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The Schematization of XR Technologies in the Context of Collaborative Design

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Abstract. Recently, the concept of Industry 5.0 has been introduced to complement, among other things, Industry 4.0's focus on efficiency and productivity with a focus on humans in digital design and production processes. The inclusion of human interaction with digital realities, extended reality (XR) technologies, such as augmented reality (AR) and virtual reality (VR), can play an essential role in Industry 5.0. While rapid advances in XR technologies are solidifying and finding their place in the product and production development process, terminology and classification scheme remain under-determined. As a result, there have been numerous classifications of XR technologies from different perspectives, but little widespread agreement. They have been classified by their level of immersion or how well they meet a specific purpose (such as training). In addition to that, the classifications are usually made for one particular field (e.g. marketing, healthcare, engineering, architecture, among others). Therefore, to set the basis for future research, it is essential to identify and outline the dimensions that intervene in product and production design in regards to XR facilitated collaboration. With the ideas proposed in this paper, we want to identify basic concepts that classify a collaborative XR system by analyzing how users interact with the environment and other users. Our motivation is that collaborative design involves not only the physical dimension but also a social dimension. Defining when an XR system contributes to increasing social and/or physical presence could clarify and simplify its categorization.

Keywords. Virtual Reality, Augmented Reality, Extended Reality, Collaborative design

1. Introduction

Recently, the concept of Industry 5.0 has been introduced to clarify Industry 4.0's focus on efficiency and productivity with a focus on humans in design and production processes. According to the EU, Industry 5.0 complements the concept of Industry 4.0 but putting research and innovation at the service of the transition to a sustainable, human-centric and resilient European industry [1]. While there are many technologies involved in the manifestation of Industry 4.0 and 5.0, one cluster of technologies that are often discussed is extended reality (XR) technologies. XR is an umbrella term that has become used to refer to virtual reality (VR), augmented reality (AR), and mixed reality (MR) technologies. The lines that separate the individual XR technologies can be blurry, and several research groups have suggested definitions and classifications of these terms [1-4]. Some definitions focus on specific hardware or software features of XR systems. In contrast, others focus on how interactions mediate between users and virtual

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environments, as in the Virtuality continuum proposed by Milgram and Kishino [4] (Figure 1).

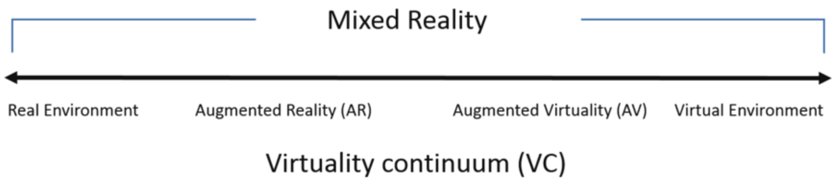

Figure 1. Virtuality continuum [2].

As industries adopt the goals of Industry 5.0, they might begin to introduce XR technologies to create a tighter interface between humans, digital tools and virtual environments. The application areas for XR are diverse, including training, meeting, collaboration, visualization, design, and testing. As XR technologies become increasingly accessible, it becomes essential to compare and decide which technologies fit a given application context and user group. Often recommendations regarding technologies are formulated in terms of expected use cases and general industry contexts. Focusing on specific applications can help avoid comparisons that are not valuable to stakeholders; as such, it is often preferable to explore categorizations and metrics of XR systems within candidate use contexts (e.g. healthcare or industry), although there are attempts to define more general ones

Categorizing hardware or software technologies into clusters can help to some extent but do not typically focus on the user's kind of interactive experience to accomplish a given task. Building a 3D digital prototype may differ between AR (where the real world is partially visible) and VR (where the real world is entirely obscured). However, this kind of distinction between systems only provides insight into what is visible to the user and the possible type of immersion. Immersion, in this case, is a measure of what percentage of a user's senses are filled with virtual information [3]. Immersion may indicate the number of digital interactions possible in a given technology but not the quality of those interactions. A metric that may provide insight into digital interaction experiences is *presence*. Presence is a concept that has been important in XR research since at least the 1980s [4]. With some oversimplification, presence is the experience of the virtual world *as if* it were the actual world. In the context of design, presence can assess how close interaction with a digital artifact in XR will align with similar interactions with the real artifact in the real world. Moreover, presence can provide insights into interactions and experiences of the design process. This latter point is crucial in collaborative design, where multiple stakeholders contribute to the design process.

