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Designing a User-Metaverse Interface for the Industrial-Metaverse

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Completed Research Paper

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Abstract

The Industrial-Metaverse will create interactions between the physical and virtual worlds to extend operations in the physical industry. This particularity and the demand for increasing immersion in the Metaverse require using XR technologies called User-Metaverse interfaces (UMI). How such a UMI must be designed for the industrial-Metaverse is unknown. This study adopts a design science approach to design a UMI based on social-cognitive theory (SCT). According to SCT, creating user-generated Metaverse content is crucial to the UMI design. It empowers users to generate content through their efforts, leading to higher self-efficacy and user engagement. We formulate two theoretically based design principles and instantiate a software artifact, which we evaluate in a laboratory experiment with 57 participants. Our study shows the importance of belief in success in the design of future UMI. Furthermore, our design principles show significant positive outcome expectations of users in their interaction with the software artifact.

Keywords: Metaverse Interface, Social Cognitive Theory, Industrial Metaverse, Design Science Extended Reality

Introduction

The Industrial-Metaverse means the convergence of virtual and augmented realities with the physical environment in industrial production and maintenance. This convergence will change how users work and interact, enabling real-time interaction with other humans and machines (MIT Technology Review Insights 2023). The revolutionary aspect of the Industrial-Metaverse is that, on the one hand, users can innovate without fear of risk or additional costs; on the other hand, it recognizes and solves certain clearly spatial problems. The interaction of digital and physical realities is enabled by extended Reality (XR) technologies which is an umbrella term for immersive technologies such as Augmented Reality (AR), Mixed Reality (MR), and Virtual Reality (VR) that are used to digitally and physically intertwine human-machine interaction in the Industrial-Metaverse (Rauschnabel et al. 2022). An example of such interaction is Burghardt et al. (2020) pairing of a digital twin and XR to control a physical robot. A digital twin of the robot's environment is displayed in XR. The XR system records the reproduces the operator's movements in the physical robot. This new way of controlling robots is especially useful for performing complicated tasks, and successful task performance depends on the experience of the operator (Burghardt et al. 2020). In order for the Industrial-Metaverse to realize its full potential, users must be able to interact with the Metaverse content, such as the digital twins, as well as create new content. To achieve this goal we need a complete understanding of the conditions under which XR interfaces are more or less effective in enabling human-machine interaction, and what types of hardware are best suited to support Metaverse applications (Dwivedi et al. 2022).

Practice-based and academic research have proposed different perspectives on how to best interact in the Metaverse. While Siyaev and Jo (2021) propose a mixed-reality interface to combine the virtual and physical worlds, using the virtual to augment the physical experience, other researchers propose a fully immersive environment where avatars act on behalf of users in the physical environment (Duan et al. 2021), drawing attention to the purely virtual experience. Other authors suggest that the Metaverse can be accessed through screen-based interfaces (Schultze and Orlikowski 2010). This inconsistency in the Metaverse interface literature has delayed the emergence of a de facto standard for designing interfaces for the Metaverse, which could be one of the reasons that have led to slower adoption of the Metaverse by users and causing some companies, such as Microsoft, to abandon the Metaverse altogether (Bonifacic I. 2023).

While most of the IS Metaverse research since the release of Second Life has focused on the screen-based interface (Chaturvedi et al. 2011; Davis et al. 2009; Schultze and Orlikowski 2010), the Metaverse has continued to evolve, which leads to new possibilities. An important evolution of the Metaverse is the increasing immersion that can only be achieved through XR interfaces. Therefore the term "User-Metaverse-Interface (UMI)" has been coined in the current IS Literature (Dwivedi et al. 2022) but how to design such a UMI has not yet been investigated in the IS literature.

To bring coherence to Metaverse interface design, this research uses a design science research approach to articulate a set of design principles for a UMI. We propose design principles for a UMI based on social cognitive theory (SCT) (Bandura 1986) and research on existing Metaverse interfaces (Biocca et al. 2007; Davis et al. 2009; Peukert et al. 2019). In doing so, we rely on an important aspect that, to our knowledge, has not yet been addressed in research, the creation of user-generated Metaverse content. The creation of user-generated Metaverse content is a key possibility suggested by SCT, as users create content through their own efforts and actions, leading to self-efficacy (Bandura 1997). We enable novice users in the Industrial-Metaverse to create user-generated Metaverse content (i.e., digital twins). The term novice user in this context describes technicians with great process knowledge but not necessarily deep spatial knowledge or any programming experiences. By empowering novice users, organizations can develop Metaverse applications on their own without the help of external IT service providers. On the one hand, this avoids expensive individual developments; on the other hand, organizations can adapt their Metaverse processes more quickly. In doing so, we investigate: *How can a User-Metaverse interface be designed to enable novice users to create user-generated Metaverse content for the Industrial-Metaverse?*

To answer this question, we conducted a comprehensive Design Science Research (DSR) project focused on eliciting design principles for XR interfaces in the Industrial-Metaverse (Gregor and Hevner 2013). Our DSR approach (Hevner et al. 2004) suggested three theoretically grounded principles that provide prescriptive knowledge about the design of XR interfaces in the Industrial-Metaverse. We evaluate the two design principles in a UMI designed to enable novice users to create user-generated Metaverse content in the Industrial-Metaverse (Yang et al. 2022; Zheng et al. 2022). We evaluate the proposed design in a large-scale laboratory experiment. More specifically, we aim to identify the major sources of self-efficacy in designing UMIs to analyze novice users' motivation to contribute content to the Industrial-Metaverse. As a result, we contribute theoretically by providing design knowledge of a UMI to create user-generated content in the Industrial-Metaverse. We also contribute practically with our two theoretically grounded design principles that support the implementation of interfaces in the Industrial-Metaverse. Finally, we show that access to a library of 3D elements and the ability to create own media and anchor them in the physical environment has a significant positive impact on the task performance and the performance-related outcome expectations of the users.

The paper is organized as follows. The basic concepts and related work are presented in the following section. The research methodology is described in the third section. In the fourth section, the meta-requirements, the design principles, and the instantiated software artifact are explained. The evaluation and results are presented in the fifth section. The final section discusses the evaluation results, limitations, and future research.

