The Effects of Virtualization on Connectedness, Presence, and Immersion: A Mixed-Methods Comparison of Real, Mixed, and Virtual Environments

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***Abstract*— Virtual environments are increasingly integrated into diverse domains, redefining how individuals perceive and interact with their surroundings. These environments hold significant potential to influence human experiences, particularly through the dimensions of presence, connectedness, and immersion. Understanding these concepts is essential for optimizing the design and application of virtual systems in education, healthcare, and other societal contexts. This research examines the impact of virtualization on the perception of presence, connectedness, and immersion by comparing real-world, mixed, and fully virtual environments using a mixed-methods approach. The qualitative analysis engaged 5 participants exploring object interactions across real, MR, and VR settings, while the quantitative analysis, involving 31 participants, assessed introductory games specifically in MR and VR scenarios. Results indicate that connectedness is strongest in real-world scenarios, diminishing with increased virtualization, while immersion and presence show no significant variance across environments. The lack of physical feedback and reduced sensory stimuli in VR and MR environments were primary contributors to these differences. The findings underscore the necessity of real interactions in education and healthcare, suggesting consumer protection measures for Virtual and Mixed Reality environments.**

Keywords*— *Extended Reality; Presence; Immersion; Connectedness.

I. Introduction

Mixed Reality (MR) and Virtual Reality (VR) create new realities that deeply impact our experiences. For instance, VR enables immersive training simulations for medical personnel [1] and revolutionizes customer experiences in retail [2]. In the entertainment industry, VR introduces new forms of cinema and interactive experiences [3]. MR is used to create realistic educational environments that enhance learners' presence and engagement [4]. This raises the question of how these technologies influence fundamental aspects of our reality.

This study examines the key concepts of presence, immersion, and connectedness in the context of VR and MR to understand how different levels of virtualization affect our perception and interactions. The significance of this research lies in gaining a deeper understanding of how these technologies shape human experience and behavior. The impact on the perception of presence, immersion, and connectedness is particularly important, as these factors significantly alter user experience in VR and MR applications, as this study demonstrates.

Despite numerous studies analyzing individual aspects of VR and MR [5][6], comprehensive investigations comparing these technologies with each other and with the real world are lacking. This study addresses this research gap by comparatively examining how experienced connectedness, presence, and immersion differ in VR, MR, and real environments.

The primary aim of this research is to systematically explore the impact of Extended Reality (XR) on experiential factors such as connectedness, presence, and immersion using a mixed-methods framework. This objective is subdivided into two specific goals: (1) The qualitative goal focuses on exploring participant perceptions of XR in terms of presence, immersion, and connectedness, aiming to extract deep insights into subjective experiences across diverse environments. Key themes and patterns discerned from this analysis inform the hypothesis development. This qualitative analysis identifies central themes and patterns that serve as the basis for hypothesis formation. (2) The quantitative goal investigates whether varying levels of environmental virtualization significantly affect participants' perceived connectedness to themselves, others, and the broader world. The qualitative analysis suggests that the perception of connectedness may be influenced by the degree of virtualization. These indications are tested in the quantitative analysis, with particular attention to the dimensions of connectedness.

These objectives lead to specific research questions. The qualitative research questions are: How is XR perceived in terms of presence, immersion, and connectedness by the participants? What central themes and patterns can be identified from the subjective experiences and perceptions of participants in various Virtual Environments (VE)? The quantitative research question is: Does the degree of virtualization of an environment significantly influence the perception of experienced connectedness? These questions guide the qualitative and quantitative investigation to gain a comprehensive understanding of the impact of XR on the experience of connectedness, presence, and immersion.

The study is divided into six sections to ensure a clear and comprehensible structure. In Section 1, the study

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introduces the topic and outlines the objectives of the study, explaining the specific research questions and the methodology used to address them. Section 2 lays the theoretical foundation, focusing on the concepts of connectedness, presence, and immersion. Section 3 describes the methodological approach, explaining the use of a mixed-methods methodology that includes both qualitative and quantitative approaches. It details the selection of methods, data collection, and analysis to ensure the research's transparency and validity. Section 4 presents the study's results, starting with the qualitative analysis followed by the quantitative analysis. It includes descriptive statistics and inferential statistical tests conducted to verify the hypotheses. Section 5 discusses the results in the context of existing scientific literature, explaining the implications for theory and practice. It critically reflects on the study's methodological weaknesses, highlighting potential limitations. In Section 6, the study summarizes the key findings, emphasizes the relevance of the results for the development of XR technologies, and outlines future research directions. It demonstrates how VR and MR influence the sense of connectedness, presence, and immersion, and outlines practical applications.