Collaborative design can be understood as the decision process beginning with the conception of a product and moving through various design iterations where multiple designers work together to integrate the perspectives of multiple stakeholders. Collaborative design often requires regular meetings, user testing in various environments, and careful coordination of design phases and steps. XR can be a valuable tool for reducing the number of in-person meetings and allow for greater access to insights for diverse stakeholders in a wide range of contexts (simulated and real). In this paper, we expose the idea that presence is an essential dimension for classifying XR systems for deciding which XR tools and technologies are suitable and beneficial to specific collaborative design processes. We provide a preliminary overview of work defining presence and distinguishing it from immersion. We then discuss methods for measuring different kinds of presence. We conclude with a discussion of how presence can be used to compare XR technologies and, importantly, how the concept of presence could also be applied to collaborative design processes to characterize the needs of designers and other stakeholders in the design process.

2. Presence and immersion

Many definitions for presence have been proposed, though there is no specific, widely accepted definition. The concept of presence was introduced in 1980 in the context of telepresence [4]. Presence in this context was related to the feeling of the operators when operating machinery remotely, often using cameras and screen-based presentations of the remote machinery's context. Witmer and Singer defined presence in 1998 as relating to this initial concept of presence and teleoperators: "the subjective experience of being in one place or environment, even when one is physically situated in another" [5]. Steuer gave one early definition of presence in the context of VR: "the extent to which one feels present in the mediated environment, rather than in the immediate physical environment" [6]. A more comprehensive definition of presence was developed by approximately 200 scholars in an online discussion about presence:

> Presence (a shortened version of the term "telepresence") is a psychological state or subjective perception in which even though part or all of an individual's current experience is generated by and/or filtered through human-made technology, part or all of the individual's perception fails to accurately acknowledge the role of the technology in the experience. Except in the most extreme cases, the individual can indicate correctly that s/he is using the technology, but at "some level" and to "some degree," her/his perceptions overlook that knowledge and objects, events, entities, and environments are perceived as if the technology was not involved in the experience. Experience is defined as a person's observation of and/or interaction with objects, entities, and/or events in her/his environment; perception, the result of perceiving, is defined as a meaningful interpretation of experience [7].

This more extended definition helps clarify what many researchers are reaching for when discussing presence and how difficult it can be to capture what that feeling is in words. While each of the definitions so far has its strengths and weaknesses, we will follow the definition of presence introduced by Kwan Min Lee in 2004: "psychological state in which virtual objects are experienced as actual objects in sensory or non-sensory ways" [10]. This definition is helpful for XR collaborative design because it is extended to apply to three dimensions of presence which are:

- *Physical presence*: psychological state in which virtual physical objects are experienced as actual physical objects in sensory or non-sensory ways.
- *Social presence*: psychological state in which virtual social actors are experienced as actual social actors in sensory or non-sensory ways.
- *Self-presence*: psychological state in which virtual self are experienced as actual self in sensory or non-sensory ways.

Understanding a collaborative design process and what tools and technologies best support that process requires consideration of more than just the interaction between product and designer. The collaborative design also includes interactions between designers that can interact with (and between) stakeholders. Thus, both the physical and social presence dimensions should be considered when considering XR technologies for collaborative design. Moreover, some XR design activities, such as testing products in a virtual environment, would likely benefit from a higher feeling of self-presence.

Presence should not be confused with immersion. As mentioned above, immersion measures how much one or several senses are "taken up" by a digital experience. Immersion can be related to the technological features that cause a flow state between the virtual environment and the user. More sensation from the digital environment may result in a greater connection to the digital environment. Immersion is mainly related to senses, and it is an objective measure of sensory feedback provided by technology. Presence and immersion are often related and may even be proportional to one another, in that greater immersion often accompanies a greater feeling of presence and vice versa.