Conceptual Foundation

Metaverse Realms

Neal Stephenson (1992) coined the term "Metaverse" in his novel "Snow Crash". According to Stephenson, the Metaverse is a computer-generated universe drawing onto goggles and pumping into earphones. Perhaps because of its fictional roots, competing technical views of the Metaverse interfaces have emerged.

These competing technical views of the Metaverse make it difficult to make design decisions because the technologies have different requirements. Therefore, we consider the existing research on the Metaverse from a sectoral perspective. The variety of Metaverse applications shows that researchers are trying to understand and describe the usefulness of this sociotechnical phenomenon (Dwivedi et al. 2022). Therefore, we consider it important to understand this phenomenon from the capability perspective of users in different sectors.

Table 1 distinguishes the different Metaverse realms using defining characteristics (i.e., the environment, the interaction, and the interface) (Park and Kim 2021), experienced immersion, and examples of application domains. While IS research has focused on Consumer- and Enterprise-Metaverse applications (Davis et al. 2009; Peukert et al. 2019; Schultze and Orlikowski 2010), it has left the Industrial realm relatively unexamined.

	Metaverse Realms		
	Consumer	**Enterprise**	**Industrial**
Definition	Create immersive experiences for entertainment and gaming purposes.	Create immersive communication and collaboration in the workplace and immersive business environments for company interactions with customers and other businesses.	Create interactions between the physical world and the virtual world to broaden the operations in the physical industry.
Environment	Predominantly an unrealistic environment	Predominantly a realistic environment	Predominantly a fused environment
Level of immersion	High	Low and High	Medium
Interaction	Controllers, gestures, speech	Keyboard, mouse, controllers, gestures, speech	Touch, gestures, speech
Interface	3D and immersive methods	Immersive and physical methods	Physical methods
Application Domain	Games, Social	Office, Marketing, Education, Health Care, Tourism	Simulation, Digital Twin, Augmented Work instructions

Table 1. Summary of the Metaverse realms and their different characteristics

The Consumer-Metaverse aims to create immersive experiences for users for social (Duan et al. 2021), or for gaming and entertainment purposes (Nickerson et al. 2022). Often it is a highly immersive three-dimensional virtual world in which people interact as avatars with other people and non-player characters in an environment that deceives the user's senses and removes the barriers between space and time (Dwivedi et al. 2022). These unrealistic environments are not related to the degree of immersion but rather to how similar the physical world and the virtual world are. In unrealistic environments, for example, physical constraints such as gravity do not matter and users can experience unrealistic scenarios such as a journey to Mars (Dwivedi et al. 2022). To enter the Consumer-Metaverse, highly immersive methods are used, allowing users to be fully immersed in a virtual environment implemented through the use of VR (Xi et al. 2023).

In contrast, the Enterprise-Metaverse aims to create immersive communication and collaboration between people in a work environment on the one hand (Purdy 2022), as well as immersive environments in which companies can conduct business and interact with customers and other companies on the other (Liu et al.

2019). These environments often mirror the physical and geographic elements of the physical environment (Dwivedi et al. 2022). These realistic environments are not related to the degree of immersion but rather to how similar the physical and virtual worlds are. For example, in realistic environments, avatars cannot exist in different worlds or defeat gravity (Dwivedi et al. 2022). Research has examined two ways of entering the enterprise metaverse: 3D interfaces shown on a display, often in screen-based applications (Porter and Heppelmann 2017), and highly immersive methods analogous to the consumer metaverse (Winkler 2018).

The Industrial-Metaverse aims to increase the efficiency and productivity of manufacturing companies (Siyaev and Jo 2021). It focuses on physical human-machine interaction, industrial process simulation, and knowledge assessment (Zheng et al. 2022). An important aspect of the Industrial-Metaverse is the fused environments where virtual elements are fused with the user's physical environment according to the laws of reality (Siyaev and Jo 2021). AR or MR technologies are required to create these fused environments and thus enter the Industrial-Metaverse (Laviola et al. 2022). The predominant use of physical human-machine interactions in the Industrial-Metaverse to semantically intertwine people, spaces, and machines, both digitally and physically, determines how users create and interact with content for the Industrial-Metaverse.

One example of an Industrial-Metaverse application based on AR/MR technologies is that of Laviola et al. (2022). With their XR application *minimal AR*, users from the Industrial-Metaverse are guided in assembling technical assets. They are provided directly at the machine with the technical instructions to conduct the desired assembly process. The efficiency of the assembly process and the field service can be increased through the convergence of augmented reality and physical reality in the form of XR-based work instructions. Instead of sending a service technician to the customer's site, industrial manufacturers could provide the XR-based work instructions to their customers so that they can perform the repair/maintenance on their own. This will create new sustainable business models for industrial organizations, which are of fundamental importance for the fifth industrial revolution (*Industry 5.0*) (Xu et al. 2021).

In all Metaverse realms, the immersion and the possibility for the user to actively participate in the Metaverse (e.g., through user-generated Metaverse content) are central key characteristics. The particularity of the Industrial-Metaverse lies in the real-time human-machine interaction and the associated fused environments (Laviola et al. 2022; Siyaev and Jo 2021). Two development directions essentially drive the Industrial-Metaverse. On the one hand, an enormous application pull is driven by changes in the business environment and a significant need for change. These are, for example, to optimize processes and increase production efficiency or to enable technical experts to virtually explore complex systems, identify problems, and test solutions without actually being physically present (MIT Technology Review Insights 2023). On the other hand, a huge technology push can impact users' daily work. The technologies relevant to the Industrial-Mmetaverse are the following: XR Interfaces, Digital Twins, Artificial intelligence, blockchain, IoT, 5G/6G (MIT Technology Review Insights 2023).

User Metaverse Interface

To advance the use of the Industrial-Metaverse, we need a better understanding of how to design Metaverse interfaces. IS researchers have identified a wide variety of effects of interface design, ranging from the consistency of interfaces across applications (Satzinger and Olfman 1998) to the effects of interface design on decision-making capabilities (Speier and Morris 2003) and many more (Vance et al. 2015). We briefly examine three different interfaces that have been explored in the IS literature and relevant designing interfaces for the Metaverse. Table 2 briefly compares the three different Metaverse interfaces discussed in the IS literature.