II. Theoretical Foundations

A. *Definition and theoretical construct of connectedness*

This study explores the concept of connectedness based on the theoretical framework proposed by Watts et al. [7]. According to Watts et al. [7], connectedness is defined as a state of feeling connected to oneself, others, and the world. The dimension of self-connectedness is often experienced in therapeutic contexts and involves a deep sense of connection with one's senses, body, and emotions [7]. It arises through awareness, acceptance, and alignment of one's behavior with this awareness [8]. Social connectedness refers to the feeling of belonging and attachment to other people and communities [9]. Watts et al. [7] describe this as the view of oneself in relation to others, cognitive structures of interpersonal relationships, and the perception of isolation. Social relationships significantly contribute to physical and mental health and act as a protective factor against depression [7]. Connectedness with others is fostered through empathy and sharing emotional experiences [10]. Connectedness to the world is described as transpersonal experiences and a sense of connection to nature and a larger spiritual principle [7]. This dimension includes an expanded self-awareness that encompasses the individual's relationship with the world and the universe [7]. Phillips-Salimi et al. [11] also describe connectedness as a multidimensional concept involving emotional closeness to others, a sense of community and belonging, and engagement in social networks. Essential characteristics of these social relationships include intimacy, empathy, trust, and reciprocity [11].

B. *Definition and theoretical construct of presence*

Slater and Wilbur [12] describe presence as a multifaceted concept that conveys the subjective feeling of actually being in a specific environment, whether real or virtual. This state of consciousness can be related to immersion and the sensation of being in a particular setting. Presence affects aspects of autonomous responses and behavior in a VE [12].

According to Witmer and Singer [13], the feeling of presence in VEs depends on various factors, including the quality of sensory impressions and the technology's ability to mask physical reality. Presence is described as the subjective experience of truly being in an environment, even if the body is physically elsewhere. The authors believe that presence is a normal consciousness phenomenon requiring focused attention and is based on the interaction between sensory stimuli, environmental factors that promote engagement and immersion, and internal tendencies towards involvement [13]. The feeling of presence is often enhanced by immersion, which describes the technological properties that enable immersion in the virtual world [12].

Presence, as described by Slater and Wilbur [12] in their work A Framework for Immersive Virtual Environments (FIVE), is a central theoretical model in this analysis. This model is used as a theoretical construct to examine the subjective experience of presence in VEs. It provides a comprehensive framework for investigating the design of VEs. Slater and Wilbur [12] state that participants who experience a high level of presence should perceive the VE as a more engaging reality than the surrounding physical world. This intense feeling leads to the environment created by the displays being perceived as real places rather than mere seen images. Another important aspect of presence is the ability to remove the participant from everyday reality and place them in an alternative, self-contained world with its own actions and dynamics. This dimension of presence, which Slater and Wilbur call "plot," allows participants to act and interact in the VE, further enhancing the feeling of presence [12].

Slater [14] introduced Place Illusion (PI) and Plausibility Illusion (Psi), distinguishing between the sensation of being in a virtual space and the credibility of the scenario [14]. Later, Slater et al. [15] emphasized that both PI and Psi are essential for realistic user responses in virtual environments [15].

C. *Definition and theoretical construct of immersion*

Immersion is a central concept in the field of VEs. This thesis primarily utilizes the theoretical framework of Witmer and Singer to examine immersion. Witmer and Singer [13] define immersion as a psychological state where an individual perceives being surrounded by an environment, continuously receiving stimuli and experiences. Factors influencing immersion include isolation from the physical environment, perception of involvement in the VE, natural interaction and control capabilities, and the perception of self-movement within the VE. The use of head-mounted displays is crucial as they obscure the physical environment and create a sense of isolation. Additionally, natural interaction enhances immersion; when users can interact and control the VE naturally, their immersion is strengthened. The perception of self-movement, or the feeling of

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navigating within the VE, is also a key aspect of immersion [13].

Slater [16] offers another theoretical construct for explaining immersion. He defines immersion as the ability of a VR system to simulate a realistic VE. The better the system mimics reality, the higher the degree of immersion. A system that involves the entire body in perception offers higher immersion than one that only allows viewing a screen. A system's capacity to replicate another is recognized as a fundamental metric for assessing immersion. A highly immersive system could simulate the experience of a less immersive one. Researchers can use these differences to study how the illusion of being in the virtual world and people's reactions to events in the virtual world are influenced by the degree of immersion [16].

Immersion is not merely a property of the system or technology enabling the experience. It is a state of deep mental engagement where awareness of the physical environment is reduced or completely dissociated due to a shift in attention [17].

Nilsson et al. [18] conduct a comprehensive analysis and categorize existing definitions of immersion into three categories: as a system property, as a subjective response to narrative content, or as a subjective response to challenges in VEs. This three-dimensional taxonomy is used to discuss how different theories of presence relate to various definitions of immersion [18].

