architecture format of the maturity model to match its intended purpose. Figure 28, provides a structured overview of the SLR process, and the details regarding the three phases are described in this appendix.

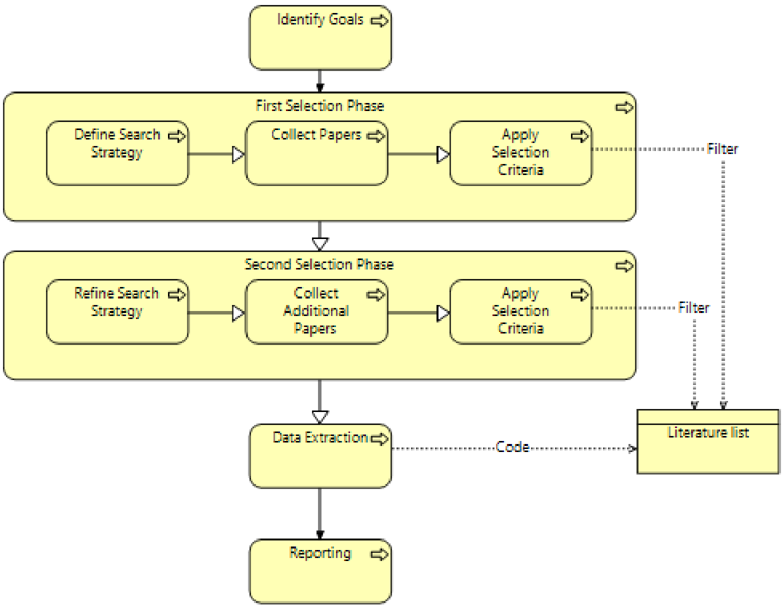

Figure 28, Systematic Literature Review approach

Data sources and search strategy

The SLR involved conducting searches across various databases to gather relevant literature. These databases include:

- Academic Databases: IEEE Xplore, Google Scholar, and Scopus were searched to identify research articles, conference papers, and technical reports related to Metaverse, its maturity, key design criteria and educational criteria.
- Industry Reports: Reports from industry research firms, market research reports, and industry publications were searched to identify the latest insights from subject field experts.
- Relevant Websites: Websites of relevant organizations, industry associations, and technology companies were explored to identify reports, whitepapers, case studies, and technical documentation related to the application of the Metaverse.

The literature review process involved an iterative approach to searching and selecting relevant papers. In the initial phase, search terms such as "Roadmap," "Applications," "Metaverse" AND "Design criteria", "Maturity Model" were applied to identify existing knowledge on the topic. This phase aimed to gain a comprehensive understanding of the concept of the Metaverse applications, as well as the construction of maturity models both in general and specifically within the context of the Metaverse.

In the subsequent phase, the specific knowledge acquired from the initial phase within relevant domains was further refined. This refinement involved formulating new search terms and related criteria based on the insights gained from the first phase. Each of the identified key design principles is searched across the scientific data bases. This included search terms such as "Embodiment", "Persistence" AND "Context awareness" to retrieve information about the definitions and maturity stages of these identified design principles. In Table 19, the search results and their respective sources, derived as outcomes from the SLR are presented for the key design principles.

Inclusion/exclusion criteria

Throughout the phases described in Figure 28, the papers were selected based on the following inclusion and exclusion criteria:

- To extract Metaverse key design principles for educative applications journal papers were reviewed. These were deemed most suitable in the context of this research. Different scenes (e.g. the industrial Metaverse) were avoided, as they may serve different purposes and require distinct criteria.
- Due to the novelty of the subject and the limited number of publications, the choice was made to include all document types for the maturity model retrieval, not only journals.
- To ensure academic quality, the source needs to be peer-reviewed; from a workshop, technical report, thesis, or book (chapter).
- To ensure relevance, the document needs to either propose a Metaverse maturity model or report on the implementation of one.

Variables maturity models

When retrieving information regarding the maturity models, a carefully selected set of variables is utilized to ensure a systematic collection of information. These variables include:

Model structure

1. Name: Model name and primary reference(s);
2. Number of levels: Quantification of the maturity levels;
3. Attribute Names: Definition of the attributes and sub-attributes that comprise the maturity model;
4. Number of Attributes: Total count of attributes and sub-attributes utilized;
5. Maturity Definition: Specifies whether a detailed definition for capability maturity is included;
6. Practicality: Offers practical recommendations or problem-specific guidance.

Model assessment

1. Name: Name of the maturity model and primary references;
2. Description of Assessment Method: Indication of whether the maturity model includes a specific assessment method;
3. Assessment Cost: Degree of expenditure associated with the assessment process;
4. Identification of Strengths and Weaknesses: Elaboration on the identification of strong and weak points within the organization;
5. Emphasis on Continuous Assessment: Focus on the pursuit of continuous improvement through ongoing assessments;

6. Prioritization of Improvement Opportunities: Differentiation of the order in which improvement opportunities are prioritized for the organization.

Model support

1. Name: Name of the maturity model and primary references;
2. Availability of Training: Existence of training opportunities to develop expertise in the model;
3. Validation Support Availability: Degree of validation for the model based on the literature review. Ranked as low for author support only, medium for validation within the organization, and high for validation outside the author's organization;
4. Tool Support: Inclusion of tools or platforms within the model;
5. Continuity across Versions: Adaptability of the model to newer versions and updates;
6. Model Origin: Academic or practical origin of the model;
7. Accessibility: Availability of freely accessible documentation for the model.

Design principle	Reference	..Derived definition
Embodiment	• Identification of users and other digital representations or entities interacting within the metaverse application (Narang, 2023). • Users should have the ability to create and customize their digital selves. This includes not only the appearance of the avatar but also its abilities and traits.. controlling a virtual avatar leads to an embodied experience and intrinsic motivation (Chen et al., 2023). • Positive learning outcomes are associated with popular teachers and realistic avatars produce similarity-spaces that closely correspond to real photographs of the same faces, so there is a need to provide avatars with realistic appearance in Education Metaverse.. (Chen et al., 2023)	Embodiment empowers learners to immerse themselves in cognitive or skill practice environments through personalized avatars or virtual representations. By embodying their identities within the virtual space, learners break free from real-world constraints, facilitating a profound sense of presence and engagement. This immersion mitigates the barriers of physical limitations and enables learners to confront challenges and risks that may otherwise be inaccessible, thus fostering cognitive and skillful engagement that surpasses conventional learning
Content Generation	• The level of objects that are generated in the scene based on the context information.. to generate unique, personalized experiences for each user (Guan et al., 2023) • High-efficiency content creation is a crucial part of user-metaverse interactions.. and drives creativity of users (Lippert et al., 2021)	Content generation empowers learners to generate diverse and immersive content, creating a dynamic learning environment. Learners are no longer passive recipients; they are active creators, constructing virtual environments, objects, characters, and interactive elements. This shift transcends the boundaries of conventional classroom settings.
User Interactive Level	• The components that afford users the ability to interact with the metaverse and with other participants in an immersive experience are key (Lippert et al., 2021) • The level of control and feedback available for the user from the entire metaverse ecosystem (Guan et al., 2023) • Interactivity refers to the avatar's responsiveness to user behavior, encompassing expressions, actions, and voices (Chen et al., 2023). • Interaction in the metaverse is classified as social networking, collaboration, and persona dialog (Dwivedi et al., 2022)	Flexible interactive options offered by Metaverse applications reduces the barrier of a one-size-fits-all learning approach. Learners can choose their level of involvement, from passive observation to active participation, aligning with their preferences. This flexibility fosters alternative and diverse perspectives, ensuring a more inclusive and engaging educational experience that accommodates varied learning styles.
Mixed-Reality Access:	• The level of mixed reality presence and immersion in the metaverse based on devices (Guan et al., 2023). • Technology enablers will also be required for the metaverse to	Learners can access the Metaverse through diverse devices, experiencing varied contexts seamlessly. This principle transcends the barrier of limited physical access, enabling learners to engage with

	reach its full potential. The first is Devices across AR/VR, sensors, haptics, and peripherals. Devices are critical to driving adoption of the metaverse.	immersive content and simulations on-demand, regardless of their location or device.
Interoperability:	• The ability of distinct systems or platforms to exchange information or interact with each other seamlessly and, when possible, transparently.. (Setiawan et al., 2022) • Computational ability, networking, and data transfer (interoperability) are the foundations of any digital world (Lippert et al., 2021).	Interoperability within Metaverse applications bridges the gap between different platforms, content, and infrastructure. This interconnectedness reduces the barriers of isolated educational experiences, allowing learners to navigate various environments and access a wealth of content. Collaboration becomes easy, facilitating cross-disciplinary learning experiences that expand beyond the confines of single platforms.
***Ubiquity of Access and Identity*:**	• Avatars unrelated to identity can have an anonymizing effect, causing users to behave in a more undisciplined manner, aiming at enhancing the user's sense of presence and providing a data foundation for intelligent teaching analysis (Chen et al., 2023) • The use of the technology of metaverse give us lots of access to helps businesses (Setiawan et al., 2022) • The metaverse also has obvious societal implications. A variety of stakeholders will need to define a road map toward an ethical, safe, and inclusive metaverse experience (Dwivedi et al., 2022)	The barrier of access is reduced through the principle of ubiquity of access and identity. Learners can access the Metaverse from a range of devices and platforms, ensuring equal opportunities for engagement. Additionally, consistent **identity maintenance** across contexts facilitates a cohesive learning journey, irrespective of the technology used.
***Privacy*:**	• Designs should incorporate features that protect user data and provide safe environments for interactions. User consent should be at the heart of any data collection or sharing, and users should have control over their personal data (Dwivedi et al., 2022) • The metaverse promises new types of personal data (such as eye tracking, sensor data, and room mapping) tied to an identity which, with underdeveloped security capabilities, may endanger personal identity and privacy (Narang, 2023) • Privacy, must be ensured for protection of data in the virtual and real worlds.. otherwise this would hamper use of applications (Rawat & El Alami, 2023)	Respecting learner privacy addresses the barrier of data security concerns. Metaverse applications need to prioritize robust privacy measures, granting learners control over their personal data. This transparency cultivates trust, empowering learners to engage with confidence, unburdened by privacy worries.