		XR	
Definition	**Screen-based**	**VR**	**AR/MR**
Definition	Through avatars, users can interact with each other and non-player characters in a non-immersive environment.	Through avatars, users can interact with each other and non-player characters in a high-immersive immersive environment.	The physical environment of the users is enhanced with digital content.

Level of immersion	Low	High	Mid-High
Interaction	Keyboard and mouse	Controllers, gestures, speech	Touch, gestures, speech
Accessibility	High	Mid	Low-Mid
Use-Cases	Second Life, Roblox, Decentraland, Sandbox	Horizon Worlds and Workrooms, VRChat	Pokémon Go, Loreal ModiFace, IKEA Place

Table 2. Summary of Metaverse interfaces in the IS literature

The first and one of the most commonly associated interfaces with the Metaverse is the screen-based interface. Users can access the Metaverse using a laptop/computer and interact with it using a mouse and keyboard. Through avatars, users can interact with each other and non-player characters in an environment that resembles the physical world without facing physical limitations (Davis et al. 2009).

The second interface, and the one most commonly associated with current views of the Metaverse, is a VR interface. Users can access the Metaverse through VR interfaces such as a head-mounted display (HMD) and interact with it using controllers, gestures, or speech. Users also interact with other users and non-player characters in a virtual environment as avatars (Peukert et al. 2019). The difference lies in the degree of immersion, which includes the degree of isolation from reality.

The third interface, and the most commonly associated interface with the Industrial-Metaverse, is an AR/MR interface. Here, users can access the Metaverse via AR/MR interfaces such as smartphones or HMDs and interact through touch, gesture, or speech. The difference between the other two interfaces (screen-based or VR interfaces) is that no virtual environment is created. Rather, the user's physical environments are augmented with digital content (Azuma 1997). An example from the IS literature is the research of the authors Biocca et al. 2007 on the impact of an AR interface technique, “the omnidirectional attention funnel,” compared to standard cueing techniques such as visual highlighting and audio cueing.

The IS literature has extensively explored the screen-based Metaverse interface. Work such as that by the authors Chaturvedi et al. 2011 developed design principles for early virtual worlds. Davis et al. (2009) laid the groundwork to define an initial understanding of virtual collaboration that has informed ongoing Metaverse research. One reason the screen-based Metaverse interface has been explored for so long is the game SecondLife, released in 2003 and associated with the Metaverse concept. (Davis et al. 2009). Another reason is that this interface is very accessible and familiar to users.

Social Cognitive Theory and XR

Design and action theory, also known as design theory, is intended to help designers create new IT artifacts more efficiently (Gregor 2006). In DSR projects, these artifacts are developed by eliciting requirements from the theories and application domains and applying them to the corresponding instantiation for rigorous evaluation (Briggs 2006). Furthermore, design theories are distinctly prescriptive and aim to guide designers in developing novel IT artifacts more efficiently. Therefore, a solid theoretical foundation is necessary to underpin design theories and justify their effectiveness in achieving specific objectives. Furthermore, this foundation should explain why these theories work and how they can achieve their intended outcomes. For this reason, Walls et al. (1992) suggested that design theories should draw upon kernel theories.

We draw on a social cognitive theory (SCT) (Bandura 1986) as a kernel theory to conceptualize and represent our contributions to design knowledge and to develop our design principles. SCT postulates that the continuous reciprocal interaction between behavioral, cognitive, and environmental factors determines human behavior. Specifically, SCT is concerned with how environmental and cognitive factors influence human behavior in a given context (Bandura 1986). Self-efficacy represents the core of the cognitive factors of SCT, which is a form of self-assessment that influences decisions about what behaviors to engage in, and the amount of effort and persistence to exert when faced with obstacles. Individuals with high self-efficacy are more likely to exhibit certain behaviors than those with low self-efficacy. Bandura (1997) proposed that self-efficacy is mainly driven by four different sources: the enactive mastery experience, the vicarious experience, the verbal persuasion, and the physiological and affective states. The enactive mastery experience is the strongest source of self-efficacy and is driven by the repetitive successful completion of tasks (Bandura 1997). Vicarious experiences are created when individuals observe someone with similar abilities performing a task successfully. Verbal persuasion or the belief in success is the thought and reinforcement of a person's belief that they have the ability to complete the task. A person's emotional and physiological state induced by task performance is the final source of self-efficacy (Bandura 1997).

Many IS researchers have used self-efficacy to study a wide variety of effects. For example, Compeau and Higgins (1995) extended SCT to include computer self-efficacy in the context of computer use. In another example, authors Hsu and Chiu (2004) extended SCT to include Internet self-efficacy to explore user acceptance of the internet. Self-efficacy also carries a crucial role in virtual environments, with implications for a wide range of domains. A large area of research is related to understanding knowledge sharing and knowledge acquisition in virtual teams (Chiu et al. 2006; Kim et al. 2011). The findings also show that self-efficacy, directly and indirectly, influences knowledge sharing in virtual teams (Hsu et al. 2007).

SCT has been applied to study the design of virtual settings. For example, the authors Koulouris et al. (2020) found that user-defined avatars lead to people being able to identify with them, leading to more learning and imitation of the avatar’s behaviors. Self-efficacy also significantly impacts whether users want to participate in virtual environments such as the Metaverse. Individuals with high self-efficacy are more willing to explore and try new experiences within virtual environments, as they believe in their ability to learn and adapt to new tasks and challenges (Pellas 2014). Most (all) of these studies focus on the exploration of SCT in virtual teams in the context of screen-based interfaces. But little is known about the effect of SCT on the utilization of XR interfaces.