D. Synergy of Connectedness, Immersion, and Presence

The study of connectedness, immersion, and presence is essential for a comprehensive understanding of user experience in various forms of reality, such as reality, MR and VR. These three aspects are closely interlinked and mutually reinforcing, enabling a profound analysis of the emotional and cognitive effects elicited by these different environments.

To further explore the complex relationships between these aspects, it is helpful to examine the role of immersion as a central component in VEs. Smith and Mulligan [19] note that various manipulations of immersion, such as field of view, audiovisual effects, and light realism, can have different impacts on memory and presence. Studies indicate that immersion in VR environments not only affects presence but also other factors like interactivity and user satisfaction. These findings are supported by Mütterlein [20], who investigates the interactions between immersion, presence, and interactivity in a VR context. Her study shows that both presence and interactivity significantly contribute to immersion, with interactivity further enhancing presence. Immersion proves to be an important predictor of user satisfaction in VEs [20]. Additionally, Servotte et al. [1] find that the feeling of presence in VR correlates with individual tendencies towards immersion. Advanced students with a higher tendency towards immersion report a stronger sense of presence. Despite an increase in stress levels during immersion, the sense of presence remains high and the level of cybersickness low [1]. These findings highlight that not only the technical design of the VR environment but also individual user differences play a crucial role in the emergence of presence and immersion.

Various factors can affect both the sense of presence and connectedness in VEs. McCreery et al. [21] find that continuous character development and socialization make the connectedness between the participant and their avatar so strong that it ultimately becomes more important for the sense of presence than media and environmental properties. A study by Young et al. [22] shows that VR can foster emotional connectedness through immersive experiences. By adopting the perspective of a protagonist in the first person and empathizing with their experiences through visual, auditory, and haptic elements, deep immersion is achieved. This intense immersion allows users to form a strong emotional bond with the protagonist, as they not only see and hear but also feel what the protagonist experiences [22].

E. Survey Instruments

For this study, specific questionnaires are selected and modified to collect both qualitative and quantitative data. The questionnaires used include the Watts Connectedness Scale (WCS) [23] for assessing connectedness, the Slater-Usoh-Steed (SUS) questionnaire [24] for measuring the sense of presence and the questionnaire by Tcha-Tokey et al. [25] for measuring immersion.

The WCS, developed by Watts et al. [7][23], measures three key dimensions of connectedness: connectedness to oneself, to others, and to the world. The scale assesses how strongly a person feels connected to their own senses, body, and emotions, as well as emotional closeness and a sense of community with others. Additionally, the WCS measures the feeling of belonging to nature and the global context, including spiritual and transpersonal connections [7][23]. A significant advantage of the WCS is that it captures multiple dimensions of connectedness simultaneously, allowing for a nuanced analysis of social experiences. This comprehensive approach ensures that all relevant dimensions of social and personal connectedness are considered, enabling a deeper and more differentiated analysis of participants' social experiences. The WCS is based on the theoretical foundations of Watts et al. [7]. The validity of the WCS questionnaire is confirmed through extensive testing, showing high correlations between the WCS scales and other related scales measuring psychological flexibility, well-being, social connectedness, nature connectedness, and anxiety [7]. These high correlations demonstrate the convergent validity of the WCS, indicating that the questionnaire reliably captures the various dimensions of connectedness.

The SUS questionnaire [24] is a recognized instrument for measuring the sense of presence in VEs and is used in various studies as a useful tool for differentiating experiences in real and virtual contexts. The questionnaire captures three key dimensions: the feeling of actually being in the VE, the extent to which the VE becomes the primary reality, and the memory of the VE as a real place. These measurements are closely related to the theoretical framework of the FIVE model by Slater and Wilbur, which is used to study presence [24].

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The questionnaire developed by Tcha-Tokey et al. [25] covers several key aspects of user experience, including presence, engagement, immersion, flow, usability, skill, emotion, experience consequence, judgment, and technology adoption [25]. However, for this study, only the section on immersion is selected, as it is concise and focused, precisely measuring the depth of participants' immersion experiences. The immersion section of the Tcha-Tokey et al. [25] questionnaire is based on the Immersion Tendency Questionnaire by Witmer and Singer [13], which forms the theoretical basis of this study's construct. The validation of the questionnaire shows reliability and sensitivity, even for the immersion section [25]. The specifically selected immersion section provides comprehensive insights into participants' immersion experiences despite its brevity, making it suitable for this study.

III. METHODOLOGY

A. Mixed-Methods Approach

For this study, selected questionnaires were used in both confirmatory quantitative and exploratory qualitative analyses. Modifications allowed for detailed qualitative insights into participants' subjective experiences, enhancing data analysis depth. Validated questionnaires increased reliability and validity. Hypotheses examined the impact of virtualization on perceived connectedness. Qualitative interviews provided insights into experiences in reality, MR, and VR, leading to two opposing hypotheses. These were tested and statistically evaluated using quantitative methods. Pilot testing validated and optimized questions, scenarios, and data collection methods. To ensure the generalizability of results, no restrictions were placed on demographic variables, allowing for a diverse participant sample. Real-world experiences serve as a benchmark for evaluating immersion, presence, and connectedness in virtual and mixed settings.