Security	• There is a need for avatar two-factor authentication and more protection of transmitted data, as well as a greater degree of vigilance in regard to a crime that may occur in the Metaverse (Rawat & El Alami, 2023). • Identity authentication in the Education Metaverse differs from traditional account and password authentication and can include multiple means, such as biometric identification, for secure user access. (Chen et al., 2023)	Security measures safeguard learner data, protect against cyber threats, and maintain a safe environment. Long-term engagement is nurtured when learners feel confident that their personal information remains confidential, and their interactions are secure. By prioritizing security, the Metaverse addresses barriers related to data privacy, fostering trust and sustained
Scalability:	• Scalability aspects for large numbers of users in a single location (Narang, 2023). • Refers to the Metaverse's ability to remain efficient with the number of concurrent users/avatars, the level of scene complexity, scope, and range of interactions between users/avatars (Rawat & El Alami, 2023). • Scalability should be a fundamental consideration from the outset, ensuring that the metaverse can accommodate expansion without degradation of user experience (Dwivedi et al., 2022)	Scalability addresses the barrier of geographical constraints, enabling learners from around the world to collaborate. Scalability ensures that the Metaverse accommodates a vast number of learners and experiences simultaneously, maintaining performance and user experience. This mitigates traditional limitations, creating a global, interconnected learning ecosystem.
Monetization:	• ..economic considerations are important in the metaverse, which might generate a vibrant community (Lippert et al., 2021) . • ..economic decisions maximize the power of player creativity for the metaverse (Guan et al., 2023) • The monetization of haptic attributes on the metaverse platform need to be explored for education (Dwivedi et al., 2022)	Monetization mechanisms support long-term engagement by providing economic opportunities to both learners and stakeholders. Learners are triggered to stay engaged through economic incentives like the sale of virtual goods, services, or certifications. This sustains motivation and commitment while removing barriers posed by traditional financial constraints, making advanced learning experiences accessible to a broader audience.
Community Engagement:	• "what the metaverse is really all about is community. The value of belonging to this community. The role you can play as a user in this community so that you feel like a stakeholder and not a "user." …more productive at work, and happier." (Narang, 2023) • ..create a free space for participants to flexibly come together and communicate with one another.. (Narang, 2023)	Community engagement address the barrier of isolation often encountered in traditional learning settings. By fostering social connections, collaboration, and shared experiences, learners transcend physical limitations. Communities unite learners across geographical distances, facilitating the exchange of diverse perspectives and expertise. This interactive learning environment empowers learners to tap into a vast network of like-minded

		individuals and experts, enriching their educational challenge.
Persistency:	• Key features as "persistent" make the Metaverse distinguishable from traditional immersive applications such as AR and VR applications (Chen et al., 2023). • Persistency.. when a user revisits the same place after a few hours and finds that their achievements or the embodied objects representing no longer exist and have been disappeared, the user might feel the place unfamiliar and strange, and feel a loss of connection (Dwivedi et al., 2022)	Persistency ensures a consistent learning experience across sessions and platforms, addressing the barrier of fragmented learning journeys. Learners can seamlessly pick up where they left off, maintaining personalized settings, achievements, and interactions. This continuity eliminates the frustration of starting anew and fosters continuous engagement.
Usability:	• .. instant access to information and intuitive experiences in which users can easily carry out their goals.. (Dwivedi et al., 2022) • Intuitive interfaces, allow users to create and interact with visual information.. the focus of needs to be on the content of the materials not on how to navigate the application (Chen et al., 2023)	Usability counters the barrier of technological complexity. Metaverse applications strive to provide intuitive interfaces that ensure accessibility for learners of varying technical expertise. User-friendly interfaces democratize access to advanced educational content, making the Metaverse a welcoming space for all learners.
Performance:	• Improved performance of avatar movement and environment rendering enables users to better self-express themselves, build social identities, and even develop online communities together with other users in the metaverse, resulting in an enhanced user engagement in the metaverse. (Dwivedi et al., 2022) • Virtual avatars are capable of providing real-time feedback on performance (Rawat & El Alami, 2023).	Performance optimization overcomes barriers related to lag and inefficiency. By ensuring smooth and responsive interactions, learners engage with content in an immersive and uninterrupted manner. Optimal performance boosts cognitive and skillful immersion, fostering a productive learning environment.
Context Awareness:	• The level of context sensing capacity in the real environment. Outlining the need for shared visualizations, and context awareness as ways to bridge the human-in-the-loop and the many virtual, mixed, and physical reality environments that they will increasingly engage in as the metaverse advances to maturity (Guan et al., 2023)	Context awareness personalizes the learning experience, addressing the barrier of uniformity in traditional education. By adapting to learners' contexts, Metaverse applications offer tailored experiences that resonate with individual needs. This personalized approach encourages higher-order thinking and engagement by presenting content in relevant and meaningful ways.

Table 19, Literature mapping of the key design principle

Appendix C: Interview Protocol and Questions

Interview Protocol:

Preparation: Prior to the interview, participants are provided with the maturity model and are instructed to familiarize themselves with the evaluation criteria. They are then asked to evaluate the MAMM based on the provided criteria, assuming they were to apply it in practice.

Evaluation of Tabs: During the interview, each section of the maturity model is discussed in chronological order, including the background information, key design principles, and maturity levels. Participants are encouraged to provide feedback on every aspect of the maturity model.

Evaluation of Processes: For each key design principle, participants are requested to respond to specific questions 4, 5 and 6 from the evaluation template, which can be found below these instructions.

Rating of Evaluation Criteria: At the Evaluation part, participants are asked to rate a set of statements related to the evaluation criteria using a 5-point scale. The evaluation statements can be found in Table 20.

Open-Ended Questions: Participants are given the opportunity to address any remaining open-ended questions from the evaluation template that were not covered during the discussion of individual sections.

Questions:

In order to ensure clear communication and shared understanding of the discussed concept during the inerview, it is important to establish a common definition of the Metaverse at the outset.. During the interviews, all participants were asked to agree upon a definition that captures the essence of the Metaverse. The agreed-upon definition was as follows:

"The Metaverse can be defined as a virtual, interconnected ecosystem that seamlessly bridges the physical and digital worlds. It facilitates immersive experiences, social interactions, and access to a virtual economy. By transcending individual technologies, it creates a collaborative environment that aims to provide a persistent digital reality."

The interview questions for evaluation of the MAMM:

1. Is the purpose of the maturity model clear?
2. Do you think the model accurately captures the key design principles for metaverse applications within enterprise context for learning purposes?
3. Are there any key design principles or practices that you would consider adding to the Metaverse maturity model? If yes, kindly elaborate which key design principles or practices that are and provide the rationale behind your suggestion.
4. Are there any key design principles or practices within the Metaverse maturity model that you believe should be removed? If so, please specify which ones and provide an explanation for your recommendation.
5. Are there any key design principles within the Metaverse maturity model that you think should be redefined or updated? If so, please clarify which ones and provide reasoning behind your suggestion for redefinition or update.

6. A tool is used to assess the level of key design principles for educative applications. Do you find this approach useful and applicable?
7. Are there any additional criteria that you think are important for evaluating the maturity of of Metaverse applications in this context?

8. Can the maturity model be utilized to identify the necessary focus areas for successful development of Metaverse applications?
9. Are there any specific design principles or factors that you believe are missing for the assessment method, but should be taken into account for evaluating the maturity of different application scenarios within the Metaverse?
10. How effective do you believe the model is in assessing the specific level of key design principles required for different user and application combinations?

During the conversation, additional topics emerged and were discussed alongside the candidate's responses.

Maturity Levels	Score
The maturity levels are sufficient to represent all maturation stages of the domain	
There is no overlap detected between descriptions of maturity levels	
Key design principles	
The key design principles are relevant to the Metaverse domain	
The key design principles cover all aspects impacting/involved in the domain	
The key design principles and practices are clearly distinct	
The key design principles and practices are correctly assigned to their respective maturity level	
Maturity Model	
Understandability	
The maturity levels are understandable	
The assessment guidelines are understandable	
The documentation is understandable	
Ease of use	
The assessment guidelines are easy to use	
Usefulness and practicality	
The maturity model is useful for conducting assessments	
The maturity model is practical for use the industry	

Table 20, Evaluation template by (Salah et al., 2009)

Appendix D: Interview notes evaluation of the Model

Interviewee:
Web Developer at PHYED
Date: 29/06/2023

Question: Do you agree with this definition of the Metaverse:

"The Metaverse can be defined as a virtual, interconnected ecosystem that seamlessly bridges the physical and digital worlds. It facilitates immersive experiences, social interactions, and access to a virtual economy. By transcending individual technologies, it creates a collaborative environment that aims to provide a persistent digital reality."

Answer*:* Yes I do agree with this definition.

Questions regarding the Metaverse Maturity Model:

Question: Is the purpose of the maturity model clear?

Answer: Yes, the purpose of maturity model is clear. The maturity model you provided outlines different levels of development and key design principles across aspects of Metaverse applications in business settings. It offers a framework for understanding and assessing the evolution of the abilities of these applications.

Question: Do you think the model accurately captures the key design principles of Metaverse applications?

Answer: The maturity model offers a comprehensive overview of various aspects that can be associated with such metaverse applications. It cover a wide range of topics. As for now, the model seems to be precise as well as accurate, but I think being flexible in research regarding Metaverse would be key as it's important to note that metaverse concept is still evolving.

Question: Are there any key design principles that you would consider adding to the Metaverse maturity model? If yes, kindly elaborate on which processes or practices you would propose and provide the rationale behind your suggestion.

Answer: I think so, we can add ethical frameworks. Developing ethical frameworks and guidelines for the metaverse can help guide the responsible development and use of virtual environments. This may involve addressing ethical concerns related to content creation, algorithmic biases, AI interactions, and societal impact.

Question: Are there key design principles within the Metaverse maturity model that you believe should be removed? If so, please specify which key design principles and provide an explanation for your recommendation.

Answer: The maturity model includes different levels of data persistence, ranging from basic to complete. However, in certain contexts, the need for partial data persistence may not be significant or practical. Depending on the specific application or use case, it may be appropriate to remove or revise this design principle to better align with the requirements and priorities of the users. Also Categorizing Basic Interface Navigation separately would be unnecessary as there would be advancements in user interface design and intuitive interaction paradigms.

Question: Are there any key design principles within the Metaverse maturity model that you think should be redefined or updated? If so, please clarify which processes or practices and provide reasoning behind your suggestion for redefinition or update.

Answer: I'm not sure but maturity model includes AI-assisted content generation as an attribute , which is undoubtedly valuable. However, given the rapid advancements in AI technologies, it would be worthwhile to redefine this key design principle to include more advanced AI capabilities, such as generative AI models, machine learning algorithms for content personalization, and natural language processing for intelligent conversational agents. This update would reflect the cutting-edge AI technologies that can enhance content creation and user experiences within the Metaverse.

<u>Questions regarding the Assessment Tool:</u>

Question: The model utilizes a tool to assess the level of key capabilities needed for user and application combinations within. Do you find this approach useful and applicable to evaluate the use of the maturity model for assessment of the key design principles?

Answer: Yes, I do think this is a structural approach. Other suggestions could be evaluating educational capabilities more specific such as in terms of: Virtual Learning Environments, Collaborative Learning abilities, Personalized Learning, Lifelong Learning and Skill Development, Gamification and Interactive Experiences, Educational Analytics and Assessment

Question: Are there any additional criteria that you think are important for evaluating the maturity of user and application combinations?

Answer: Assessing how well applications can adapt to changing user needs, business requirements, and technological advancements is important. This criterion considers factors like the ease of application customization, configurability, extensibility, and the ability to support future enhancements. Adding 'Adaptability and Flexibility' can be significant in maturity of user and application combinations.

Question: The model utilizes an excel tool to indicate the assessed level of requirement for each criterion, providing a clear overview of the necessary focus areas. Do you find this approach helpful in guiding design practices?

Answer: Yes. It is very simple yet effective, highlighting each assessed criterion makes it easy to know the progression of the model.

Question: Are there any specific design criteria or factors that you believe are missing from the assessment framework, but should be considered for evaluating the maturity of user and application combinations within the Metaverse ecosystem?

Answer: No.

Question: How effective do you believe the model is in assessing the specific level of key design criteria required for different user and application combinations?

Answer: The model shows promise in assessing the specific level of key design criteria required for different user and application combinations within the Metaverse ecosystem. However, the model should be kept updated as per the requirements. So, the model can be improvised in future but as of now, it seems quite promising.