Design Science Research Project

We conducted a comprehensive Design Science Research (DSR) approach (Hevner et al. 2004), focusing on the design of innovative artifacts for the Industrial-Metaverse. In doing so, we propose an innovative solution to a real-world problem (Gregor and Hevner 2013). We address the lack of design knowledge about how to design a UMI to create user-generated Metaverse content (digital twins) for the Industrial-Metaverse. In this way, we hope to improve access to the Industrial-Metaverse for the specific target group (e.g., service technicians). We divided the DSR project into two successive design cycles (Kuechler and Vaishnavi 2008). This paper focuses on the quantitative evaluation results from the second design cycle. The following section briefly describes the overall DSR project to provide additional information and highlight the overall research goal.

In the **first design cycle**, we examined how XR applications can be integrated into these application domains in two organizations (i.e., a manufacturing company and a logistics company). For this purpose, we conducted a focus group and a think-aloud study in each organization to identify the requirements for XR applications in the respective contexts. Despite the different application domains, the case studies revealed that users have problems carrying out and documenting their physical tasks in a process-compliant manner. For example, a user from the logistics company that performs depth measurements in a harbor mentioned the following: “*I probably look at the monitor 80% of the time and only about 20% out of the window*.” Another example from the manufacturing company from a user who is responsible for the final assembly of technical energy assets said: “*If I am thrown off track during the assembly by a colleague or something similar, it happens more often that I don’t remember which step I was actually at*.” These two examples show the need for process guidance during task completion (Morana et al. 2017). We then used the results of the literature review and focus groups to formulate an initial set of design principles.

We instantiated these initial design principles into two different software prototypes. The prototype in the manufacturing sector is an XR guidance tool that guides users step-by-step through the assembly process of an industrial asset. With XR instructions, only the required information is displayed in the right place in the physical environment at the right time. The prototype from the logistics sector represents another XR guidance tool in which users are displayed a bearing line representing the measurement route in their field of view. Followed by evaluating the software prototypes in a case-study (logistics sector) and a think-aloud study (manufacturing sector). The detailed approach and the results of the case study from the logistics sector can be found in our previous publication (Bräker et al. 2022). In line with the literature, our results have shown that using XR-based process guidance systems offers great potential for companies (Choi et al. 2022). This is one possible reason why a large part of the XR applications in the industrial sector can be classified as process guidance systems (Kortekamp et al. 2019). In addition, we have found that a major problem in practice is not using XR applications but the complex, time-consuming, and cognitively challenging creation of XR content (Ashtari et al. 2020). Creating XR content requires strong programming skills and deep spatial knowledge, making it difficult for novice users (Nebeling and Speicher 2018).

We began the **second design cycle** with ten interviews with experts in XR content creation to further understand XR content creation (i.e., Metaverse authoring). We also read more on SCT to broaden our theoretical design base. We adapted the design principles based on the SCT because individuals are generally more willing to embrace new technologies due to high self-efficacy. We then instantiated the design principles in an industry-independent prototype. The evaluation of the industry-independent prototype is based on the framework for evaluation design science, which consists of four sequential steps (i.e., outline the objectives of the evaluation, select an evaluation strategy, define the properties to be evaluated, and create the evaluation episodes) (Venable et al. 2016). The objective of the evaluation is to verify the validity of the proposed design principles instantiated in a software artifact (i.e., Metaverse authoring tool) that provides a solution for a real-world problem. To facilitate the creation of metaverse content for novice users so that they can contribute to the industrial Metaverse, we followed the evaluation strategy of technical risk & efficacy, which is used to rigorously determine the effectiveness of the software artifact. In applying the technical risk & efficacy strategy, we checked whether a specific technology (i.e., Metaverse authoring tool) had the intended effects, as proposed in the design. Venable et al. (2016) recommend starting the evaluation with a laboratory experiment to clarify the boundaries of the technologies. The focus of the evaluation properties is on the validity of the proposed design principles, the effect of user-generated metaverse content on self-efficacy, and the associated intention of users to participate in the Metaverse. In a laboratory experiment, we evaluated the effects on the cognitive and behavioral factors of the users by using different rich Metaverse authoring tools to create a digital twin (XR-based process guidance system). Using a between-subject design, we examine how the richness of the Metaverse authoring interfaces affects self-efficacy, perceived functionality, perceived usefulness, and task performance.

Conceptual and Instantiation of the Design

Meta Requirements and Design Principles

Our formulated design principles (DP) are based on the schema proposed by Gregor et al. (2020), which suggests how DP should be formulated in order to be usefully applied in a real-world context. The authors point out the need to involve actors in formulating the DP so that they provide prescriptive knowledge of "how to do something to achieve the goal" (Gregor et al. 2020). The structure of a DP consists of the aim, the implementer, the user, the context, the mechanism, and the rationale (Gregor et al. 2020).

Our first meta requirement for a UMI is that novice users must be able to create their user-generated Metaverse content for the Industrial-Metaverse (**MR1**). Since the enactive mastery experience and the creation of user-generated Metaverse content are closely related, as users can create content through their own efforts and actions, such as writing a blog or creating videos, which results in a resilient sense of self-efficacy. In the process of creating user-generated Metaverse content, users are actively involved in achieving an outcome that promotes the acquisition of generative skills (Bandura 1997). Not only in social media, user-generated content has an enormous impact (Goh et al. 2013) but also in several successful Metaverse applications like SecondLife or Roblox, user-generated content is an important element (Bessière et al. 2009; Rospigliosi 2022). In these applications, users can not only navigate through the virtual environments but also create their own game experiences by creating their own content, such as virtual skins (i.e., a costume for avatars) or entire structures (Bessière et al. 2009; Rospigliosi 2022). Our second meta-requirement relates to the general design approach of the UMI, as the creation of XR content poses special and unique challenges to users. The creation of XR content requires good programming skills as well as deep spatial knowledge. (Ashtari et al. 2020; Azuma 2016; Nebeling and Speicher 2018). Nebeling and Speicher (2018)analyzed existing XR authoring tools in their research. As a result, they were able to divide the existing tools into five different groups. Considering the skills and resources required to use applications from these five groups, they can be categorized into two categories. In the first category (consisting of groups 4 and 5), a high level of programming skills and deep spatial knowledge is required to make adaptations. In the second class (consisting of groups 1, 2, and 3), no programming skills and less spatial knowledge are necessary to make adjustments. XR authoring tools in this class are no-code or low-code tools for developing XR content. Tools from this class differ from conventional no-code, low-code tools from software development because they provide an XR interface allowing 3D content to be anchored in the physical environments (Azuma 1997) or to create fully immersive virtual worlds. These aspects make the XR authoring tools unique.