B. Qualitative Methodology

The qualitative methodology of this study explored how presence, immersion, and connectedness are experienced in real, MR, and VR environments. An experimental approach was used, ensuring maximum possible comparability across settings. Although the tasks do not cover the entire spectrum of XR applications, they were carefully selected to reflect realistic use cases, enhancing ecological validity where possible. Each participant completed tasks in all three realities—utilizing real objects in the real environment, a combination of real and virtual elements in MR, and solely virtual elements in VR. In the object-finding task, participants located and placed tennis balls using real, mixed, or virtual elements depending on the environment. For the painting task, they engaged with either real artworks or virtual representations to assess emotional responses and presence. The plant-watering task involved using real and virtual watering cans to tend to real or virtual plants.

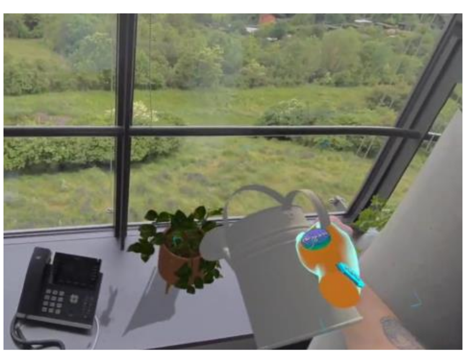

Figure 1. Plant casting task in the MR (created with Figmin XR)

The MR environment used the Meta Quest 3 [26], while the VR environment used the Oculus Rift S [27]. The selection of these head-mounted displays was driven by optimization criteria for each specific application. Although different headsets were used, potential biases were minimized by selecting devices with comparable technical specifications and user experience characteristics. The VR experiment was conducted at the University of Applied Sciences Würzburg-Schweinfurt, using Unity [28] to construct an intricate representation of the physical space, alongside Sketchfab [29] models. Figmin XR [30] was used for MR tasks.

Strict ethical standards were maintained, with informed consent and anonymized data. Participants, aged 23 to 55, were selected based on VR and MR experience and technological affinity, resulting in 5 participants.

Semi-structured interviews, averaging 22 minutes per scenario, were conducted and transcribed manually. The interview guide followed Misoch's [31] recommendations, covering presence, immersion, and connectedness. Modified questionnaires were used, with closed questions converted into open-ended ones to gain more detailed insights. Presence questions were based on the SUS questionnaire [24], immersion questions on Tcha-Tokey et al. [25], and connectedness questions on the WCS [23].

Thematic coding identified patterns in participants' experiences across environments. Case summaries and descriptive analyses supported the findings.

C. Quantitative Methodology

The quantitative methodology aimed to systematically investigate perceived connectedness and the impact of virtualization. Based on qualitative insights, the null hypothesis (H_0) posited no impact of virtualization on connectedness, while the alternative hypothesis (H_1) suggested higher virtualization weakens this perception.

The quantitative component employed an experimental design, randomly assigning participants to MR or VR conditions to minimize order effects and facilitate causal inference. To ensure a comprehensive dataset, each participant engaged with all three scenarios, namely reality, MR, and VR. They completed standardized questionnaires reflecting on recent real-world experiences and then interacted with either MR or VR applications. The study was conducted in a controlled lab environment to ensure data comparability.

However, it is important to note that the scenarios were not fully comparable across environments. The applications

"First Encounter" [32] (MR) and "First Contact" [33] (VR) were chosen for their role as playful introduction games designed to familiarize users with the fundamental interactions of VR and MR using the Meta Quest 3. The selection of these applications was made because they simulate typical interactions and challenges encountered in real-world XR scenarios, thereby enhancing the ecological validity of the study and offering realistic interactions particularly relevant in the XR industry. The global VR market, estimated at $12.3 billion in 2023, is growing at a projected average annual growth rate of over 23%, with the gaming industry being a significant driver of this growth [34]. For the real-world scenario, participants were instructed: "Think of a moment when you recently discovered or explored something new." This instruction served as the real-world baseline, without the use of any specific app or task.

Strict ethical standards were maintained, with informed consent and anonymized data. Participants, aged 18 to 70, were recruited based on diverse backgrounds and technology experiences, resulting in 31 participants.

The variables examined included the degree of virtualization as the independent variable and perceived connectedness as the dependent variable, evaluated using the questionnaires outlined in the Survey Instruments Section. Immersion and presence were treated as secondary variables, also assessed using these instruments, and these measurements involved a sample of only 5 participants. Data analysis involved descriptive and inferential statistics using JASP [35]. The Shapiro-Wilk test was used to check data normality. Parametric tests (paired *t*-tests) were used for normally distributed data, while non-parametric tests (Wilcoxon signed-rank tests) were used for non-normally distributed data. A significance level of 0.05 was set.