3. The measure of presence and factors that influence the presence

While presence has been discussed since the early 1980s and many definitions have been suggested, few measures of presence have been developed and validated. Further, a lot of the research into presence in XR was carried in the early 2000s, when even the best VR technology was significantly limited compared to many of today's consumer-grade systems (i.e., narrower field of view, lower frame rate, lower resolution, higher weight, less content, less comfortable, etc.). In the early 2010s, XR technologies underwent a paradigm shift that resulted in a significant technological advance and cost reduction. While XR research on presence prior to 2015 should not be ignored, it should also be carefully considered in its original context and thoughtfully applied and re-validated with modern XR systems. Thus, while presence is a valuable dimension of XR for collaborative design, measuring and validating presence is ongoing and rapidly developing.

Physical presence has been measured in various ways, including questionnaires, interviews, and physiological responses. Research regarding measures of physical presence date from at least the '90s. One of the first studies developed a 6-item questionnaire to measure the feeling of physical presence and a 7-item questionnaire to measure the fidelity of interactions in VR when the refresh rate was changed [9]. Witmer and Singer [6] also designed what they called a "Presence Questionnaire" to measure the physical presence in VR as well as an "Immersive Tendencies Questionnaire" to measure the differences in behavioural tendencies of the participants when they experience different levels of physical presence. Witmer and Singer's questionnaires seemed to indicate correlations between physical presence and immersion. They also observed a weak but consistent correlation between task performance and their measure of physical presence, indicating that task performance improved with a physical presence. Slater, McCarthy and Maringelli also developed questionnaires to explore physical presence [10], finding a positive correlation between physical presence and amount of body movement. They also identified a correlation between task complexity and gender, with women reporting a higher feeling of physical presence when performing more complex tasks in a virtual environment. There is criticism around using questionnaires to measure physical presence. Some researchers argue that measuring physical presence with questionnaires post-experience can lead to a significant bias and inaccurate data [11]. One way to address this concern is to compare participant responses to the questionnaires during a VR experience and after a VR experience. This approach indicates that responses during and after are similar, although there is less variability when questionnaires are used during the experience [12]. There is also some research relating to physiological responses. This research aims to avoid subjectivism in measuring physical presence by tying physical presence to physiological measures such as heart rate, blood pressure and galvanic skin response [13]. Grassini and Laumann did a systematic literature review about the relation between questionnaires measures and physiological correlations of presence [14]. They concluded that most of the academics had chosen questionnaires, with Witmer and Singer's Presence Questionnaire being the most prevalent. Among the physiological measures, electroencephalography (EEG) was the most frequently used. Grassini and Laumann also mention that at the current state of research, no physiological measure has collected enough evidence to be considered "good enough" to be reliably used alone, without the user giving their subjective evaluation of the experience [14]. Generally, presence studies find a positive correlation between the realism, interactivity level of the virtual environment, technology level, etc., and the feeling of physical presence

There has been some research into social presence in XR, but this area is underexplored compared to physical presence in XR. Research has shown that a higher level of immersion or physical presence does not necessarily relate to a higher feeling of social presence. The main difference between physical and social presence is that it requires a co-present entity that one can readily take the intentional stance towards. When there is another intentional agent, a "person" of some kind, one can experience a social presence in the digital environment. The other agent may be a natural person, either in the same room or joining remotely, or an artificial agent of some kind. The research into social presence indicates that the experience of social presence may be correlated to both physical presence and psychological distance between the subjects. Regarding virtual environments, qualities that lead participants to perceive that they are together with another person seem essential to achieve a social presence [15]. There is less research into the experience of social presence across XR technologies and how the specific hardware affects or relates to social presence.

There is less research relating to self-presence and its measure, though questionnaires seem to be the primary method for measurement as with other types of presence. A related concept of embodiment is likely related and, in some cases, the same as self-presence, though the similarity between these concepts is not guaranteed. Rabindra Ayyan Ratan and Béatrice Hasler developed what they called the Standard Self-presence Questionnaire [16]. This same questionnaire was used to measure self-presence in collaborative environments [17]. They found that one's virtual body seems not to affect self-presence. In addition, they also concluded that social presence seems to be related to self-presence.