Through the concept of a Metaverse authoring tool (i.e., a no-code tool for creating XR content), novice users are empowered to create XR content without any prior experience or programming knowledge (**MR2**) (Nebeling and Speicher 2018). Since the Metaverse authoring tool is used in the Industrial-Metaverse and applications from this context require fused environments, these tools should be based on AR or MR interfaces (Laviola et al. 2022; Siyaev and Jo 2021).

The two meta requirements aim to create higher self-efficacy and, thus, higher user participation in the Metaverse, which can catalyze psychological empowerment (Leung 2009). As a result, users enactive mastery experience their activities as meaningful and have confidence in their work tasks, which could lead to more proactivity (Zimmerman 1990). The meta requirements are supported by SCT, which argues that the content and type of user interaction in the context of the constructed environment influence user engagement (Bandura 1986). The two meta requirements described above form the foundation for the first design principle we propose:

DP1: *Design of a UMI in the form of a Metaverse authoring tool empowering novice users to contribute to the Industrial-Metaverse with user-generated Metaverse content.*

The third meta requirement refers to providing novice users with a library of abstract 3D elements that can be anchored in the user's physical environment (**MR3**). The use of AR content is necessary to represent the digitally and physically intertwined human-machine interaction, which is the focus in the industrial context (Laviola et al. 2022; Porter and Heppelmann 2017; Siyaev and Jo 2021). However, in the literature, it has been found that the use of complex XR elements has a negative impact on user attention, as users can be distracted by complex XR elements, which could affect the error rate (Lavric et al. 2022). In addition, recent research has shown that the best results in this context can be achieved using abstract 3D elements combined with media content (i.e., pictures or videos) (Jasche et al. 2021). Therefore, the fourth meta-requirement refers to the need for novice users to be able to create their own media for the Metaverse application. (**MR4**).

The two meta-requirements aim on the one hand to enable novice users to create perceived useful applications for the Industrial-Metaverse in their specific application domain, thereby increasing their outcome expectations. On the other hand, the perceived functionality (i.e., completeness) of the Metaverse authoring tool should increase the belief of success of the users. By increasing outcome expectations and the belief in success, users will be more willing to perform challenging tasks, thereby increasing their intention to use the Metaverse (Bandura 1986; Hsu et al. 2007). The two meta requirements thus form the final design principle that we propose:

DP2: *Provide the UMI with a library of abstract 3D elements and allow novice users to add their own media in order to create complete and perceived useful applications for the Industrial-Metaverse.*

Instantiation of the Design

To instantiate our design principles, we developed a software artifact of a Metaverse authoring tool. The first design principle maps to the basic design of a standalone Metaverse authoring tool that runs on a tablet without the need to install additional software or plug-ins or use additional hardware. Through the use of a no-code development approach, the graphical user interface does not require users to implement their code. Therefore, users can create Metaverse applications (i.e., XR-based process guidance systems) via drag and drop, enrich them with 2D and 3D elements, and anchor them in the physical environment.

The second design principle is the 2D node editor and the 3D authoring environment. The 2D Node Editor is used to define the structure and sequence of commands. Three different node types are available to the user. The first node type is the Info-Node, where only 2D elements (i.e., text) can be added. An Instruction-Node represents one step in an instruction, and an Exploration-Node can only display location-specific content. The display and information elements used to represent the XR-based process guidance systems are defined in the 3D authoring environment. For our application domain, the library of 3D elements is built on the six information types (i.e., identity, location, way-to, notification, order, and orientation) proposed by Gattullo et al. (2022) to fully map XR-based process guidance systems. In addition, we have implemented an attention funnel that supports users in highlighting dangers or obstacles in a visual search or spatial navigation (Biocca et al. 2007). In addition to 3D elements, 2D elements such as media or text can be added to an instructional step.

Apart from creating the XR-based process guidance systems, novice users can also use them to carry out their work in a process-compliant manner. In a Viewer Mode, the XR-based process guidance systems can be displayed. As the name suggests, changing or adapting the AR instructions in the viewer mode is impossible. The designed 2D and 3D content is rendered precisely where the creators placed it. Figure 1 shows the Node Editor on the left and the XR authoring environment on the right.