This methodological approach facilitated valid insights into the effects of virtualization on connectedness. Statistical evaluations were conducted with significance determined at *p*-values below 0.05, and effect sizes calculated to ascertain practical relevance.

IV. RESULTS

A. Qualitative Results

The results revealed nuanced differences in the subjective experiences of participants, which were critically analyzed to identify recurring patterns and deviations.

The findings pertaining to presence underscored its dependence on attention, a sense of being, and the clarity of memory. In the real environment, participants demonstrated consistently high levels of attention, with their presence marked by an acute awareness of their surroundings and vividly clear memories of the experiences. The qualitative accounts suggest that the tangibility of the real environment and the natural continuity of interactions were instrumental in sustaining this strong sense of presence. In MR, presence remained robust yet exhibited slight variability due to the duality of real and virtual elements. While many participants appreciated the added richness of MR, they also noted occasional challenges in maintaining focus or seamlessly integrating the two layers of reality. By contrast, VR posed distinct challenges to presence, as some participants reported diminished attention or felt disconnected from the immersive environment, attributing these effects to its artificial nature or technological limitations. However, others found the novelty of the VR experience engaging, which heightened their attention and focus.

Immersion, a pivotal construct in the study, was deeply influenced by individual preferences and the participants' expectations of the environments. In VR, participants who perceived the virtual environment as sufficiently high-quality and engaging reported profound immersion, characterized by deep emotional and cognitive involvement. However, for others, technological shortcomings or a perceived lack of realism detracted from their ability to fully engage with the virtual environment. MR, while offering a more balanced integration of real-world familiarity and virtual novelty, elicited diverse responses. Several participants described MR as enabling a unique, albeit somewhat partial, sense of immersion, reflecting both the strengths and inherent limitations of blending real and virtual elements. The real environment, conversely, evoked a stable yet less dynamic form of immersion, anchored in the predictability of familiar settings.

Connectedness, encompassing emotional and physical bonds with oneself, others, and the broader environment, exhibited a clear inverse relationship with the degree of virtualization. Participants consistently reported the strongest feelings of connectedness in the real environment, which they attributed to direct sensory feedback, natural social interactions, and the inherent authenticity of their surroundings. In MR, connectedness was notably weaker, as participants often struggled to reconcile the duality of real and virtual elements. VR elicited the lowest levels of connectedness, with several participants describing a pronounced sense of isolation. This phenomenon was particularly evident in their qualitative accounts, where descriptions of VR environments frequently included metaphors of detachment and enclosure, such as being "sealed in a bubble" or "cut off from the outside world." These findings suggest that the abstraction inherent in virtual environments may undermine the fundamental human need for tangible and reciprocal interactions.

To build upon these findings, hypotheses were derived to formalize the observed relationships between virtualization and its effects on connectedness. The null hypothesis (H_0) posited that the degree of virtualization exerts no influence on connectedness across its various dimensions. In contrast, the alternative hypothesis (H_1) proposed that increasing levels of virtualization, from reality to MR and VR, progressively diminish connectedness. These hypotheses, while rooted in the qualitative observations, were designed to guide subsequent quantitative analyses, thereby enabling the systematic validation of theoretical assumptions.

The transition to a quantitative approach sought to empirically test these hypotheses through standardized instruments designed to measure presence, immersion, and connectedness across the three environments.

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TABLE I. *T*-TEST FOR PAIRED VARIABLES OF THE WCS

Variable 1	*Variable 2*	*t*	*p*	*Cohen's d*
WCS in reality	WCS in MR	5.798	< 0.001	1.041
WCS in reality	WCS in VR	5.321	< 0.001	0.956
WCS in MR	WCS in VR	-0.023	0.982	-0.004

B. *Quantitative Results*

The descriptive statistics indicated a clear decline in connectedness as the degree of virtualization increased. Connectedness to oneself, others, and the world was highest in reality, followed by MR and VR. For example, connectedness to oneself in reality had a mean of 66.253 (SD = 16.518) and a median of 67.833, compared to MR (M = 54.172, SD = 19.873) and VR (M = 54.871, SD = 15.165). Total connectedness scores followed a similar trend, with reality yielding the highest mean (M = 59.156, SD = 12.688) compared to MR (M = 45.125, SD = 10.116) and VR (M = 45.169, SD = 9.752).

Normality tests using the Shapiro-Wilk test showed that most paired differences adhered to a normal distribution ($p >$ 0.05), allowing for the use of paired t-tests in hypothesis testing. For non-normally distributed variables, the Wilcoxon signed-rank test was applied to ensure statistical rigor. The results highlighted significant differences in connectedness between reality and both MR and VR across all dimensions, while comparisons between MR and VR revealed negligible differences.