Question: Could you please assign a score ranging from 1 to 5 (5 is optimal) for each of the criteria:

Maturity Levels	Score
The maturity levels are sufficient to represent all maturation stages of the domain	4
There is no overlap detected between descriptions of maturity levels	5
Key design principles	
The key design principles are relevant to the Metaverse domain	4
The key design principles cover all aspects impacting/involved in the domain	4
The key design principles and practices are clearly distinct	4
The key design principles and practices are correctly assigned to their respective maturity level	5
Maturity Model	
Understandability	
The maturity levels are understandable	5
The assessment guidelines are understandable	4
The documentation is understandable	4
Ease of use	4
The assessment guidelines are easy to use	4
Usefulness and practicality	4
The maturity model is useful for conducting assessments	4
The maturity model is practical for use the industry	4

Interviewee :
Inaugural Chair of the World Metaverse Council
Date: 10/07/2023

Question: Do you agree with this definition of the Metaverse:

"The Metaverse can be defined as a virtual, interconnected ecosystem that seamlessly bridges the physical and digital worlds. It facilitates immersive experiences, social interactions, and access to a virtual economy. By transcending individual technologies, it creates a collaborative environment that aims to provide a persistent digital reality."

Answer: Yes and no, there are different versions of the metaverse, so this definition does not capture the complete essence of the Metaverse. However, I agree with this definition in the case when it pertains to the use of the metaverse for educational purposes in the context of applications. In that sense, the Metaverse can be understood as a merged virtual ecosystem that bridges the physical and digital worlds, enabling immersive experiences, social interactions, and a virtual economy.

Question: Is the purpose of a maturity model clear?

Answer: Yes, the purpose of the maturity model is clear. It aims to assess the progress and development of metaverse applications in the enterprise context. It serves as a guideline to progress through various stages, ensuring that applications meet specific criteria as they continue to evolve.

Question: What are your thoughts on the use of maturity models in relation to standards and capabilities assessment for metaverse applications?

Answer: Maturity models are often used by big companies for assessing standards and capabilities. Therefore, I hold a positive view regarding the utilization of maturity models for the assessment of standards and capabilities in the context of metaverse applications.

Question: Do you think smaller companies would use maturity models?

Answer: I don't think startups would use maturity models. Maturity models are more suitable for industrial settings.

Question: What are your reflections on the types of Metaverse and their potential usage of maturity models?

Answer: When diving in the diverse landscape of the Metaverse, it becomes evident that various iterations exist, each catering to different purposes and audiences. The Metaverse encompasses realms like Web 3, which focuses on decentralized interconnectedness, gaming-centric virtual environments, and expansive ventures pursued by tech giants like Meta.

In light of this diversity, the application of maturity models necessitates a thoughtful approach. It's crucial to recognize that the suitability of a maturity model heavily relies on aligning it with the specific type of Metaverse being considered. Factors such as the intended use, the intricacies of user interactions, and the nature of the virtual economy come into play. Each type of Metaverse may follow its unique trajectory of growth and development, making it imperative to tailor the maturity model accordingly.

Therefore, when applying maturity models in the context of different Metaverse types, it becomes apparent that a nuanced and adaptable approach is required. Refining the target audience and the intricacies of the model to harmonize with the distinct characteristics of each Metaverse type will be essential for its effective utilization. Therefore, I believe that you should refine your target audience and focus on specific industries and their Metaverse use cases.

Question: What do you think about the classification matrix in the maturity model?

Answer: The classification matrix, while a valuable framework, could benefit from further refinement to enhance its logical coherence. A factor to consider is aligning this matrix with the distinct categories of Metaverse applications. The current application scenarios, while a step in the right direction, would be more impactful if tailored to the specific type of Metaverse being employed.

Recognizing the inherent diversity among Metaverse applications is essential, as the capabilities and features they require can significantly differ. Whether we're delving into educational applications, business-oriented ecosystems, or a combination of both, the classification matrix should accommodate these nuances. The maturity model needs to be refined to better align with the specific industries and types of Metaverse applications that are adopting these technologies. By doing so, the matrix can provide a more accurate depiction of the maturity levels across various application types. The model should be tailored based on the specific industry's use of the Metaverse.

Question: How do you suggest I proceed with refining the maturity model?

Answer: Focus on identifying industries and companies that are adopting Metaverse technologies and collaborating with them for insights. Also, consider developing a more detailed classification system.

Question: What should I consider when refining the maturity model for industrial use cases?

Answer: Consider the specific industries and companies that are adopting Metaverse technologies. Align the maturity model to their needs and use cases.

Question: Do you have any suggestions for relevant case studies and references for the maturity model as you mentioned?

Answer: I can provide you with case studies and references that might be useful for your research. Just send me an email, and I'll share them with you.

Question: What's your opinion on the potential for mobile-based Metaverse experiences?

Answer: Some Metaverse applications are shifting towards mobile-based experiences, especially in regions like Asia. The model needs to account for different modes of access.

Question: How can I improve the classification matrix to better suit different Metaverse applications?

Answer: The matrix should be refined to match different Metaverse types and industries. Consider how key design criteria and features align with specific contexts.

Question: Should the maturity model be focused on startups or big industries using Metaverse?

Answer: The maturity model is likely more relevant to big industries that are adopting Metaverse technologies. It's important to consider the specific target audience.

Follow-up interview conducted on 20/08/2023, building upon the previous interview.

Question: Considering that I focus on enterprise applications that can be used within educational context, are there any key design principles or practices that you would consider adding to the Metaverse maturity model? If yes, kindly elaborate, and provide the rationale behind your suggestion.

Answer: There are additional design principles to consider. For instance, emphasizing cross-platform accessibility and AI-driven personalization would enhance user experiences, promoting inclusivity and engagement.

Question: Are there any key design principles or practices within the Metaverse maturity model that you believe should be removed? If so, please specify which ones and provide an explanation for your recommendation.

Answer: The existing principles seem pertinent; however, as the metaverse evolves, periodic reviews to ensure relevance would be prudent.

Question: Are there any key design principles within the Metaverse maturity model that you think should be redefined or updated? If so, please clarify which ones and provide reasoning behind your suggestion for redefinition or update.

Answer: In time, the model's principles might need revision to mirror the changing metaverse landscape and technological advancements.

Question: A tool is used to assess the level of key design principles for educative applications. Do you find this approach useful and applicable?

Answer: Certainly, employing a tool to assess key design principles for educational applications is both logical and beneficial for systematic development.

Question: Are there any additional criteria that you think are important for evaluating the maturity of user and application combinations for the user experience of Metaverse applications in this context?

Answer: Evaluation should also address factors like interoperability, data privacy, and user agency to ensure a holistic user experience in metaverse applications.

Question: Can the maturity model be utilized to identify the necessary focus areas for the successful development of Metaverse applications?

Answer: Absolutely, the maturity model effectively guides developers by addressing areas of significance for successful metaverse application creation.

Question: Are there any specific design principles or factors that you believe are missing for the assessment method but should be taken into account for evaluating the maturity of user and application combinations within the Metaverse?

Answer: Consideration should be given to impact mitigation strategies, as sustainable practices for long-term use gain importance in metaverse development.

Question: How effective do you believe the model is at this point in assessing the specific level of key design principles required for different user and application combinations?

Answer: The model holds promise in assessing key design principles for different scenarios, but continuous fine-tuning will likely be necessary due to the rapidly evolving metaverse.

Can you assess the model on the following criteria on a scale from 1-5:

Maturity Levels	Score
The maturity levels are sufficient to represent all maturation stages of the domain	4
There is no overlap detected between descriptions of maturity levels	4
Key design principles	
The key design principles are relevant to the Metaverse domain	4
The Key design principles cover all aspects impacting/involved in the domain	3
The key design principles are clearly distinct	4
The key design principles are correctly assigned to their respective maturity level	4
Maturity Model	
Understandability	
The maturity levels are understandable	4
The assessment guidelines are understandable	4
The documentation is understandable	5
Ease of use	
The assessment guidelines are easy to use	4
Usefulness and practicality	
The maturity model is useful for conducting assessments	4
The maturity model is practical for use the industry	3

Interviewee:
Researcher Educational Technology
Date: 04/07/2023

Question: Do you agree with this definition of the Metaverse:

"The Metaverse can be defined as a virtual, interconnected ecosystem that seamlessly bridges the physical and digital worlds. It facilitates immersive experiences, social interactions, and access to a virtual economy. By transcending individual technologies, it creates a collaborative environment that aims to provide a persistent digital reality."

Answer: Yes

Question: Is the purpose of the maturity model clear?

Answer: Yes, the purpose of the maturity model is clear. This practical model serves as a framework. It provides an approach for assessing key design principles of applications in the Metaverse

Question: Do you think the model accurately captures the key design principles of Metaverse applications?

Answer: The model captures the design principles for development of Metaverse applications. Its inclusivity spans various aspects that contribute to the overall quality of Metaverse experiences. The model encompasses a wide range of criteria that influence user engagement and satisfaction within the Metaverse environment.

Question: Are there any key design criteria that you would consider adding to the Metaverse maturity model? If yes, kindly elaborate on which key design criteria you would propose and provide the rationale behind your suggestion**.**

Answer: While the existing model covers essential criteria, I believe an important dimension missing is ethical considerations. It's important to factor in how different stakeholders, shaped by their cultural values and objectives, can influence the construction of Metaverse environments. Incorporating ethical design principles would address the challenge of accommodating diverse perspectives and values within the Metaverse ecosystem.

Question: Are there any key design principles within the Metaverse maturity model that you believe should be removed? If so, please specify which key design principles and provide an explanation for your recommendation.

Answer: Connectedness and open standards might cause confusion. I don’t see a complementary value against the other principles. Other design principles within the model hold significance within their context; I don't find any specific principles that should be removed. However, the criticality of each principle might vary based on the intended purpose of the application. Some principles are more valued than others, depending on the specific goals and outcomes pursued by the application.

Question: Are there any key design criteria within the Metaverse maturity model that you think should be redefined or updated? If so, please clarify which key design criteria and provide reasoning behind your suggestion for redefinition or update.

Answer: The levels and their labels within the model require more clarity for effective interpretation. Currently, it may be misconstrued that 'initial' represents the lowest level of quality, and 'mature' represents the highest level. However, I propose reconsidering this perspective. For certain applications and goals, the 'initial' to 'intermediate' levels might be more appropriate than the 'mature' level. For instance, considering the "uncanny valley" effect, realism in avatars might adversely impact user emotions. Moreover, in education, comprehensive XR environments may lack specific design principles crucial for learning processes.

Question: The model utilizes a tool to assess the level of key design criteria for user and application combinations. Do you find this approach useful and applicable?

Answer: An assessment tool is effective in conveying the assessment status of each criterion, offering a concise overview of focus areas. However, determining the relative importance of specific design criteria remains a challenge. Deciding the criticality of a criterion for user, application, and goal alignment requires further exploration and experimentation. However, there's room to enhance the model's visual presentation to improve its readability and user-friendliness.

Question: Are there any additional criteria that you think are important for evaluating the maturity of user and application combinations?

Answer: While the model considers applicability in different context, it's important to recognize that underlying goals or outcomes might necessitate distinct design criteria at different maturity levels. Factors such as inspiration, branding, community building, and commerce, in the context of business applications, or collaborative learning, instructional design, and skill development, in education, may require tailored design considerations.

Question : Can the maturity model be utilized to identify the necessary focus areas for successful development of applications for the Metaverse ecosystem?

Answer: While the maturity model aids in providing a comprehensive overview of principles within Metaverse applications, its direct correlation to "successful development" is uncertain. Maturity levels may not always correspond to effectiveness. Nevertheless, the model serves the purpose of offering insights into focus areas and guiding development efforts.

