Evaluating Presence and Technology Acceptance of an Intelligent Reality Virtual Museum Prototype

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Abstract— **Intelligent Reality refers to the fusion of integrated technological innovations to develop complex computing systems aiming to blend the real with digital worlds and enable humans and machines to seamlessly work together leveraging each other's strengths. This paper presents the results of a study evaluating the user experience of visiting an Intelligent Reality virtual museum prototype in terms of presence, technology acceptance, and environment perceptions, as a small-scale Cyber-Physical-Social Eco-System proof of concept. A virtual reality (VR) system was designed, and a real robot was placed in a technology museum to foster cyber-physical synchronisation, for users to visit and navigate in the environment. The study results revealed high degree of presence achieved by users in the VR world, with positive acceptance of technology and environment evaluation. Most importantly, the results highlighted the importance of presence in such systems and how it relates to acceptance and to the overall users' perception of a VR world.**

I. INTRODUCTION

Intelligent Reality is a term that describes the fusion of integrated technological innovations (such as eXtended Reality, Artificial Intelligence, Machine Learning, Digital Twins, Internet of Things, 5G, and others) to develop complex computing systems aiming to blend the physical world with digital spaces and enable humans and machines to seamlessly work together and leverage each other's strengths. It concerns the symbiosis of technology and the real world through the fusion of emerging disruptive technologies in ways that make the difference between real and digital worlds less distinct. In Intelligent Reality systems, real-time data can be generated and processed in multidirectional ways interchangeably between the real and digital spaces. Intelligent Reality systems and their behaviour can be engendered by humans and support visualisation, interpretation and utilisation of data to create knowledge and support decision making, applicable to a plethora of domains. The development of such systems is fostered by the recent technological advancements and introduction of emerging disruptive technologies in our lives such as Robots, Artificial Intelligence, Virtual and Augmented Reality, Internet of Things, and others.

This paper explores the potentials of using AI, Robotics and Immersive Technologies as a fusion to develop Intelligent Reality systems to disrupt the way humans explore and understand data, interact in real and virtual worlds, by means of artificial and real agents, and with each other. It demonstrates an example of a Cyber-Physical-Social Eco System (CPSeS) prototype and presents the results of an evaluation study focussing on technology acceptance and user experience concerning the user feeling of presence and overall system perceptions of experiencing a Virtual Museum.

II. EMERGING TECHNOLOGIES FOSTERING INTELLIGENT REALITY

The Covid-19 pandemic forced the introduction of a new normal into everyone's life, where the use of digital technologies was paramount for business, education, and life continuity in general. This sudden and unguided shift to an enforced digital lifestyle undoubtedly contributed towards a significant leap in the digital transformation of the society and the large-scale introduction of digital spaces, XR (eXtended Reality – an umbrella term used to encapsulate Virtual, Augmented and Mixed Reality), IoT and other technologies into our lives. Major tech companies and technology innovators have leveraged the momentum and announced their involvement in the metaverse [1], a trend keyword used to encapsulate persistent virtual universe merging synthetic environments with reality and the physical world through the convergence of multiple emerging technologies, facilitating communication and dynamic interactions with the real and virtual worlds, objects, avatars and humans [2]. The term originates from the fiction novel called *Snow Crash* by Neal Stephenson, describing a virtual environment parallel to reality in which humans were living and interacting as avatars [3]. An example of a system in the metaverse would provide interactive experiences using immersive technologies, replicate the real world through digital twins, utilise blockchains to build an economic system and merge with the physical reality through an identity systems where users can exist and create content in both worlds [4]. In fact, the concept became so popular that the industry has embedded new types of business models into their corporate strategies to involve the metaverse [4]. Even policies of national and international organisations have been modified to accommodate this new eco-system [4], and technology developers devoted significant efforts in the development of tools and environments that fit into the metaverse [5].