The paired t-tests demonstrated that reality consistently yielded significantly higher connectedness scores than both MR and VR for all dimensions of connectedness. Table I summarizes the paired t-test results for the WCS variables. For connectedness to oneself, comparisons between reality and MR (t = 2.876, p = 0.007, Cohen's d = 0.517) and between reality and VR (t = 2.882, p = 0.007, Cohen's d = 0.518) revealed statistically significant differences, indicating a marked reduction in self-connectedness as virtualization increased. A similar trend was observed for connectedness to others, with reality scoring significantly higher than MR (t = 3.510, p = 0.001, Cohen's d = 0.630) and VR (t = 4.512, p < 0.001, Cohen's d = 0.810). The differences were most pronounced for connectedness to the world, where reality also outperformed both MR (t = 5.519, p < 0.001, Cohen's d = 0.991) and VR (t = 3.608, p = 0.001, Cohen's d = 0.648). The aggregated total connectedness scores mirrored these findings, with reality scoring significantly higher than MR (t = 5.798, p < 0.001, Cohen's d = 1.041) and VR (t = 5.321, p < 0.001, Cohen's d = 0.956).

These results demonstrate that reality offers a consistently higher degree of connectedness across all dimensions compared to MR and VR. The effect sizes (Cohen's d), ranging from moderate (0.517) to large (1.041), underscore the substantial impact of virtualization on reducing connectedness.

In stark contrast, no significant differences were found between MR and VR for any dimension of connectedness. The paired t-tests for total connectedness (t = -0.023, p = 0.982, Cohen's d = -0.004) and connectedness to oneself (t = -0.190, p = 0.851, Cohen's d = -0.034) revealed negligible effects. Wilcoxon signed-rank tests further supported these findings for non-normally distributed variables, such as connectedness to others (p = 0.565) and connectedness to the world (p = 0.276), where no significant differences were detected.

As a result, the alternative hypothesis (H_1) is only partially supported. While the degree of virtualization significantly affects connectedness when comparing reality to MR or VR, it does not do so between MR and VR.

The quantitative analysis of immersion and presence was conducted with 5 out of 31 participants under reality, MR, and VR conditions. The Shapiro-Wilk test indicated normality for 27 out of 36 variable pairs (p > 0.05). Paired t-tests showed significant differences in 2 of 15 presence pairs, with reality showing higher presence than MR, and in 1 of 21 immersion pairs, with VR showing higher immersion than reality. Wilcoxon signed-rank tests showed no significant differences across any pairs.

V. DISCUSSION

A. *Interpretation of Qualitative Results*

The qualitative analysis provided detailed insights into participants' subjective experiences across different reality forms.

Presence varied across settings. Real-world environments often fostered stronger presence due to physical interaction and sensory feedback. Participants described vivid memories and high attentiveness. In VR, presence depended on familiarity with the tasks and the VE. Some participants felt deeply immersed when the VE was realistic, while others reported lower presence due to difficulty engaging with the virtual scenario. In MR, presence combined real and virtual elements, offering advantages like familiarity through physical elements but also challenges, such as confusion about the nature of objects.

Immersion measures the depth of engagement in a scenario. VR offered the highest immersion, supported by its isolating nature and ability to create a sense of self-involvement in the VE [13]. Participants noted deep engagement during VR tasks, enhanced by the immersive design. MR had moderate immersion due to its mix of real and virtual elements, which sometimes caused confusion. Real-world environments provided physical interaction but were perceived as less challenging, leading to lower immersion.

Connectedness revealed notable differences between the environments. Real-world settings fostered the strongest emotional and physical connections. Watts et al. [7] describe self-connectedness as the integration of sensory, bodily, and emotional experiences. Participants in real environments reported a stronger connection to their senses and emotions than in VR or MR. Social connectedness was also highest in real settings, attributed to physical interactions and immediate feedback. In VR, isolation was common, while MR retained moderate connectedness by incorporating real-world elements. Connections to a greater purpose or nature were weakest in virtual environments, as participants found the artificial settings less meaningful.

B. Interpretation of Quantitative Results

Quantitative analysis examined connectedness (to self, others, and the world), presence, and immersion.

Watts et al. [23] emphasize the importance of sensory and emotional integration for self-connectedness. The lack of physical feedback in VR and MR might have contributed to the lower scores. Furthermore, cognitive dissonance caused by latency or visual artifacts in virtual environments could have hindered participants' ability to engage deeply with their senses and emotions.

Physical proximity and immediate feedback in these environments facilitated stronger interpersonal bonds, consistent with Watts et al.'s [23] framework, which describes social connectedness as a relational and structural concept. In VR and MR, the artificial nature of interactions may have limited participants' ability to build similar connections, and the absence of immediate physical feedback could have contributed to weaker social connectedness.