Question : Are there any specific criteria that you believe are missing from the assessment method, but should be taken into account for evaluating the maturity of user and application combinations within the Metaverse ecosystem?

Answer: In addition to considering user and application types, it's vital to acknowledge the role of specific goals or outcomes that drive application development. Different learning objectives, business goals, or community-building aims should be integrated into the assessment method to ensure tailored design criteria are adequately addressed.

Question: How effective do you believe the model is in assessing the specific level of key design criteria required for different user and application combinations?

Answer: The model's strength lies in its ability to highlight focus areas for development. However, determining the assessment's effectiveness requires practical implementation and user experience experimentation. The model's clarity and applicability can be enhanced by providing concrete examples and scenarios illustrating the impact of different design criteria on user experiences.

Could you please assign a score ranging from 1 to 5 for each of the criteria:

Maturity Levels	**Score assigned by interviewee**
The maturity levels are sufficient to represent all maturation stages of the domain	4
There is no overlap detected between descriptions of maturity levels	4
Key design principles	
The key design principles are relevant to the Metaverse domain	4
The key design principles cover all aspects impacting/involved in the domain	4
The key design principles are clearly distinct	3
The key design principles are correctly assigned to their respective maturity level	4
Maturity Model	
Understandability	
The maturity levels are understandable	4
The assessment guidelines are understandable	4
The documentation is understandable	4
Ease of use	
The assessment guidelines are easy to use	5
Usefulness and practicality	
The maturity model is useful for conducting assessments	4
The maturity model is practical for use the industry	4

Interviewee:
Editor in Chief Rocking Reality
Date: 04/07/2023

Question: Do you agree with this definition of the Metaverse: "The Metaverse can be defined as a virtual, interconnected ecosystem that seamlessly bridges the physical and digital worlds. It facilitates immersive experiences, social interactions, and access to a virtual economy. By transcending individual technologies, it creates a collaborative environment that aims to provide a persistent digital reality."

Answer: Yes, I do agree with this definition. The ability to offer immersive experiences and facilitate social interactions within this interconnected environment is indeed a defining aspect of the Metaverse. Additionally, the concept of a virtual economy and transcending individual technologies highlights the potential of the Metaverse to be a unified digital space that goes beyond isolated platforms.

Question: Is the purpose of the maturity model clear?

Answer: Certainly, the purpose of the maturity model is clear. It serves as a framework that assesses the progressive stages and criteria necessary for the development and evaluation of applications within the Metaverse ecosystem. Each stage represents a level of advancement in terms of key design criteria. This hierarchical approach makes it clear how an application can evolve from basic functionalities to more comprehensive and mature capabilities.

Question: Do you think the model accurately captures the key design criteria of the Metaverse ecosystem?

Answer: Yes so far I believe the model effectively captures the essential design principles required for Metaverse applications. The model seems comprehensive and encompassing, encompassing a wide spectrum of aspects such as security, user interaction, privacy, and more. These key design criteria directly contribute to the richness of experiences within the Metaverse, and the model addresses them.

Question: Are there any key design principles that you would consider adding to the Metaverse maturity model? If yes, kindly elaborate on which processes or practices you would propose and provide the rationale behind your suggestion.

Answer: Currently, I do not perceive the need to introduce additional key design criteria to the Metaverse maturity model. The existing criteria appear to holistically cover the necessary aspects for creating immersive and engaging experiences within the Metaverse. However, it's important to ensure that the model remains adaptable to technological advancements and user expectations.

Question: Are there any key design principles within the Metaverse maturity model that you believe should be removed? If so, please specify which key design criteria and provide an explanation for your recommendation.

Answer: From my perspective, the existing key design criteria seem to be relevant, contributing to the holistic understanding of Metaverse application features. Therefore, I don't find the need to recommend the removal of any specific criteria.

Question: Are there any key design principles within the Metaverse maturity model that you think should be redefined or updated? If so, please clarify which key design criteria and provide reasoning behind your suggestion for redefinition or update.

Answer: While the existing criteria appear to be comprehensive, one aspect that should be approached with caution is the Monetization principle. While the model outlines the integration of virtual currencies or tokens for monetization, it's essential to recognize that this may not always align seamlessly with enterprise contexts. The practicality and feasibility of integrating digital currencies within enterprise applications need careful consideration and, in some cases, may require more nuanced approaches.

Question: The model utilizes a tool to assess the level of key design principles needed for user and application combinations. Do you find this approach useful and applicable?

Answer: The concept of an assessment tool is valuable in assessing applications structured. However, the model might benefit from a presentation that enhances its visual appeal and readability. This could potentially improve its applicability and user-friendliness.

Question: Are there any additional criteria that you think are important for evaluating the maturity of user and application combinations?

Answer: The criteria included in the matrix seem comprehensive and relevant for evaluating the maturity of user and application combinations. Expanding the criteria might introduce unnecessary complexity and potentially affect the clarity of the assessment process negatively.

Question: Can the maturity model be utilized to identify the necessary focus areas for successful development of applications for the Metaverse ecosystem?

Answer: The maturity model holds promise in guiding the development of applications within the Metaverse ecosystem by offering a structured roadmap for achieving specific levels of design principles. However, for more effectiveness, it might be beneficial to refine the model's presentation to make it more focused and less abstract. This refinement could ensure that the model effectively guides developers and stakeholders toward clear focus areas for development.

Question: The tool presents a visual overview in a graph to indicate the assessed level of requirement for each criterion, providing a clear overview of the necessary focus areas. Do you find this approach helpful in guiding design practices and ensuring user satisfaction?

Answer: Yes, the utilization of visuals to indicate the assessed level of requirement is a straightforward and intuitive way to convey the status of each criterion. It provides an immediate visual indication of the level of maturity achieved and the areas that require further development. This approach aids in aligning design practices and ensuring user satisfaction by offering a clear and accessible overview.

Question: Are there any specific design criteria or factors that you believe are missing from the assessment method, but should be taken into account for evaluating the maturity of user and application combinations for metaverse applications?

Answer: As of now, the assessment method appears to cover a broad spectrum of design criteria that are useful to evaluating the maturity of user and application combinations within the

Metaverse ecosystem. However, it's essential to stay open to future developments and that might warrant inclusion.

Question: How effective do you believe the model is in assessing the specific level of key design criteria required for different user and application combinations?

Answer: Its abstract nature might present challenges in translating the assessment into practical information. The effectiveness of the model could potentially be improved by providing more concrete examples and scenarios that illustrate how different user and application combinations align with specific maturity levels.

Could you please assign a score ranging from 1 to 5 for each of the criteria:

Maturity Levels	Score
The maturity levels are sufficient to represent all maturation stages of the domain	4
There is no overlap detected between descriptions of maturity levels	4
Key design principles	
The key design principles are relevant to the Metaverse domain	4
The key design principles cover all aspects impacting/involved in the domain	4
The key design principles are clearly distinct	3
The key design principles are correctly assigned to their respective maturity level	3
Maturity Model	
Understandability	
The maturity levels are understandable	4
The assessment guidelines are understandable	4
The documentation is understandable	4
Ease of use	
The assessment guidelines are easy to use	3
Usefulness and practicality	
The maturity model is useful for conducting assessments	3
The maturity model is practical for use the industry	3

Appendix E: Tool introduction

Background Information

The purpose of this tool is to simplify the evaluation of key design principles for Metaverse applications and establish a systematic approach to assessing compliance with these key design principles. Its specific design aims to streamline the assessment process, making it more efficient and structured.

By utilizing this tool, the adherence to the essential design capabilities can effectively be evaluated, ensuring a comprehensive and systematic assessment.

The goals of the Metaverse Capability Maturity Model are:

1) Identify and define essential focus areas: The model aims to define the necessary key design principles required to design Metaverse applications.
2) Establish a comprehensive assessment framework: The model seeks to develop a structured framework that allows for the assessment of maturity levels in different focus areas
3) Foster Collaboration and knowledge sharing: Collaboration and knowledge exchange among Metaverse researchers are encouraged to enhance collective insights and best practices.
4)Guide metaverse development and advancement: The model aims to provide guidance for decision-making and resource allocation, thereby driving the growth and development of the Metaverse ecosystem.

Instructions

1) **Assess each key design principle.** Each design principle needs to be evaluated manually by using the tab to indicate agreement with the description as "yes" or "no". For these key design principles, only a generic description is provided, which can be applied to the statement. If the current abilities do not align with the statement, it can be assessed in the adjacent tab whether it is desired for the future to align with that key desgin criteria, selecting "yes" or "no". Additionally, if the user does not agree with the statement but wants to provide feedback on the maturity level, a comment box is provided.

2) **Maturity levels are calculated automatically** After assessing each statement, the maturity scores for the key design principles, as well as the corresponding maturity levels, are automatically calculated and presented in the results tab. The desired maturity levels are also included in the results. In the visualization tab, any gaps between the current and desired maturity levels are immediately highlighted, providing a starting point for constructing an improvement roadmap.

3) **Fill in the evaluation form**. Several statements are presented along with questions related to the content of the assessment tool. The evaluation is conducted to further improve the model in the following areas:
- Maturity levels
- key design principles
- Understandability
- Ease of use
- Usefulness and practicality

4) **Present results**. After the assessment is complemented, the results are summarized, presented and discussed with the participant

Figure 29, First tab - Background Information and Instructions.