However, the significant increase in computing power, hardware, software and networking speeds, in conjunction with XR improving and becoming consumer friendly, advanced technological leaps in Artificial Intelligence, introduction of Blockchain technology, Internet of Things, Internet of Everything and other disruptive technologies, the premises for the implementation of metaverse-like technologies and beyond that applicable to a plethora of domains are starting to grow.

Immersive technologies enable users to experience the sense of immersion through high fidelity, quality, and quantity of sensory information [6], and is a term mostly associated with the XR technologies of VR, AR and MR [7]. XR offers

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opportunities to experience and interact with computer generated 3D environments (VR) [8], environments that create illusions of computer generated artificial elements existing in the real world in real time (AR) [9], and environments that enable the symbiosis of the real and digital worlds and their ability to interact with each other (MR) [10]. The XR landscape is now becoming mainstream as a result of the significant reduction in cost of ownership and increase in portability and comfortability [11], and is extensively used by governments, organisations, the industry, academia and individuals to support various domains and digital transformation initiatives [12]. Especially when XR is used in convergence with other emerging disruptive technologies as a fusion, to help creating complex computing systems and Intelligent Reality environments. For example, the implementation of AI tools and techniques (such as machine learning, natural language processing, neural networks, deep learning, agents and other) in XR environments enable to create new functionalities [13]. Examples of adaptive virtual environments capable of understanding users behaviour to support, improve and enhance their interaction with the environment [14, 15], intelligent agents capable of perceiving, thinking, acting, and providing interactions with users and the environments [16-19], and intelligent social agents using voice recognition, speech synthesis and language understanding to support agent-human interactions [16] are among a wide range of application examples.

The developer's toolkit contains many tools and techniques enabling to simulate environments, human intelligence, behaviour, and cognition. The implementation of such capabilities in XR unleashes the potentials of deploying innovative and immersive intelligent digital worlds controlled and influenced by AI and humans interchangeably [20]. Implementation of digital twins that bring together humans and AI and visualize through immersive XR are used for development and management of complex computing systems to support intelligent decision making [21]. Internet of Things through smart devices connected via various communication mediums that share intelligence [22], as well as interconnected smart objects and services that enable to establish human-to-human, human-to-physical, and physical-to-physical connections are forming the Internet of Everything (IoE) [23], and together with other solutions, are technological innovations driving the new era of Intelligent Reality.

A. *Cyber-Physical-Social Eco Society Systems (CPSeS)*

The deployment of such systems brings a lot of attention to the development of Cyber-Physical-Systems among other complex computing systems. CPS are *"engineered systems that are built from, and depend upon, the seamless integration of computational algorithms and physical components"* [24]. These are interconnected integration of infrastructure, smart computational devices, physical environments and humans [22] that employ computational and physical capabilities such as sensing, actuating, and communicating, to integrate physical and information systems [22, 25]. CPS are commonly found in the industrial sector (manufacturing, smart structures, waste management, aviation, warehousing and others [26]), in the development of innovative systems combining of a wide range of technological disciplines such as embedded systems, robotics, software, wireless sensors and networks, cloud computing, and others [22]. While CPS focus on connecting and interfacing the physical with the computational world, the introduction of social elements that concern human and social input and their influence in the system in the form of Cyber-Physical-Social Systems (CPSS) also exist and draw a lot of research interest recently [27, 28]. While a CPS connects the physical to the cyber space, the infrastructure lacks important element of human interaction with the system [29] and a CPSS introduces the human and social element into the system[30].

A further architectural concept extension has recently been proposed in [31], focussing on emerging intelligent systems that seamlessly blends the real with digital spaces through the interplay of real and artificial agents and elements involved in both realities, influenced by humans and their behaviour, as a new type of a Cyber-Physical-Social Eco-Systems (CPSeS). A CPSeS inherits the computational, physical, and social capabilities of CPS and CPSS, and amalgamates realities via real and virtual agents, digital twins and actuators that interact with humans and their avatar in real time and provide a direct link to both realities in an Eco-System of multidirectional data stream. To date, initial prototypes of such system have been developed to support cultural heritage [20, 31, 32] and education [33, 34]. This paper demonstrates and evaluate an example of a CPSeS system, to determine its technological acceptance and evaluate the users' perceptions during their immersive experience.