Connectedness to the world, including self-transcendence, purpose, and nature connection [23], was examined across environments. Differences in sensory and emotional input may influence the depth of experiences, with real-world scenarios offering a richer context compared to the reduced authenticity of virtual environments.

As was the case with previous expectations, presence and immersion showed no significant differences between reality forms, though VR tended to offer more immersive experiences, and real-world settings slightly higher presence. These trends could reflect the influence of task design and individual familiarity with the environments.

The results clearly support the hypothesis that real environments foster the highest levels of connectedness. However, the underlying reasons for these differences might lie in the sensory and emotional authenticity of real environments, which could have facilitated deeper engagement across all dimensions of connectedness. In contrast, MR and VR seem to have provided similar but less impactful experiences, as no significant differences were observed between these two settings. The lack of a clear pattern in presence and immersion was unexpected.

C. Contextualizing Connectedness

Watts et al. [23] highlight the multidimensional nature of connectedness, including self-awareness, social ties, and global purpose. Previous studies suggest XR technologies enhance connectedness through empathy-driven experiences. For example, Schutte and Stilinović [36] found VR scenarios, such as a refugee documentary, significantly increased empathy compared to 2D media. Herrera et al. [37] demonstrated that VR experiences of homelessness foster long-lasting positive attitudes and increased social engagement. Additionally, Deighan et al. [38] explored VRChat as a tool for supporting social connectedness and well-being, highlighting the platform’s potential for mental health support. Similarly, Thabrew et al. [39] reported that immersive experiences could reduce social isolation and improve connectedness among hospitalized children and young people.

The concept of self-connectedness is also well-supported in VR research. Ganschow et al. [5] observed that perspective-taking exercises in VR enhanced self-continuity and emotional connection to one’s future self.

Connectedness to the world, specifically to nature, can also be enhanced through VR. Leung et al. [41] found that exposure to nature in immersive VR increased individuals' connectedness to nature, particularly among those with low affinity for natural environments. Additionally, Stepanova et al. [40] noted that VR simulations of the "Overview Effect"—a phenomenon experienced by astronauts viewing Earth from space—can evoke a profound sense of global connectedness and environmental responsibility.

These studies demonstrate XR's potential to enhance connectedness. However, when comparisons are made, they are typically limited to traditional media or conventional methods, such as perspective-taking exercises, empathy-building tasks, or self-reflection activities, rather than directly contrasting XR with real-world experiences. This limitation highlights the need for further research directly comparing XR and real environments.

D. Implications

In education, the empirical findings indicate that the strongest connectedness was observed in real environments, suggesting a substantiated prioritization of real interactions in learning settings to enhance the sense of connectedness. Strategies to enhance connectedness in virtual environments are crucial, focusing on methods such as fostering physical feedback mechanisms or incorporating real-world elements.

In healthcare, MR can enhance the effectiveness of medical education, training, diagnosis, and treatment, as well as strengthen doctor-patient relationships [42]. However, the study also demonstrated isolation effects in pure VR applications, highlighting the need for measures to mitigate these effects to improve therapeutic outcomes.

The results also underscore the necessity of addressing the reduced connectedness experienced by general consumers in XR technologies to safeguard their emotional well-being.

No significant differences in presence and immersion were found between VR, MR, and real environments, suggesting that VR and MR can offer comparable experiences. Further research is needed to address limitations in fostering emotional and social connectedness.

E. Limitations

This study faced several limitations that should be considered when interpreting the results.

The sample size and composition posed a key limitation. While the qualitative sample included 5 participants and the quantitative sample 31, these numbers might be insufficient for drawing generalizable conclusions. Although demographic diversity was ensured, future studies with larger and more varied samples could enhance the robustness of findings.

A notable methodological limitation was the design of scenarios for the virtualization levels. Despite careful replication, these tasks did not reflect typical use cases, potentially limiting the authenticity and applicability of MR and VR experiences to real-world scenarios.

In the quantitative analysis, standard introduction applications were used to ensure representative MR and VR experiences. However, these applications differed between conditions, restricting direct comparability. For instance, real-world experiences relied on participants recalling past events, which significantly depended on the nature of the memories themselves. This reliance may have influenced the comparability with MR and VR scenarios, as the type and context of the recalled memory could impact the measured variables. With more resources, improved research designs could potentially have led to more robust findings.

Another limitation was the absence of social interaction in the connectedness measurements. Scenarios lacked interaction with other users, reducing the ability to assess social connectedness. While efforts were made to cover all aspects of connectedness, resource constraints unfortunately limited the ability to address each aspect equally well. Future studies should include social components for a more comprehensive understanding of connectedness.