Phase	Capabilities	Description	Alignment to Description	Desired	Comments
Level 1: Experimental	Embodiment	**Basic avatar representation** - Users can create simple avatars with limited customization options.	Yes	Yes	
Level 1: Experimental	User Interactive Level	**Passive observation** - Users can observe the metaverse but have limited interaction or influence over the environment.	Yes	Yes	
Level 1: Experimental	Community Engagement	**Social presence** - Users can see the presence of others within the metaverse but have limited communication options.	Yes	Yes	
Level 1: Experimental	Content generation	**Basic object creation** - Users can create simple objects or modify existing ones within predefined templates.	Yes	Yes	
Level 1: Experimental	Virtual-Physical Agency	**Basic Interaction** - Users can perform simple actions within the metaverse, such as object manipulation or basic locomotion.	Yes	Yes	
Level 1: Experimental	Scalability	**Limited concurrent users** - The metaverse supports a small number of simultaneous users, typically within a single instance or environment.	Yes	Yes	
Level 1: Experimental	Security	**Basic user authentication** - Users log in with simple credentials, such as usernames and passwords.	Yes	Yes	
Level 1: Experimental	Performance	**Basic performance optimization** - The metaverse ensures a baseline level of performance to maintain smooth interactions for most users.	Yes	Yes	
Level 1: Experimental	Privacy	**Basic data protection** - The metaverse implements standard privacy measures to safeguard user data and prevent unauthorized access.	Yes	Yes	
Level 1: Experimental	Persistency	**Basic data retention** - The metaverse retains minimal user data and experiences, with limited capabilities for saving and storing information. User progress may not be preserved between sessions, resulting in a relatively transient experience.	Yes	Yes	
Level 1: Experimental	Context awareness	**Basic user profile** - The metaverse maintains a user profile with basic information, such as preferences and progress	Yes	Yes	
Level 1: Experimental	Mixed-Reality access	**Desktop and mobile access** - Users can access the metaverse through traditional desktop computers or mobile devices.	Yes	Yes	
Level 1: Experimental	Interoperability	**Limited data sharing** - Basic data exchange between metaverse components, allowing for limited integration.	Yes	Yes	
Level 1: Experimental	Connectedness	**Basic network connectivity** - The metaverse ensures stable network connectivity for users to access and interact with the virtual environment.	Yes	Yes	
Level 1: Experimental	Open standards	**Component interoperability** - Different components within the metaverse can communicate and exchange data using basic interoperability standards.	Yes	Yes	
Level 1: Experimental	Usability	**Basic interface navigation** - Users can navigate the metaverse through simple menus and buttons.	Yes	Yes	
Level 1: Experimental	Ubiquity of access and identity	**Device compatibility** - The metaverse supports access from a range of devices, including PCs, smartphones, and tablets.	Yes	Yes	
Level 1: Experimental	Monetization	**In-app purchases** - Users can buy virtual items or services within the metaverse using real-world currency.	No	Yes	
Level 2: Developing	Embodiment	**Enhanced avatar customization** - Users have more extensive options to personalize their avatars, including appearance, clothing, and accessories	No	Yes	
Level 2: Developing	User Interactive Level	**Basic interaction** - Users can perform simple actions such as clicking, selecting, or manipulating objects within the metaverse.	Yes	Yes	
Level 2: Developing	Community Engagement	**Text-based communication** - Users can exchange text-based messages and engage in chat conversations with others.	Yes	Yes	
Level 2: Developing	Content generation	**Advanced object creation** - Users have more flexibility to create complex objects with custom shapes, textures, and interactions.	No	Yes	
Level 2: Developing	Virtual-Physical Agency	**Physical object integration** - Users can interact with physical objects in the real world that are digitally connected to the Metaverse.	No	Yes	
Level 2: Developing	Scalability	**Moderate concurrent users** - The metaverse can handle a moderate number of users across multiple instances or environments.	Yes	Yes	
Level 2: Developing	Security	**Two-factor authentication** - Additional security measures, such as SMS verification or biometric authentication, are employed for user access.	No	No	
Level 2: Developing	Performance	**Enhanced rendering and graphics** - The metaverse incorporates advanced rendering techniques and high-quality graphics to enhance visual fidelity.	No	Yes	
Level 2: Developing	Privacy	**User-controlled Privacy Settings** - Users have the ability to manage and customize their privacy settings, granting or restricting access to their personal information.	Yes	Yes	
Level 2: Developing	Persistency	**Partial data persistence** - The metaverse evolves to provide improved data retention capabilities. Users can save and access certain aspects of their experiences and progress, allowing for a partial sense of continuity across sessions. Howev	Yes	Yes	
Level 2: Developing	Context awareness	**User context tracking** - The metaverse tracks user actions and behavior to provide personalized experiences and recommendations.	No	Yes	
Level 2: Developing	Mixed-Reality access	**Virtual reality (VR) headsets** - Users can immerse themselves in the metaverse using VR headsets, enhancing the sense of presence.	Yes	Yes	
Level 2: Developing	Interoperability	**Standardized protocols** - Common protocols and APIs are established to facilitate interoperability between different metaverse components.	No	No	
Level 2: Developing	Connectedness	**Regional server distribution** - Servers are strategically distributed to ensure reliable connections and minimize latency for users in different regions.	No	No	
Level 2: Developing	Open standards	**Standardized protocols** - Common protocols and APIs are established to facilitate seamless integration between diverse metaverse components.	No	No	

Figure 30, Second tab - Assessment page

Main Capabilities	Level 1: Foundational	Status	Aim	Level 2: Basic features	Status	Aim
Embodiment	Basic avatar representation	0	-	Enhanced avatar customization	0	-
User Interactive Level	Passive observation	0	-	Basic interaction	0	-
Community Engagement	Social presence	0	-	Text-based communication	0	-
Content generation	Basic object creation	0	-	Advanced object creation	0	-
Virtual-Physical Agency	Basic interaction	0	-	Physical object integration	0	-
Scalability	Limited concurrent users	0	-	Moderate concurrent users	0	-
Security	Basic user authentication	0	-	Two-factor authentication	0	-
Performance	Basic performance optimization	0	-	Enhanced rendering and graphics	0	-
Privacy	Basic data protection	0	-	User-controlled Privacy Settings	0	-
Persistency	Basic data retention	0	-	Partial data persistence	0	-
Context awareness	Basic user profile	0	-	User context tracking	0	-
Mixed-Reality access	Desktop and mobile access	0	-	Virtual reality (VR) headsets	0	-
Interoperability	Limited data sharing	0	-	Standardized protocols	0	-
Connectedness	Basic network connectivity	0	-	Regional server distribution	0	-
Open standards	Component interoperability	0	-	Standardized protocols	0	-
Usability	Basic interface navigation	0	-	Intuitive controls	0	-
Ubiquity of access and identity	Device compatibility	0	-	Cross-platform integration	0	-
Monetization	In-app purchases	0	-	Virtual currency economy	0	-
Total Score	Level Completeness:	0%		Level Completeness:	0%	

Main Capabilities	Level 3: Advanced	Status	Aim	Level 4: Advanced	Status	Aim
Embodiment	Advanced avatar animation	0	-	Real-time Facial Tracking	0	-
User Interactive Level	Environment design	0	-	Anonymous participation	0	-
Community Engagement	Privacy by design	0	-	Social groups and guilds	0	-
Content generation	Voice communication	0	-	Procedural generation	0	-
Virtual-Physical Agency	Real-time physics simulation	0	-	Gesture recognition	0	-
Scalability	High concurrent users	0	-	Seamless cross-platform integration	0	-
Security	Encrypted communication	0	-	Content filtering and moderation	0	-
Performance	Low latency interactions	0	-	High-fidelity simulations	0	-
Privacy	Enhanced data preservation	0	-	End-to-End Encryption	0	-
Persistency	Privacy by Design	0	-	Robust data continuity	0	-
Context awareness	Adaptive environments	0	-	Environmental sensing	0	-
Mixed-Reality access	Augmented reality (AR) integration	0	-	Wearable devices	0	-
Interoperability	Cross-platform integration	0	-	Open metaverse standards	0	-
Connectedness	Global server infrastructure	0	-	Edge computing	0	-
Open standards	Cross-domain integration	0	-	Environmental sensing	0	-
Usability	Customizable user interfaces	0	-	Contextual user guidance	0	-
Ubiquity of access and identity	Single sign-on	0	-	Universal identity standards	0	-
Monetization	Creator economy	0	-	Cross-platform commerce	0	-
Total Score	Level Completeness	0%		Level Completeness	0%	

Main Capabilities	Level 5: Full immersion	Status	Aim	"Current Score"	"Aimed Score"
Embodiment	Full-Body Tracking and Haptic Feedback	0	-	0	0
User Interactive Level	Self-sovereign identity	0	-	0	0
Community Engagement	Community-driven content and events	0	-	0	0
Content generation	AI-assisted content generation	0	-	0	0
Virtual-Physical Agency	Real-time environment adaptation	0	-	0	0
Scalability	Global-scale infrastructure	0	-	0	0
Security	Blockchain-based security	0	-	0	0
Performance	Quantum computing optimization	0	-	0	0
Privacy	Self-Sovereign Identity and Data Ownership	0	-	0	0
Persistency	Complete data persistence	0	-	0	0
Context awareness	Cognitive understanding and anticipation -	0	-	0	0
Mixed-Reality access	Spatial computing	0	-	0	0
Interoperability	Universal metaverse integration	0	-	0	0
Connectedness	Decentralized networking	0	-	0	0
Open standards	Collaborative governance	0	-	0	0
Usability	Adaptive interfaces	0	-	0	0
Ubiquity of access and identity	Decentralized identity and portability	0	-	0	0
Monetization	Blockchain-based economy	0	-	0	0
Total Score	Level Completeness	0%			

Figure 31, Third tab - Dashboard showing overview of scores for each key design principle.

Row Labels	Sum of Current Score	Sum of Desired Score
Community Engagement	2	4
Content generation	1	4
Context awareness	1	4
Embodiment	1	4
Interoperability	1	2
Mixed-Reality access	2	3
Performance	2	4
Persistency	3	3
Privacy	2	3
Scalability	2	4
Security	2	2
Ubiquity of access and identity	1	3
Usability	3	5
User Interactive Level	2	4
Virtual-Physical Agency	1	4
Grand Total	**26**	**53**

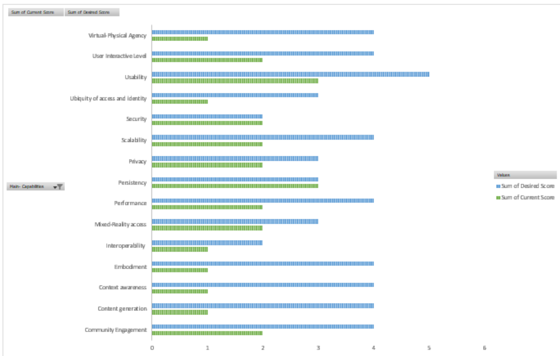

Figure 32, Fourth tab - Visual overview of the results

Appendix F: Protocol case studies

Selection: Participants were chosen based on their familiarity with the metaverse applications. Moreover, if participants lacked knowledge of one or more key design principles, they were encouraged to refer to colleagues who could fill this knowledge gap.

Preparation: Each participant received the assessment tool in advance and was advised to review it in preparation.

Assessing key design principles: Participants were introduced to the model, its key design principles, and maturity levels. They were then asked to assess each of these principles in the specific context.

Evaluating Processes: Participants were requested to address the questions from the evaluation template for a systematic assessment method.

Rating Evaluation Criteria: In the Evaluation tab, participants were tasked with rating a set of statements regarding the evaluation criteria on a 5-point Likert scale. These evaluation statements corresponded to those from the expert interviews.

Open Questions: Participants were required to answer other open questions from the evaluation template, if these had not yet been covered during the discussion of individual tabs.

Returning Results: Following the interview, participants received the completed assessment for validation.

Results: After the assessment, the results were discussed

Evaluating Recommendations: At the conclusion, participants were asked to rate the recommendations based on the maturity model evaluation criteria: understandability, ease of use, usability, and practicality.

Appendix G: Interviews Case Studies

Interviewee:
Candidate Business development representative
Date: 24/08/2023
Case study 1: Metaverse Experience and Business Meetings:

Question: Do you agree with this definition of the Metaverse? :

"The Metaverse can be defined as a virtual, interconnected ecosystem that seamlessly bridges the physical and digital worlds. It facilitates immersive experiences, social interactions, and access to a virtual economy. By transcending individual technologies, it creates a collaborative environment that aims to provide a persistent digital reality."

Answer: Yes

Question: Is the purpose of the Metaverse clear?

Answer: Absolutely. The Metaverse creates a sense of closeness that traditional virtual meetings lack. It feels like we're physically present in the same room, fostering better connections and interactions.

Overall Reflection:

Question: How would you summarize your preference for Metaverse ideation sessions over traditional sessions?

Answer: Metaverse ideation sessions offer a unique and fun experience, activating our brain to be creative. The immersiveness contributes positively to the brainstorming process.

Question: Do you believe the Metaverse enhances integration with clients compared to traditional face-to-face interactions?

Answer: Yes, the Metaverse could significantly enhance client integration in the session by providing a more interactive and immersive platform for presenting ideas and concepts. It is refreshing.

Question: How effective did you find the Metaverse sessions, and do you have suggestions for improvement?

Answer: The sessions in the Metaverse were effective in terms of active participation and engagement. To enhance effectiveness, addressing physical comfort and refining ease of use are recommended.