III. CASE STUDY – VIRTUAL MUSEUM OF COMPUTERS

To demonstrate the attributes and technological capabilities of a CPSeS, a proof-of-concept system has been developed based on the CPSeS infrastructure described in [31]. The system was installed in the Cyprus Computer History Museum (www.mouseio.org) for a short period of time to test its affordances and to conduct this evaluation study. This is a technological museum located in Nicosia, Cyprus, dedicated to the education of the history of computers. It features more than 100 computers and consoles between 1970 to early 2000, peripherals, and a large collection of vintage software (Fig. 1).

Figure 1 – Cyprus Computer History Museum

To build and evaluate the capabilities of a CPSeS system, the 'Cyprus VR Museum of Computers' was designed. This is a multi-user VR environment where uses can access and experience using their Android powered smartphone devices and cardboard-based head mounted displays. It was developed with Unity3D game engine and Google VR software development kit. To facilitate the physical link to the CPSeS, a mobile robot (Turtlebot II) was placed in the museum premises. Turtlebot [35] is a low-cost research robot controlled by an NUC mini PC and featuring the Robotic Operating System (ROS) software. It is a modular robot equipped with a moving base, a Kinect high quality camera, a robotic arm and other sensors. Using the architecture described in [31], we have connected the real robot to the virtual environment created in Unity3D using the RosBridge and Ros Sharp components [41]. To provide multiuser capabilities, we have used the free version of the Photon Engine communication infrastructure, allowing up to 20 concurrent users to be connected on the environment simultaneously. To support multiuser communication, a textual chat module was developed.

The VR environment features several exhibits that are not at display in the real museum, because they are extremely expensive, difficult, or impossible to source. The environment features the digital twin of the Turtlebot, shadowing its operation and movement in the physical world at real time, and connects to its camera to stream live feed of the view of the robot in the museum directly in VR (Fig. 2). An AI guide agent is also implemented responsible to interact with the user by providing information and navigating the user around in the virtual world.

Figure 2 – The VR Computer History Museum

A. Research Methodology

This study was set out to investigate the users experience in terms of Technology Acceptance, the development of the subjective feeling of Presence during the virtual experience, and the users' perceptions regarding the Virtual Environment's design. To guide this study, we have formulated the following research questions:

- *RQ1: What are the users' perceptions towards the Virtual Museum, based on their perceived enjoyment (PE), ease of use (PEOU), usefulness (PU), personal innovativeness (PI), and intentions to use (ITU)?*
- *RQ2: What are the relationships between the constructs of PE, PEOU, PU, PI and ITU?*
- *RQ3: What are the users' perceptions of presence in the Virtual Environment?*
- *RQ4: What are the users' overall perception of the environment design and its controls?*
- *RQ5: What is the relationship between Presence and the users' perception of the environment with the constructs of PU, PEOU, ITU, PE and PI?*

1) Data collection

To investigate the user's perception towards Technology Acceptance, the constructs of the generic Acceptance Model proposed by Davies [36] consisting of Perceived Usefulness (PU), Perceived Ease of Use (PEOU), and the Intention to Use (ITU) were used. PU investigates the extent to which users perceive that the utilisation of the system will enhance their job performance and measures the system functionality. PEOU determines the extent to which users perceives the exploitation of the system as free of effort. ITU investigates the extent to which users plan to perform specified future behaviours. In addition to the basic constructs of TAM, the study investigated the participants level of enjoyment while interacting with the environment (Perceived Enjoyment - PE), and how their innovativeness of using new technology influence their intention to use the application (Personal Innovativeness - PI). The TAM questionnaire consisted of 22 questions, measured in five-point Likert scale (1 – Strongly Disagree to 5 – Strongly Agree). The items focussing on Perceived Ease of Use, Perceived Usefulness, and Intention to Use have been adopted from the study by Davis (1989). The items related to the Personal Innovativeness are adopted from Agarwal and Prasad [37]. The items measuring Perceived Enjoyment are adapted from Venkatesh et al. [38].