The use of the WCS scale introduced another constraint. Originally developed for general connectedness and validated in contexts such as psychedelic experiences [7], the WCS was not specifically designed for VR and MR. This limitation may have prevented it from capturing nuanced aspects of connectedness unique to these environments.

The quantitative analysis used limited statistical methods; additional techniques such as ANOVA or MANOVA could have provided deeper insights into variable relationships, especially if demographic factors were included.

Several factors, suggested by prior research as potentially influencing VR and MR experiences, were not examined in this study.

Consequently, claims regarding XR’s impact on connectedness should be made cautiously until sufficient empirical evidence supports them.

VI. CONCLUSION AND FUTURE WORK

A. Conclusion

This study provided significant insights into VR and MR research, particularly concerning connectedness, presence, and immersion. The qualitative analysis explored how XR environments are perceived regarding these variables, while the quantitative analysis examined the impact of virtualization levels on perceived connectedness, focusing on self, others, and the world.

Findings revealed no consistent significant differences in presence and immersion between VR, MR, and real environments. However, connectedness was found to be stronger in real environments compared to VR and MR, partially confirming the hypothesis that the degree of virtualization influences connectedness. The absence of significant differences between VR and MR suggests that these technologies may affect connectedness in similar ways, with physical presence and sensory stimuli likely being key factors for fostering connectedness.

These findings emphasize the importance of real-world sensory stimuli and physical presence for connectedness while highlighting VR and MR's potential as less intensive alternatives. Prior research indicates that VR and MR can enhance connectedness when replacing empathy-focused tasks, but caution is warranted when these technologies substitute real-world experiences, as they may reduce connectedness. By directly comparing these technologies with real environments, this study contributes to understanding their social and psychological impacts.

The practical applications of these findings are diverse. The strong connectedness observed in real environments suggests that educational settings should prioritize real interactions. In cases where physical presence is not possible, MR and VR can be effective alternatives, provided strategies are implemented to address the lower levels of connectedness typically found in virtual environments.

Given the widespread use of VR, AR, and MR in industries such as gaming, healthcare, and education, addressing connectedness is essential for user well-being. Research shows that connectedness to self, others, and the world is often significantly lower in VR and MR. Measures should be taken to understand and mitigate potential negative effects on emotional well-being, particularly in therapeutic contexts where a lack of connectedness could hinder treatment outcomes.

The study also suggests that VR and MR can achieve levels of presence comparable to real-world settings, opening new possibilities in training, education, and therapy without concerns about perceived presence. Similarly, immersion effects in VR and MR are comparable to those in real environments, making these technologies suitable for applications requiring deep engagement.

However, the study faced limitations. The small sample size may limit the generalizability of results. The absence of social interactions in measuring connectedness and the use of the WCS, which was not specifically designed for VR and MR, further constrained the findings.

This study makes valuable contributions to VR and MR research, demonstrating how these technologies influence connectedness, presence, and immersion. The findings hold practical relevance for education, therapy, and entertainment while forming a foundation for future studies to further explore and expand these insights. While VR and MR offer numerous benefits, their potential to create new realities that influence connectedness must be critically examined to ensure their use delivers positive outcomes without unintended negative effects.

B. Future Work

Several areas for future research remain to deepen and expand the findings of this study. Future studies should incorporate larger and more diverse samples to enhance the generalizability of results. Utilizing advanced data analytics platforms could facilitate this process. Including participants from varied demographic groups could provide valuable insights, as connectedness, presence, and immersion may be

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experienced differently across populations. This is particularly important given the limited research comparing VR and MR environments to real-world settings.

Further exploration of specific variables, such as the long-term effects of VR and MR experiences, is needed. Wearable technology could help track these over time. Examining how connectedness, presence, and immersion evolve over time could reveal the sustainability of these effects. Methodological improvements, such as refining and validating the WCS for VR and MR contexts, could enhance the accuracy of future studies. VR platforms with built-in tools can streamline this process. Additionally, new or supplementary methods could provide richer data and better address the unique challenges of these environments.

Practical applications of these findings in education, therapy, and industry warrant further investigation. Developing interventions based on these results could improve the effectiveness and usability of VR and MR technologies. AI-driven social interactions could enhance realism. Integrating social interactions in VR and MR environments may improve the measurement of social connectedness and provide more realistic application scenarios.

Longitudinal studies are needed to assess the long-term stability and application of these findings. Regular monitoring of connectedness, presence, and immersion over time could offer a more comprehensive understanding of their progression. Interdisciplinary collaboration could bring new perspectives and foster innovative approaches by involving experts from psychology, sociology, and computer science.

Finally, social and cultural factors should be examined to understand their impact on VR and MR experiences. Adapting research to various cultural and social contexts could increase the generalizability and relevance of findings. Leveraging international research networks could be beneficial. Exploring emerging technologies and methods since this study could also enhance future research, enabling greater accuracy and applicability of results.

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