Question: Do you have any additional suggestions for improving Metaverse sessions or any barriers you encountered?

Answer: Enhancements in comfort, realism, and ease of use would be valuable. Overcoming potential barriers related to joining rooms and security is key for broader adoption.

Question: Is there anything else you'd like to share about your Metaverse experience or the implications you see?

Answer: The Metaverse holds great potential for transforming how we collaborate and interact, but careful consideration of ethical, privacy, and practical aspects is essential for its successful integration.

Question: How did you find the concentration and focus in the Metaverse?

Answer: The improved concentration and focus in the Metaverse are a result of the environment. When you're in the same room virtually, distractions are minimized, allowing for better engagement with the meeting's objectives.

Question: How did you find the gamified aspect in the sessions as you told me earlier?

Answer: The gamified aspect adds an interesting dynamic. While it might initially feel like a game, it's a different kind of engagement that prompts us to explore its potential for more serious interactions. Gamified aspects bring good elements of competition to the table. People like to win, so it is a good psychological effect that got stimulated.

Question: How do you think the experience would change over time?

Answer: As we become more accustomed to the Metaverse, the novelty wears off, and we start taking it more seriously. This transition makes us more open to using it for effective discussions and collaborations. As I did not experience as that effective yet but the first sessions were more explorative.

Question: How do you view the potential of reproducing your office in the Metaverse?

Answer: Reproducing our current office in the Metaverse would be a game-changer. It could provide clients with a truly immersive experience and potentially revolutionize how we interact with them.

Question: What are your thoughts on customization in the Metaverse?

Answer: Customization in the Metaverse is fantastic. Being able to personalize the environment brings more active participation to the sessions.

Question: What factors do you think affect the accessibility of the Metaverse for clients?

Answer: User-friendliness and security are key for successful integration. If clients struggle to join meetings or if data security is compromised, it undermines the Metaverse's potential.

Question: How important do you think realistic avatars are?

Answer: Realistic avatars are important for establishing genuine connections. When avatars resemble real people, interactions feel more authentic and relatable.

Question: Were there any issues with the realism or interaction during sessions?

Answer: The fatigue we experienced during sessions could impact its suitability for longer meetings. While the Metaverse is immersive, addressing this issue would be essential for its effectiveness.

Question: How do you think the Metaverse could benefit remote work?

Answer: The Metaverse's potential for remote work is immense. It brings remote employees closer together, providing a sense of collaboration despite physical distance.

Question: Do you think the Metaverse could replace physical meetings?

Answer: While the Metaverse can't replace face-to-face meetings yet, it might be feasible in the future as technology advances and we adapt to its dynamics.

Question: How can the Metaverse be used for social interactions like brainstorming?

Answer: The Metaverse enhances brainstorming by creating a shared virtual space. Interactions are more natural, and tools like virtual whiteboards mimic real-life collaboration.

Question: How do you see the challenge of client participation in the Metaverse?

Answer: The challenge of client participation could slow down Metaverse adoption. If clients can't easily join meetings, it might limit its use for client interactions.

Question: What are your thoughts on the ethical implications of the Metaverse use in corporate settings?

Answer: The risk of impersonation and inconsistent behavior is a concern. Ensuring users present themselves genuinely is important for building trust.

Question: How important are inclusivity and ethical considerations for Metaverse development?

Answer: Inclusivity and ethical considerations are key for Metaverse development. It's essential that all users feel represented and respected within the virtual environment.

Question: What concerns do you have about data privacy and transparency in the Metaverse?

Answer: Data privacy and transparency are significant concerns. Without clear information on what's being collected and how it's used, trust in Metaverse providers is challenged.

Question: How do you see the balance between the Metaverse and real-world interactions?

Answer: Spending excessive time in the Metaverse could impact our real-world interactions and productivity.

Question: How do you see the potential of using the Metaverse for interacting with clients?

Answer: The potential of using the Metaverse to interact with clients is promising. It provides a unique platform for showcasing ideas and concepts, which can enhance client engagement.

Question: Were there any barriers or challenges you encountered while using the Metaverse for meetings?

Answer: The ease of joining rooms and ensuring security are barriers. If these aspects are not streamlined, it could hinder effective use of the Metaverse.

Question: How important do you think realism is in the Metaverse experience?

Answer: Realism enhances the seriousness of interactions. As the Metaverse becomes more realistic, its fun aspect might decrease, making it more suitable for professional use.

Metaverse Maturity Model:

Question: How do you find the MAMM's application in this context?

Answer: The Metaverse Maturity Model can provide a structured framework to assess the application's on the included criteria in the framework. It helps identify areas for improvement.

Question: Do you believe the Metaverse Maturity Model captures the key design principles accurately?

Answer: Yes, the model reflects the required design principles for Metaverse applications. It addresses customization, realism, interaction, and privacy concerns, which are essential for a successful experience.

Question: Are there any design principles you would add to the Metaverse Maturity Model?

Answer: One design principle to consider adding is "Integration with Existing Workflows." Ensuring seamless integration with current work processes could enhance user adoption**.**

Question: Are there any design principles you believe should be removed from the Metaverse Maturity Model?

Answer: The existing design principles are relevant. No removals seem necessary, as each principle contributes to the overall user experience.

Question: Do you think any design principles within the Metaverse Maturity Model need redefinition or updating?

Answer: The principle of " Interaction" might benefit from an emphasis on physical comfort during prolonged sessions. Addressing potential discomfort would improve user satisfaction.

Assessment of the model

Question: How do you find the MAMM's application in this context?

Answer: By examining the maturity of various dimensions, such as technology, user engagement, content creation, and interoperability, the MAMM enables a comprehensive assessment. However, it's important to note that its primary focus lies within the realm of technical assessment, and while it does highlight areas for improvement, it may benefit from incorporating more diverse perspectives beyond the technical aspects, such as ethical considerations, societal impacts, and user experience.

Question: Do you believe the Metaverse Maturity Model captures the key design principles accurately?

Answer: Yes, the model reflects an extensive set of design principles for Metaverse applications, covering four important domains. However, the principles could be further adapted to include more user experience perspectives to enhance their accuracy and relevance. There is an opportunity to tailor the design principles to encompass a broader spectrum of user experience perspectives, ensuring a more holistic evaluation that prioritizes usability, inclusivity, accessibility, and ethical implications

Question: Are there any design principles you would add to the Metaverse Maturity Model?

Answer: Incorporating ethical considerations into the evaluation process for ensuring responsible and equitable development and deployment of metaverse technologies. This could encompass principles related to data privacy, consent mechanisms, algorithmic transparency, inclusivity, cultural sensitivity, and mitigation of potential biases. By integrating these ethical dimensions, the model can guide developers and stakeholders to create metaverse applications that prioritize ethical standards and societal well-being.

Question: Are there any design principles you believe should be removed from the Metaverse Maturity Model?

Answer: The existing principles within the Model are relevant, with each principle making a valuable contribution to the overall user experience and the development of metaverse applications. Therefore, at this point, no design principles seem redundant or in need of removal. Each principle addresses specific aspects for a good evaluation of metaverse applications, ensuring that a broad spectrum is considered in the assessment process.

Question: Do you think any design principles within the Metaverse Maturity Model need redefinition or updating?

Answer: To provide a more inclusive and accurate representation of the metaverse applications, a broader definition that encompasses various dimensions of usability, including navigation of the application, and overall user satisfaction, would be beneficial criteria. Additionally, periodic updates and refinements to all principles within the model are essential to ensure it remains it relevance.

Question: Can you rate each of the following criteria on a scale from 1-5:

Maturity Levels	Score
The maturity levels are sufficient to represent all maturation stages of the domain	4
There is no overlap detected between descriptions of maturity levels	4
Key design principles	
The key design principles are relevant to the Metaverse domain	4
The key design principles cover all aspects impacting/involved in the domain	4
The key design principles are clearly distinct	4
The key design principles are correctly assigned to their respective maturity level	3
Maturity Model	
Understandability	
The maturity levels are understandable	4
The assessment guidelines are understandable	4
The documentation is understandable	4
Ease of use	
The assessment guidelines are easy to use	5
Usefulness and practicality	
The maturity model is useful for conducting assessments	5
The maturity model is practical for use the industry	4

Interviewee:
Business development representative
Date: 24/08/2023
Case study 1: Business meetings and ideation session in the Metaverse

Question: Is the purpose of the maturity model clear?

Answer: Absolutely.

Question: Do you think the model accurately captures the key design principles for metaverse applications within the enterprise context?

Answer: Yes, the model captures the essential design principles needed for metaverse applications within the enterprise context. It takes into account various dimensions. These dimensions are relevant for creating an ideation program that meets the needs of employees transitioning into the metaverse environment.

Question: Are there any key design principles or practices that you would consider adding to the Metaverse maturity model? If yes, kindly elaborate which key design principles or practices that are and provide the rationale behind your suggestion.

Answer: Given that the ideation sessions, I would consider adding a dimension related to "Educational Resources." This would encompass a range of learning materials, and interactive guides specifically tailored for newcomers to the metaverse.

Question: Are there any key design principles or practices within the Metaverse maturity model that you believe should be removed? If so, please specify which ones and provide an explanation for your recommendation.

Answer: As the metaverse program is targeted at easing employees into the virtual environment, I would suggest a slight modification. The dimension related to "Complex multiplayer interactions" might be more relevant for entertainment or gaming contexts. In an enterprise setting, the focus should be more on collaborative interactions, team coordination, and social communication. Adjusting this aspect would better align the model with the goals of the onboarding program.

Question: Are there any key design principles within the Metaverse maturity model that you think should be redefined or updated? If so, please clarify which ones and provide reasoning behind your suggestion for redefinition or update.

Answer: Within the "user Interactive Level" dimension, the stage of "social interaction" could be redefined to emphasize practical workplace interactions. While social connections are essential, highlighting features such as virtual team meetings, collaborative project spaces, and work-related discussions would better reflect the objectives.

Question: A tool is used to assess the level of key design principles for educative applications. Do you find this approach useful and applicable?

Answer: Yes, the use of a tool to assess the level of key design principles is indeed valuable and applicable for the metaverse program. It provides a quantifiable and systematic way to evaluate the maturity of the program's different dimensions. By using a tool, can be ensured that the program approach aligns with the desired level of sophistication as employees transition into the metaverse.

Question: Are there any additional criteria that you think are important for evaluating the maturity of user and application combinations for the user experience of Metaverse applications in this context?

Answer: Given that the program aims to ensure a seamless transition for employees, "ease of navigation" could be an important criterion. This would encompass how easily users can navigate through the metaverse environment, access tools, collaborate with colleagues, and locate resources. A clear and intuitive navigation experience is essential for a positive experience.

Question: Can the maturity model be utilized to identify the necessary focus areas for successful development of Metaverse applications?

Answer: Absolutely, the maturity model serves as a guide for identifying focus areas in the development of Metaverse applications. By analyzing the various dimensions, can be focused on areas that require enhancement or prioritization to ensure a comprehensive and effective experience. It allows to align the development efforts with the needs of employees transitioning into the metaverse.

Question: Are there any specific design principles or factors that you believe are missing for the assessment method, but should be taken into account for evaluating the maturity of user and application combinations within the Metaverse?

Answer: A criteria that measures users' contributions during the sessions. In this way the performance of different employees can be compared, and this would stimulate employees to actively participate during the sessions.

Question: How effective do you believe the model is in assessing the specific level of key design principles required for different user and application combinations?