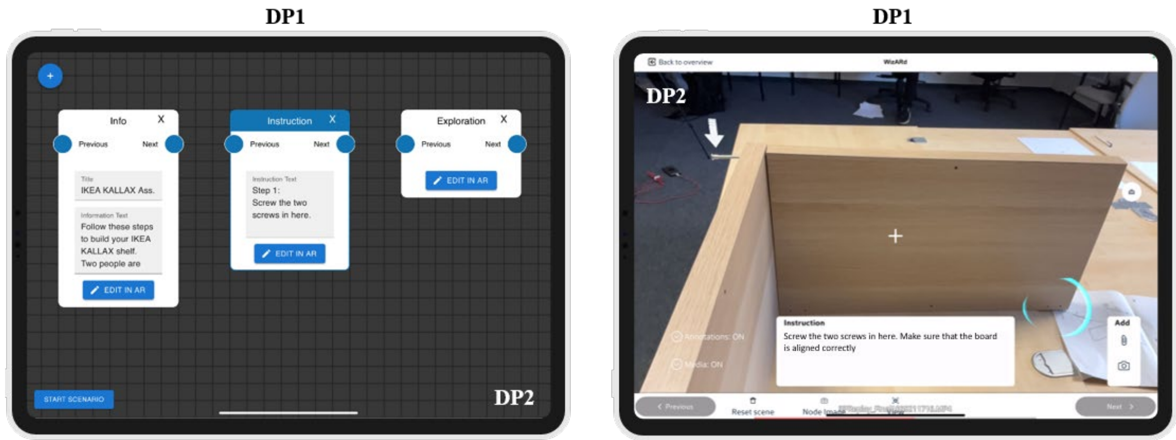

Figure 1. Software artifact: Metaverse authoring tool

Evaluation

In a laboratory experiment, we evaluated the impact of the proposed DPs and the resulting instantiated artifacts in a controlled laboratory environment. In order to test the functionality of our first DP, we investigate the impact of user-generated Metaverse content on self-efficacy and users' intention to contribute to the Metaverse. To test the functionality of the second DP, we have developed two XR authoring tools of different richness, which can be used to create Metaverse content of different richness. On the one hand, we want to check the functionality of our second DP. On the other hand, we want to identify the most relevant 3D elements based on the evaluation results and, if necessary, adapt our DPs accordingly. We argue that when novice users feel empowered to create Metaverse content (i.e., they have everything they need to create complete XR-based process guidance systems), belief in success increases, and if they believe that the created content is useful for other users, this, in turn, increases their outcome expectations. The two factors' belief in success represented by perceived functionality as outcome expectations represented by perceived usefulness will increase task performance.

As described in Chapter "Instantiation of the Design" the first prototype (rich XR authoring tool) provides users with seven different 3D elements; additionally, the users can add their own media. On the other hand, in the second prototype (reduced XR authoring tool), only two 3D elements are available to the user (i.e., arrow and point of interest). In addition, users cannot add any media to an instruction step.

Hypotheses Derivation

We formulate hypotheses regarding the proposed effects of the DPs based on existing research to evaluate their validity. Figure 2 shows the conceptualized research model and hypotheses.

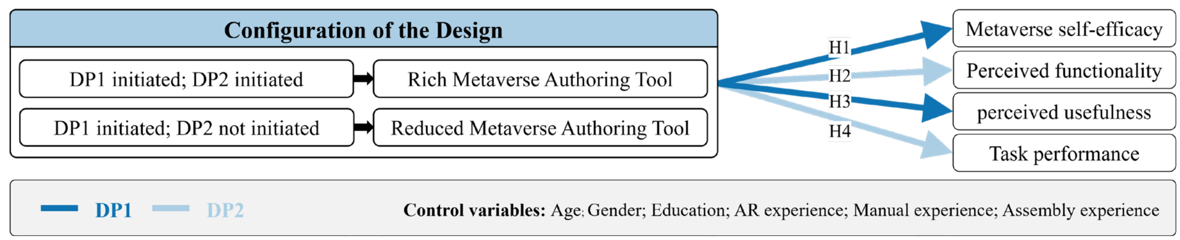

Figure 2. Research model

According to SCT, users who have a strong belief in their ability to successfully complete (belief in success) a task have greater self-efficacy (Bandura 1997). The perceived functionality of technology has a decisive impact on this. For example, Strong et al. (2006) found that adapting technology's functionality to the task positively affects the user's belief that he or she can perform the task successfully. The rich Metaverse authoring tool is designed with all the functionalities to create task-specific Metaverse applications in the context of the Industrial-Metaverse. Therefore we hypothesize that:

H1: *The perceived functionality of the rich Metaverse authoring tool is higher than that of the reduced Metaverse authoring tool.*

The outcome results from actions and can be anticipated by users by assessing how well they can behave in a given situation (Bandura 1997). This means users estimate their expected outcomes before taking action. This relationship connects the belief of success and outcome expectations. Positive outcomes can strengthen an individual's behavior, whereas those who doubt their capability or lack the necessary skills may perceive their actions as pointless and ineffective (Bandura 1997; Compeau et al. 1999). Furthermore, individuals who believe they possess the required skills to perform well in a given context, such as using a computer, are more likely to anticipate positive outcomes compared to those who doubt their abilities (Compeau et al. 1999).

IS studies have found a strong correlation between self-efficacy and perceived usefulness and between outcome expectations and perceived usefulness. For example, Compeau and Higgins (1995) found that both computer self-efficacy and performance outcome expectations significantly impact usage. Also, in virtual environments such as a Metaverse, a strong correlation has been proven between knowledge-sharing self-efficacy and knowledge-sharing behavior and personal outcome expectations and knowledge-sharing behavior (Hsu et al. 2007). Furthermore, previous HCI studies have found a strong positive influence of the perceived functionality of an interface on its perceived usefulness (Cho et al. 2009). Therefore, since we assume that the belief in success of the rich Metaverse authoring tool is higher, we hypothesize that:

H2: *The perceived usefulness of the rich Metaverse authoring tool is higher than the reduced Metaverse authoring tool*

The creation of user-generated Metaverse content has a major impact on self-efficacy, as this is closely linked to the enactive mastery experiences. The enactive mastery experiences are the biggest influencing factors on self-efficacy, as they provide the most reliable evidence of whether a user can muster all the resources to accomplish a task successfully (Bandura 1997). Enactive mastery experiences and the creation of user-generated Metaverse content are closely related, because users can create content through their own efforts and actions, such as writing a blog or creating videos, which results in a resilient sense of self-efficacy. In the process of creating user-generated Metaverse content, users are actively involved in achieving an outcome that promotes the acquisition of generative skills (Bandura 1997). Since with both Metaverse authoring tools, novice users can create Metaverse content on their own, the enactive mastery experience will probably remain unchanged. However, since we expect the rich metaverse authoring tool to have a positive impact on both the belief in success and the outcome expectations, we hypothesize that:

H3: *The Metaverse self-efficacy of the rich Metaverse authoring tool is higher than the reduced Metaverse authoring tool.*

Task performance is a key element of Bandura (1986) SCT because both self-efficacy and outcome expectations are closely related to actual task performance. Thus, users with high self-efficacy and positive outcome expectations approach tasks with greater confidence and motivation and persevere in the face of challenges or obstacles, which can lead to better task performance or a higher level of achievement (Bandura 1997). This assumption of SCT has been demonstrated in several studies from different disciplines (Lent et al. 1994; Tams et al. 2018). Therefore, since we assume that the self-efficacy and the perceived functionality of the rich Metaverse authoring tool are higher, we hypothesize that:

H4: *The task performance of the rich Metaverse authoring tool is higher than that of the reduced Metaverse authoring tool.*

In the lab experiment, we used a between-subjects design to test our hypotheses, with different participants testing one of the two Metaverse authoring tools. We chose a between-subjects design to minimize possible learning effects when the same participants use both Metaverse authoring tools sequentially to create instruction, as repetition could introduce bias into the collected data.