4. Presence in XR collaborative design

Due to the numerous collaborative situations involved, collaborative XR design systems can be very complicated to put together and develop. For instance, a meeting using XR to discuss comfort aspects of vehicle seats may involve different considerations than a meeting using XR to discuss the impacts of changes to steering wheel configurations on driver visibility. The discussion of comfort may include looking at seat shape in detail, perhaps looking inside the seat with some form of virtual x-ray or cutaway visualization. A physical prototype, combined with AR or MR, may be helpful, but it should have features relevant to comfort. Driver visibility, on the other hand, may require a model of the entire vehicle, which the meeting participants can sit inside of and walk around. These two meetings might require different levels of presence to have a successful outcome. Moreover, not all the participants in each meeting might require the same level of either physical, social or self-presence to play their role in the meeting successfully.

Moreover, collaborative XR systems are usually asymmetric (i.e. different users across the team use different XR equipment [18]). In design teams, not everyone in the collaborative process has the same task or equipment. Moreover, different tasks usually involve different equipment (especially if we consider that XR technologies have a specific purpose). For example, an ergonomics team that assesses a product's physical and cognitive efficiency likely requires various types of body tracking systems and high-fidelity VR equipment. In contrast, the mechanical engineering team who design 3D models of mechanical parts might require versatile VR visualization equipment to seamlessly step in and out of virtual meetings to discuss design aspects. This asymmetry in the technology used also implies an asymmetry in the feeling of presence. At the same time, some users might have a high feeling of presence (both social and physical), others might have a lower feeling of presence. This is not undesirable; it can be desirable if each role participating in the design process has what is needed to perform that task most efficiently and effectively. Following the ergonomics team and the mechanical designers' example, the ergonomists can require a high level of physical and self-presence to experience the product as a user would do to run usability tests and ergonomics analyses. On the other hand, the mechanical designers' team does not require those physical or self-presence levels. However, they would need certain levels of social presence to have productive meetings in the virtual environment.

Therefore, different types of collaborations will have different kinds of necessities. Meetings require a higher feeling of social presence to be engaging [19], and design tasks require a higher sense of physical presence to be beneficial [20]. Therefore, if we identified what is needed to engage a higher feeling of social and physical presence and to which extent each type of presence is required in each situation, the development of XR collaborative systems could potentially be more efficient. They could be classified in a better way. To the best of our knowledge, there are very few XR collaborative systems developed or conceptualized with the concept of presence as a basis.

4.1. Example of tackling a situation with the proposed idea

In practice, identifying the right XR technologies for a collaborative design process should involve considering the type and amount of presence required for the design process. In order to further clarify how presence may relate to different XR design scenarios and how thinking in terms of presence leads to some important questions, we will briefly consider two common types of multi-user XR setup.

Figures 2 and 3 show two different collaborative situations that could occur during a collaborative process. In situation one, the users are together in the virtual environment. They can see a representation of each other, and they hear each other.

Figure 2. Collaborative situation 1.

The set-up in situation two is similar, except that the users share physical space and virtual space. They also can see a representation of each other in the virtual environment; however, they hear each other through the real world.

While in situation one, all interaction is mediated through a virtual environment, in situation two, the visual interaction occurs in the virtual environment, and the auditive interaction occurs in the physical environment.

Figure 3. Collaborative situation 2.

The feeling of presence will be different in each scenario, and most likely, each user's outcome and experience will be different. How does each type of situation affect the feeling of presence of each user? How does the sense of presence of each user affect their performance in the virtual environment? A collaborative design system should handle these two situations in a way that feels natural to the users to collaborate efficiently.

5. Conclusion

In this paper, we propose that in deciding on XR technologies to implement in collaborative design contexts, physical, social and self-presence should be considered. Translating a collaborative design process to an XR environment can be challenging, especially considering the number of interactions that can occur. Identifying what kind of presence is needed for a given collaborative design context to appropriate technologies according to the type of presence they create could be a valuable idea to approach this problem.

While there is still no widely agreed upon and validated measure of presence, we suggest that identifying and validating a measure of presence will be useful for collaborative XR design as presence might be a critical dimension for deciding which kind of design context or technology that might be more beneficial. In essence, we hypothesize that the requirements on a given collaborative design context, the factors of the virtual environment that need to be adapted, or the equipment that would be best may be well supported by the concept of presence.

Much research was carried in the field of presence in the 90s and early 00s. Current research incorporates many of the ideas and theories formulated back then. However, more research and unification around the concept of presence is needed [14]. Further conceptualization and measures on the feeling of physical, social and self-presence can be especially beneficial to apply the ideas proposed in this paper.

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