Answer: General principles are included that are promising for further expansion of metaverse application development.

Question: Can you assess the proposed model using assessment scores ranging from 1-5:

Maturity Levels	Score
The maturity levels are sufficient to represent all maturation stages of the domain	4
There is no overlap detected between descriptions of maturity levels	4
Key design principles	
The key design principles are relevant to the Metaverse domain	5
The key design principles cover all aspects impacting/involved in the domain	3
The key design principles are clearly distinct	4
The key design principles are correctly assigned to their respective maturity level	4
Maturity Model	
Understandability	
The maturity levels are understandable	4
The assessment guidelines are understandable	5
The documentation is understandable	4
Ease of use	
The assessment guidelines are easy to use	4
Usefulness and practicality	
The maturity model is useful for conducting assessments	4
The maturity model is practical for use the industry	4

Interviewee:
Cyber Security Engineer
Date: 24/08/2023
Case study 2: Onboarding program in the Metaverse

Interviewer: Do you agree with this definition of the Metaverse: "The Metaverse can be defined as a virtual, interconnected ecosystem that seamlessly bridges the physical and digital worlds. It facilitates immersive experiences, social interactions, and access to a virtual economy. By transcending individual technologies, it creates a collaborative environment that aims to provide a persistent digital reality."

Interviewee: Yes, I completely agree with this definition of the Metaverse.

Interviewer: Can you tell us about your experience in the Metaverse onboarding program?

Interviewee: Sure. The Metaverse onboarding program I participated in was an unique experience. I entered a virtual campus designed for our onboarding experience. I was given the chance to create an avatar that closely resembled my real self. It was interesting because I had control over every detail, from my avatar's appearance to its hairstyle and body shape.

Guided by an instructor, my avatar navigated to another virtual environment. Various training spots were available and social hubs where my new colleagues' avatars were hanging around. These guides were teaching us how to maneuver using the controllers. They introduced me to the concept of 'teleportation,' enabling instant jumps from one place to another within the application.

This virtual realm was referred to as One Accenture Park, an integral part of the broader Accenture’s Nth Floor metaverse. It felt like a parallel universe where hidden spots, breathtaking views, and even exhilarating activities like a simulated zip-line ride were offered.

What made the experience even more engaging was the gamified approach. For instance, we were taken to a spot known as the 'phishing pier,' where we were taught to identify online security threats. As we reached the pier, virtual dolphins leaped around in the water. In a light-hearted mishap, I accidentally got too close to the edge, causing my avatar to plunge into the virtual waters. This humorous incident underscored that, even in the digital world, there's room for mistakes and laughter. Overall, I found the experience incredibly enjoyable and innovative.

Interviewer: Do you favor the onboarding program experience in the Metaverse over traditional onboarding programs?

Interviewee: Absolutely, I find the onboarding program experience in the Metaverse to be significantly more appealing than other methods I have experienced. The immersive nature of the Metaverse allows new joiners to explore, collaborate, and compete with peers in a gamified environment, fostering engagement with new collegues.

Interviewer: Do you think this experience enhances your integration within the company compared to traditional e-learning methods?

Interviewee: Without a doubt, the Metaverse onboarding experience has enhanced my integration within the company much better. The nature of the Metaverse enables me to form connections with colleagues I wouldn’t have encountered otherwise, it allowed me to adapt faster, and feel like an integral part of the team.

Interviewer: How effective did you find the onboarding program, and do you have any suggestions for enhancing such applications that provide these experiences?

Interviewee: The onboarding program was effective, presenting a refreshing approach to learning. The engagement and interactivity were highlights, and I appreciated the exposure to diverse subjects., A well-structured learning path can significantly enhance the experience by helping employees understand the metaverse's features, interactions, and its applications. Moreover, new challenges would keep the experience dynamic and appealing.

Interviewer: Do you have any other suggestions for how these onboarding programs can be improved? Or barriers that you encountered?

Interviewee: At this time, I don't have any specific suggestions for improvement or encountered any significant barriers. The overall experience was positive and enriching.

<u>The maturity model assessment:</u>

Interviewer: Is the purpose of the maturity model clear?

Interviewee: Yes, the purpose of the maturity model is clear. To enhance its usability, I'd suggest reorganizing the principles into categories that reflect their themes. For example, grouping principles related to security and privacy under a main title called "Security & Privacy." Similarly, principles related to usability could be grouped under "Usability." This approach would provide a more structured view of the design principles and facilitate better comprehension.

Interviewer: Do you think the model accurately captures the key design principles for metaverse applications in an enterprise context for educational purposes?

Interviewee: Yes, the model captures key design principles for metaverse applications within an enterprise context, especially in the realm of education. It encompasses aspects like user engagement, interactive learning, and immersive experiences that align well with the goals of educational applications in the metaverse.

Interviewer: Are there any key design principles or practices that you would consider adding to the Metaverse maturity model? If yes, kindly elaborate on which key design principles or practices you would propose and provide the rationale behind your suggestion.

Interviewee: In my opinion, the existing model covers a comprehensive range of key design principles. Therefore, I don't see a need for additional principles at this time.

Interviewer: Are there any key design principles or practices within the Metaverse maturity model that you believe should be removed? If so, please specify which ones and provide an explanation for your recommendation.

Interviewee: I believe that all the key design principles currently included in the Metaverse maturity model are relevant and valuable.

Interviewer: Are there any key design principles within the Metaverse maturity model that you think should be redefined or updated? If so, please clarify which ones and provide reasoning behind your suggestion for redefinition or update.

Interviewee: As of now, I don't see a need for redefining or updating any of the key design principles within the Metaverse maturity model. They seem to be well-defined and comprehensive.

Coming back to the maturity model, can you please assign a score ranging from 1 to 5 for each of the criteria:

Maturity Levels	Score
The maturity levels are sufficient to represent all maturation stages of the domain	4
There is no overlap detected between descriptions of maturity levels	3
Capabilities and Practices	
The key design principles are relevant to the Metaverse domain	4
The key design principles cover all aspects impacting/involved in the domain	5
The key design principles are clearly distinct	4
The key design principles are correctly assigned to their respective maturity level	4
Maturity Model and use of the assessment tool	
Understandability	
The maturity levels are understandable	5
The assessment guidelines are understandable	4
The documentation is understandable	4
Ease of use	
The assessment guidelines are easy to use	4
Usefulness and practicality	
The maturity model is useful for conducting assessments	5
The maturity model is practical for use the industry	5

Interviewee:
Technology & Strategy consultant
Date: 27/08/2023
Case study 2: Onboarding program in the Metaverse

<u>About the maturity model</u>
Question: Is the purpose of the maturity model clear?

Answer: Absolutely.

Question: Do you think the model accurately captures the key design principles for metaverse applications within the enterprise context?

Answer: It covers al lot of design principles. However, I would suggest to remove some for, as that would make the model easier to ease, and more accessible.

Question: Are there any key design principles or practices that you would consider adding to the Metaverse maturity model? If yes, kindly elaborate which key design principles or practices that are and provide the rationale behind your suggestion.

Answer: Given that the onboarding, I would include some focus areas that can quantify the quality of the experience. This would deliver the company with more specific outcomes and areas for improvement.

Question: Are there any key design principles or practices within the Metaverse maturity model that you believe should be removed? If so, please specify which ones and provide an explanation for your recommendation.

Answer: Mixed-reality access is not really applicable, as we received the required hardware from the company. And, there weren't any monetization options in the onboarding programme, so in this scenario that principle isn't applicable.

Question: Are there any key design principles within the Metaverse maturity model that you think should be redefined or updated? If so, please clarify which ones and provide reasoning behind your suggestion for redefinition or update.

Answer: As the metaverse onboarding program is aimed at facilitating employees' integration into the company culture, I would recommend expanding the engagement domain. This could involve suggesting more collaborative efforts and outcomes that can measure the degree of integration post-program completion. This might be achieved through the integration of achievements or an internal competition. Another crucial focus area should be related to rewarding employees after successfully completing the onboarding program. This adjustment will better align the model with the goals of the onboarding program.

Question: A tool is used to assess the level of key design principles for educative applications. Do you find this approach useful and applicable?

Answer: Yes, a tool is useful, and makes it easier for the company to collect feedback.

Question: Are there any additional criteria that you think are important for evaluating the maturity of user and application combinations for the user experience of Metaverse applications in this context?

Answer: Not really, as I already mentioned maybe a more quantitative approach as this assessment is more subjective.

Question: Can the maturity model be utilized to identify the necessary focus areas for successful development of Metaverse applications?

Answer: For sure, it is good that some focus areas are suggested, and these areas do present mindful suggestions, and point out interesting areas to expand the functioning of the application.

Question: Are there any specific design principles or factors that you believe are missing for the assessment method, but should be taken into account for evaluating the maturity of user and application combinations within the Metaverse?

Answer: For the metaverse onboarding program, "User accessibility" should be considered. This involves ensuring that the metaverse environment is accessible to individuals with diverse abilities, including those with disabilities. Implementing features like screen readers, voice commands, and accessible interfaces is essential to provide an inclusive onboarding experience for all employees.

Question: How effective do you believe the model is in assessing the specific level of key design principles required for different user and application combinations?

Answer: The model is effective in assessing the specific level of key design principles, as it provides a clear progression from foundational to advanced stages across multiple dimensions. This allows to tailor the onboarding experience based on the specific needs and roles of employees. By addressing each dimension's requirements, can a targeted and effective onboarding process be ensured for different user and application combinations within the metaverse.

Maturity Levels	Score
The maturity levels are sufficient to represent all maturation stages of the domain	4
There is no overlap detected between descriptions of maturity levels	4
Capabilities and Practices	
The key design principles are relevant to the Metaverse domain	5
The key design principles cover all aspects impacting/involved in the domain	4
The key design principles are clearly distinct	4
The key design principles are correctly assigned to their respective maturity level	4
Maturity Model and use of the assessment tool	
Understandability	
The maturity levels are understandable	4
The assessment guidelines are understandable	4
The documentation is understandable	4
Ease of use	
The assessment guidelines are easy to use	4
Usefulness and practicality	
The maturity model is useful for conducting assessments	5
The maturity model is practical for use the industry	4

Interviewee:
Presales consultant business technologies
Date: 10/07/2023
case study 3: SAP BTP application

Question: You mentioned that using the metaverse could help make products more interactive and engaging. Can you provide some examples of how the metaverse enhances the user experience compared to traditional educational methods?

Answer: Certainly. In our case, we're working on a product that can be a bit challenging to convey through traditional means, like a static web page. With the metaverse, we can create immersive experiences where users can actually interact with our product. For instance, instead of describing how our product works on multiple web pages, users can now explore different aspects of it in a single virtual room. This visual and interactive approach makes it easier for users to understand and engage with functionalities of our product.

Question: You touched on the idea of having multiple pages open on a laptop screen versus using a metaverse room. Could you elaborate on how this spatial layout in the metaverse positively impacts the way users interact with the content?

Answer: Absolutely. The metaverse offers a spatial layout that reproduces real-world interactions. Instead of searching multiple pages on a screen, users can simply turn around in the metaverse room to access different information. This makes the experience much more intuitive and streamlined. For instance, they can look at instructional materials on one side and then turn around to view the product in action. It's like having everything spread out in a physical space, which reduces cognitive load and enhances the overall user experience.

Question: It's interesting to hear that the software is evolving quickly. Could you share some insights into the specific improvements that you anticipate or would like to see in the software's capabilities within the metaverse?