As part of our experiment, we collected qualitative and quantitative data using our Metaverse authoring tools. The task performance of the XR-based process guidance systems was evaluated as a dependent variable. In addition, participants evaluated self-efficacy, perceived functionality, and perceived usefulness through self-reports as part of the post-experiment survey. As an independent variable, the feature set of the Metaverse authoring tool was examined using two AR authoring tool prototypes with different levels of richness.

Setup and Procedure

At the beginning of each experiment session, we briefed our participants about our research objective - evaluating our Metaverse authoring tool - and the experimental procedure. In addition, a pre-experiment written survey was used to collect demographic data and insights into participants' previous experiences with XR.

Before starting the experiment, we demonstrated the Metaverse authoring tool to the participants, explaining its features and how to use it. After introducing the tool, a simple demonstration task was presented to the participants. Here the participants had to create content (2D and 3D) independently and then manipulate the 3D content in the real environment. The task was considered complete when the users stated they understood how to use the tool. After this introduction to the tool and demonstration task, no further information on how to use the tool was provided to the participants.

Participants were randomly assigned to one of the two groups (rich metaverse authoring tool or reduced metaverse authoring tool). As the main task of the experiment, we requested participants to assemble a 2x2 IKEA KALLAX shelf following IKEA's paper-based instructions, which contain eight assembly steps. Next, we asked participants to use the Metaverse authoring tool to create an XR-based process guidance system, which means replicating the eight steps of the paper-based instruction and improving this instruction through XR visualizations. After reading this task to the participants, we briefly showed them where each shelf component was placed. The placement of the components was identical for each experiment session. Participants were given 20 minutes to create their XR-based process guidance system. The experimental task was completed when it was completed or when the time ran out.

Data Collection and Sample

We asked participants to complete a post-experiment survey. We used the internal computer self-efficacy questionnaire from Thatcher et al. (2008) to measure self-efficacy. To collect data on the perceived usefulness of the tool, we used the scale of perceived usefulness by Wixom and Todd (2005). The task performance is based on the average of two XR authoring experts' ratings for the XR-based process guidance systems created by the experiment participants.

A total of 57 participants took part in the laboratory experiment. We excluded 2 speeders and 5 participants who did not complete the questionnaire. Of the 50 participants, 19 are male, and 31 are female, with an average age of 21.86. Of these student participants, 45 are enrolled in business administration and 5 in industrial engineering. Although participation in the experiment was voluntary as a reward, participants received three bonus points for a written exam. Regarding their previous experience with XR, 38 participants stated that they have experience using XR to varying degrees, mainly XR games, social media filters, and shopping applications. Twelve participants indicated that they had never used any XR application before. 8 participants stated that they'd developed XR applications before. None of the participants used an XR authoring tool before this study. A total of 26 participants used the rich Metaverse authoring tool and 24 participants used the reduced Metaverse authoring tool.

Results

We conducted a statistical analysis of the dependent variables collected through our laboratory experiment to test our hypotheses. Given that t-tests postulate normally distributed and homogeneous variables, we tested our variables for normal distribution with the Shapiro-Wilk-Test (Shapiro and Wilk 1965) and for homogeneity of variance using Levene's test (Levene 1960). The two tests show that a normal distribution and homogeneity can be assumed for all examined dependent variables, as all values are significant at the $\alpha < 0.05$ level. In testing our hypotheses, we examine the differences in the mean values of the two different design configurations. For this purpose, we compared the results of the two design configurations using a t-test. Table 3 summarizes the results of the comparison of the two design configurations.

	Reduced Tool		**Rich Tool**			
Dependent Variable	**M**	**SD**	**M**	**SD**	**t-test**	**Hypothesis**
Metaverse self-efficacy	4,3611	1,2274	3,9744	1,3562	1,054	H1: not supported
Perceived functionality	3,9028	0,8310	4,5	0,9809	-2,313*	H2: supported
Perceived usefulness	5,1875	0,8668	5,4423	0,8869	1,026	H3: not supported
Task performance	2,5833	0,7614	3,0769	0,6276	-2,509*	H4: supported
*p<0.05						
M = Mean; SD = standard derivation						

Table 3. Results of the t-test

Comparing the results of the two design configurations to test our second hypothesis (H1) shows that the actual functionality of the Metaverse authoring tool has a significantly higher positive effect on the performance-related outcome expectation (perceived functionality). Therefore, we assume that hypothesis H1 is supported.

The result of comparing the two design configurations to test our third hypothesis (H2) shows that the functionality of the Metaverse authoring tool has no significant positive effect on the users' perceived usefulness. We detected only a slight (but not statistically significant) difference in perceived usefulness. Since both outcome expectations and self-efficacy influence perceived usefulness (Cho et al. 2009; Hsu et al. 2007), and since we could not prove a significant difference for Metaverse self-efficacy, we assume that there is no statistical significance for perceived usefulness either. Therefore, we assume that hypothesis H2 is not supported.

The result of the comparison of the two design configurations to test our first hypothesis (H3) shows that the functionality of the Metaverse authoring tool has no significant positive effect on the users' Metaverse self-efficacy. Rather, an opposite effect can be observed: the users with the reduced tool show a higher (but not statistically significant) Metaverse-self efficacy.

The result of comparing] the two design configurations to test our fourth hypothesis (H4) shows that the functionality of the Metaverse authoring tool has a large significant positive impact on task performance in the chosen application domain (Industrial-Metaverse). Therefore, we assume that hypothesis H4 is supported.

Discussion

According to Gregor and Hevner (2013) DSR Knowledge Contribution Framework, our research can be classified as an improvement. We have developed a new solution for a known problem. The enormous impact of XR in organizations has been well-researched for a long time (Choi et al. 2022; Porter and Heppelmann 2017). However, XR has not yet been widely adopted in an industrial context. In line with the literature, we have identified that one possible reason may be XR content creation's complexity (Ashtari et al. 2020; Azuma 2016; Nebeling and Speicher 2018). Similar to software development (Maruping and Matook 2020), where no-code or low-code tools help novice users develop new applications, the Metaverse authoring tools help novice users create XR content. We have shown that the Metaverse authoring tools increase both the enactive mastery experience and the belief in success of novice users, which are important contributors to user engagement for the Industrial-Metaverse.

Compared to existing XR authoring tools like MinimalAR (Laviola et al. 2022), HoloWFM (Damarowsky and Kühnel 2022), or HoloFlows (Seiger et al. 2019), we developed a UMI (Metaverse authoring tool), which on the one hand, enables novice users by creating user-generated content to fully map digital twins (i.e., XR-based process guidance system) for the Industrial-Metaverse and on the other hand enables different novice users to use these digital twins to carry out their work in a process-compliant manner. With the proposed design of the UMI, we first contribute to the call of the research by Dwivedi et al. (2022), for which goals and under which conditions VR or AR represents the more effective user interface and which hardware is best suited for this application context. On the other hand, we support the development of immersive, interactive, and persistent 3D Metaverse applications through our theoretically based design principles instantiated in a software artifact.

Self-Efficacy is an important aspect of the design of an interface. A lack of self-efficacy can have serious consequences for the acceptance and use of an interface (Schymik et al. 2017). For example, unsuccessful experiences using technologies negatively impact learning new technologies (Johnson et al. 2016). Therefore, the design of interfaces that positively influence self-efficacy is a central design aspect. This study aimed to identify the key sources of self-efficacy for the UMI in the context of the Industrial-Metaverse. In this study, we investigated how the belief in success affects self-efficacy. Although we found a significant difference in the different rich AR authoring tools, we surprisingly did not find a difference in the actual self-efficacy. This could be due to the fact that the belief in success is only one of three sources of self-efficacy. The strongest source of self-efficacy is the enactive mastery experience and is part of both the rich and the reduced authoring tools, as both tools allow users to create metaverse content on their own. In a third design cycle, it would be very interesting to explore how the enactive mastery experience (i.e., the strongest of the self-efficacy sources) affects the creation instead of using the Metaverse content.

Although a significant positive influence of belief in success and perceived functionality on outcome expectations associated with perceived usefulness has been demonstrated in the literature (Cho et al. 2009), we could not confirm this significant influence in our study. We measured a slight but not significant impact. A possible reason for this deviation could be that the participants of the laboratory study had to create an application for the Industrial-Metaverse without having any relation to this context. For participants to evaluate the usefulness of a created application for the Industrial-Metaverse, they need to know the environment and influencing factors associated with the context. This challenge can be addressed through a real-world evaluation of different industrial companies in the third design cycle (Venable et al. 2016).

The understanding of the concept of self-efficacy in the context of the Industrial-Metaverse was broadened and contextualized. To the best of our knowledge, our DSR project is the first to consider user-generated content creation and the associated self-efficacy in the context of the Metaverse. We provide prescriptive knowledge about how the type of content and user interactions in constructed environments affect user engagement. We present a software artifact as a UMI that enables both the creation and use of Metaverse content through three software components (i.e., 3D authoring environment, 2D node editor, and viewer mode) and two theoretically grounded design principles that provide prescriptive knowledge about the impact of self-efficacy in the Industrial-Metaverse.

We were able to use the SCT by contextualizing it in the Metaverse to make a theoretical contribution to the design of UMI, which enables the creation and utilization of Industrial-Metaverse content. We have extended SCT in several ways: in line with internet (Eastin and LaRose 2000) and computer (Compeau and Higgins 1995) self-efficacy, our study has shown that self-efficacy greatly impacts users' intention to contribute to the Metaverse in the context of the Industrial-Metaverse. Existing research on the impact of self-efficacy in virtual teams (Hsu et al. 2007; Pellas 2014) has examined this impact on screen-based interfaces. Our research extends SCT by examining the impact of novice users' self-efficacy when interacting with XR interfaces. Self-efficacy in Metaverse can be distinguished from self-efficacy on the internet, as the use of XR interfaces confronts users with specific challenges, such as necessary spatial knowledge (Nebeling and Speicher 2018). The belief that one can successfully perform a set of behaviors required to use and create Metaverse content goes beyond basic PC, application, and internet skills.

Limitations and Future Research

Although we conducted the DSR project and evaluation described in this research according to established guidelines, there are limitations that require further research. First of all, despite a significant difference in belief in success, we could not identify a difference in self-efficacy. A possible reason for this could be that self-efficacy is closely linked to the cognitive abilities of the users (Bandura 1997), and increasing functionality also leads to an increased mental load. Thus, the lower self-efficacy when using the rich Metaverse authoring tool might also be caused by other theories, such as the Cognitive Load Theory (CLT) (Sweller 1988) or the Media Richness Theory (Daft and Lengel 1986). Therefore, for future research, we recommend considering core CLT aspects such as information overload or split-attention effects when creating user-generated Metaverse content. Next, the DPs we have formulated are only valid for XR interfaces for the Industrial-Metaverse. It cannot be assumed that our DPs are valid on screen-based or VR interfaces which are often associated with the Metaverse in the IS literature without adaptations. Therefore, for future research, we recommend verifying the validity of our two DPs using screen-based or VR Metaverse applications. An additional aspect is that the DPs we propose only refer to the Metaverse authoring tools used by novice users. It cannot be assumed that they are also valid for Metaverse authoring tools used by AR experts. Another limitation to mention is that the evaluation was conducted only with participants who do not correspond to the target group (i.e., service technicians). In order for the results to be richer and more generalizable, the evaluation must be conducted with participants from the target audience. Although two AR authoring experts evaluated the quality of XR instructions created by participants, a representative target group may perceive the quality of XR-based instructions differently. In a two-stage evaluation, the XR-based instructions created by the domain experts could be assessed by other domain experts, which could lead to new and representative results. Finally, it is important to note that the research was conducted from a socio-technical perspective. Looking at the same research from a purely technical perspective such as software interactive interfaces designs could lead to different DPs.

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