Answer: Definitely. While the current software is promising, there's always room for improvement. I would like to see more seamless integration between different elements within the metaverse environment. This could involve smoother transitions between different spaces and enhanced ways to interact with objects. Additionally, refining the realism of avatars and interactions would be beneficial. I anticipate that features like advanced customization, realistic animations, and even haptic feedback for embodiment, could significantly enhance the sense of presence and immersion.

Question: When considering the maturity of the BTP metaverse application, what aspects do you believe still need improvement in terms of its design principles and features?

Answer: In terms of design principles, ensuring a user-centric approach is crucial. The metaverse experience should prioritize ease of use and accessibility. As for features, refining collaboration tools would be beneficial. While the metaverse fosters interaction, incorporating functionalities like real-time collaboration on documents or presentations within the virtual space could enhance productivity. Additionally, expanding the library of pre-built environments and templates could make it easier for users to create engaging experiences without starting from scratch.

Question: You mentioned that customization of avatars has been impactful in creating a more comfortable user experience. Could you delve deeper into the role of avatars in enhancing user engagement and interaction within the metaverse?

Answer: Avatars play a role in bridging the gap between virtual and real-world interactions. When users can personalize their avatars, it creates a sense of ownership and identity. This translates to more natural interactions as avatars can convey emotions, gestures, and expressions similar to face-to-face interactions. It's about establishing a connection with the virtual space. People tend to feel more at ease when communicating through avatars, and this level of personalization enhances engagement and makes the overall experience more relatable.

Question: In your opinion, how do you see the metaverse integrating more deeply into SAP's future? You mentioned it might take around 10 years for substantial integration, but what areas within SAP's operations could benefit the most from metaverse technologies?

Answer: I envision the metaverse becoming integral to various aspects of SAP's operations. Indeed a significant area is education and training. The metaverse could revolutionize how we onboard new employees or conduct training sessions, offering immersive simulations and interactive learning environments as the architecture of the BTP in the Metaverse. Additionally, conferences and events could transition to the metaverse, creating dynamic and engaging virtual spaces for collaboration and networking. The metaverse could also enhance customer interactions, enabling personalized product demonstrations and consultations in a virtual setting.

Question: In the context of your experiences, can you share a specific example where the integration of the metaverse has positively impacted a project or task you were working on?

Answer: Certainly. We recently created a VR world for an event, and the engagement was beyond our expectations. Participants could navigate the virtual space to access information and interact with our product. This not only made the event more memorable but also allowed attendees to get in touch with the product in a more interesting way. The metaverse provided an immersive experience that would have been difficult to replicate through traditional means.

Question: You mentioned the idea of integrating digital currencies or tokens within the metaverse to introduce new monetization models. How do you envision this integration benefiting both the provider and users? Can you provide a scenario where such a model could be particularly advantageous?

Answer: Integrating digital currencies within the metaverse introduces a new dimension to software monetization in our case. For providers, it opens up opportunities to offer premium features, extensions, or exclusive content in exchange for these tokens. This allows providers to generate revenue while offering enhanced value to users. Users, on the other hand, can customize their experience by purchasing these tokens and accessing specialized functionalities. For instance, in an educational application within the metaverse, users could acquire tokens to access advanced courses, personalized tutoring, or virtual workshops, creating a win-win scenario for both parties.

Question: Considering the potential of user-generated content (UGC) within the metaverse, how do you see this aspect influencing the expansion of the applications? Can you provide an example of how UGC could enhance a specific software solution?

Answer: User-generated content in the metaverse allows users to contribute and shape their experiences. In the context of software applications, consider a project management tool. With UGC, users could create custom templates, interactive dashboards, or even virtual project rooms that cater to their specific workflows. This not only enhances the tool's functionality but also builds a sense of community around it. UGC transforms users from passive consumers to active contributors.

Question: Lastly, what do you believe are the key takeaways for software developers and businesses looking to leverage the metaverse's capabilities? How can they best embrace its potential to drive innovation, user engagement, and business growth?

Answer: Developers should place a strong emphasis on crafting user-centric experiences that prioritize ease of use, interactivity, and personalization. Leveraging the capabilities of the metaverse allows us to introduce fun and innovative offerings. Furthermore, expanding these offerings can be achieved through collaborations with third parties.

Part two: Assessment of the maturity model:

Question: Do you agree with this definition of the Metaverse:

"The Metaverse can be defined as a virtual, interconnected ecosystem that seamlessly bridges the physical and digital worlds. It facilitates immersive experiences, social interactions, and access to a virtual economy. By transcending individual technologies, it creates a collaborative environment that aims to provide a persistent digital reality."

Answer: Yes, I agree with this definition of the Metaverse. It accurately reflects the core attributes of the Metaverse. Additionally, the notion of transcending individual technologies and fostering collaboration aligns with the overarching goal.

Question: Is the purpose of the maturity model clear?

Answer: Yes, the purpose of the maturity model is clear. It aims to provide a framework for evaluating the maturity of metaverse applications. The model intends to assess key design principles, and identify areas for improvement in order to create more effective and engaging metaverse applications.

Question: Do you think the model accurately captures the key design principles for metaverse applications within an enterprise context?

Answer: Yes, the model does a good job of capturing key design principles for metaverse applications within an enterprise context. It encompasses aspects like user interaction, customization, immersive experiences, and collaboration, which are focus areas for successful metaverse application development in such settings.

Question: Are there any key design principles or practices that you would consider adding to the Metaverse maturity model? If yes, kindly elaborate which key design principles or practices that are and provide the rationale behind your suggestion.

Answer: One potential addition could be the principle of trust in the applications or more ethical considerations. As metaverse applications gather user data and facilitate interactions, ensuring robust data protection mechanisms and user privacy is important. Incorporating this principle would address focus areas around data handling and build user trust in the application.

Question: Are there any key design principles or practices within the Metaverse maturity model that you believe should be removed? If so, please specify which ones and provide an explanation for your recommendation.

Answer: As of now, the key design principles in the model seem relevant and valuable for assessing metaverse application maturity within an enterprise context. However, ongoing evaluation and adaptation based on emerging trends and technologies could be necessary to ensure the model's continued effectiveness.

Question: Are there any key design principles within the Metaverse maturity model that you think should be redefined or updated? If so, please clarify which ones and provide reasoning behind your suggestion for redefinition or update.

Answer: The principle of "Customization" could benefit from further clarification. It could specify the extent to which customization is possible, such as avatar personalization, environment modification, and content creation. This clarity would provide developers and users with a clearer understanding of the customization capabilities offered by the application.

Question: A tool is used to assess the level of key design principles for educative applications. Do you find this approach useful and applicable?

Answer: Yes, the use of a tool to assess the level of key design principles for educative applications is useful and applicable. Such a tool would provide a standardized and objective way to evaluate the presence and maturity of design principles. It would aid in identifying strengths and weaknesses in the application's design, ultimately leading to improvements.

Question: Are there any additional criteria that you think are important for evaluating the maturity of different applications for the user experience of such applications in this context?

Answer: In addition to the existing criteria, it could be beneficial to assess the inclusivity of the application. This could involve evaluating whether the application caters to users with diverse abilities, ensuring that it is accessible and usable by a wide range of individuals.

Question: Can the maturity model be utilized to identify the necessary focus areas for the successful development of Metaverse applications?

Answer: Yes, the maturity model can definitely be utilized to appoint focus areas. By assessing the maturity level of key design principles, developers can address areas that need improvement and prioritize efforts accordingly. This structured approach helps.

Question: Are there any specific design principles or factors that you believe are missing for the assessment method, but should be taken into account for evaluating the maturity of user and application combinations within the Metaverse?

Answer: Metaverse applications may need to seamlessly integrate with other applications or platforms, allowing users to transition between different virtual environments, and third-party applications. This focus area would enhance the overall user experience and encourage widespread adoption.

Question: How effective do you believe the model is in assessing the specific level of key design principles required for different user and application combinations?

Answer: The model appears effective in assessing the levels of key design principles, as it covers a broad range of factors contributing to the design of metaverse applications. However, the model needs to ensure it adapts alongside new innovations.

Maturity Levels	Score
The maturity levels are sufficient to represent all maturation stages of the domain	4
There is no overlap detected between descriptions of maturity levels	4
Capabilities and Practices	
The key design principles are relevant to the Metaverse domain	4
The key design principles cover all aspects impacting/involved in the domain	4
The key design principles are clearly distinct	3
The key design principles are correctly assigned to their respective maturity level	4
Maturity Model and use of the assessment tool	
Understandability	
The maturity levels are understandable	5
The assessment guidelines are understandable	4
The documentation is understandable	4
Ease of use	
The assessment guidelines are easy to use	4
Usefulness and practicality	
The maturity model is useful for conducting assessments	5
The maturity model is practical for use the industry	4

Appendix H: Guide and principles towards a design strategy

Drawing upon the research findings, and the utilization of the MAMM, below is a strategy aimed at positioning development of Metaverse applications. By strategically developing an approach, organizations can improve their offerings. Figure 33, outlines the 8 key activities for the design of Metaverse applications:

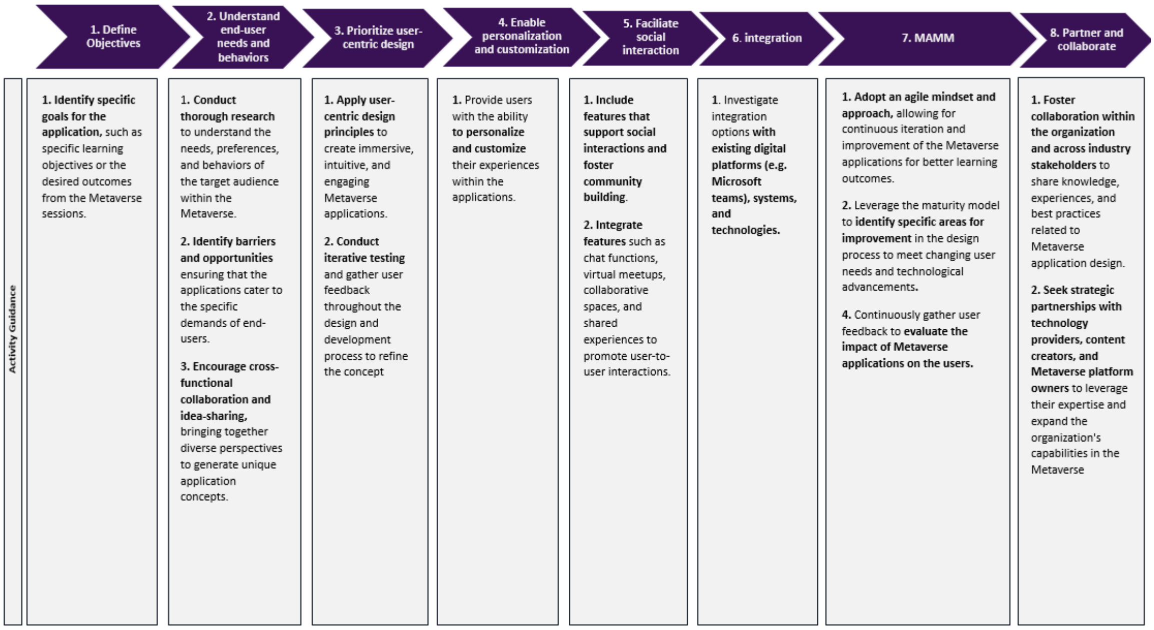

Figure 33, Development strategy Metaverse Applications