This study also aimed at investigating the user's perception of presence in the VR environment. Presence is *"the subjective experience of being in an environment when physically situated in another"* [39]. To measure users' perceptions of presence in the VR environment, the short version of the Presence Questionnaire (PQ) was used [39]. This is a well-known, reliable, and validated questionnaire that measures the user's degree of presence experienced in a virtual environment, by addressing factors that influence the degree of immersion and involvement: control (CF), realism (RF), sensory (SF) and distraction factors (DF). CF relate to the actions of the user and the expected behavior of the environment in response. RF relate to the meaningfulness of the experience, the realism of the scene, content and consistency of information. SF concern the visual information received by the user and the richness of the environment. DF relate to distractions that may occur during the experience which could negatively impact the user's sense of presence in the virtual environment. The total PQ score is calculated by aggregating all items for each participant (Min=19, Max=133) in a 7-point disagree/agree response format.

To gain a better understanding of the users' perceptions of the environment and their overall experience, a set of questions focusing on the environment design, its functionality, the experience with the interaction with the digital twin of the robot, and general satisfaction of the experience were provided and also measured in five-point Likert scale (Table 1)

2) Experimental Task

To conduct this investigation, an ethical approval was sought from the relevant national ethics committee. To participate in this study, users were invited from the professional networks of the authors and from an open invitation communicated through social media. The study participants were connected to the system from remote locations and followed specific instructions outlined in a web document. Users were provided a weblink to read the study description and consent to participate. The link included a further weblink directing them to download and install the Virtual Museum application on their smartphone. Cardboard based Head-Mounted Displays (HMD) were provided to them in advance. Users were asked to insert their smartphone into the HMD and follow on-screen instructions. As soon as they connected to the environment, they were landing in a virtual orientation area, providing them with information on how to use the environment, how to interact with artefacts and with each other, and send messages. The orientation task took approximately 4-5 minutes. Users then navigated to the Virtual Museum where they were requested to navigate in the environment, read educational materials and study the exhibits, interact with the digital twin of the robot, and the virtual guide agent. The session took around 40 minutes. Users were then provided a web-link to complete a post-experiment questionnaire describing their experience. The experiment was running for 2 hours in two different sessions, and participants were connecting at time of their convenience.

IV. Data Analysis & Results

We have collected data from 16 participants (10 male and 6 female) aged between 18 and 45. Participants had limited experience with VR (M=2.69, SD=1.35), and they were mainly comfortable setting up the cardboard HMD and using their smartphone to enter the virtual world on their own (M=3.88, SD=1.1). Before running any data analyses, the degree of normality for all scales were tested and normality assumptions were fulfilled, therefore the data was analyzed using parametric tests. The reliability of TAM and PQ scales have been previously validated and reported by the original authors. Nevertheless, we have also tested the reliability of the scales using the Cronbach's alpha coefficient, and the internal consistency of the items comprising the scales used in this study were highly reliable (TAM α= 0.94, Presence α=0.95). The Environment Evaluation scale (Table 1) we have designed, also yielded high internal consistency (α=0.72).

The data analysis began by investigating the TAM results. Participants have perceived the environment as enjoyable (PE, M=4, SD=.47), easy to use (PEOU, M=3.98, SD=.51), and useful (PU, M=3.9, SD.6). The results showed a relatively high degree of personal innovativeness (PI, M=3.7, SD=1) and participants expressed positive intentions to use if they had access to it (ITU, M=3.73, SD=.65), demonstrating a generally high acceptance of the system as a tool to support their virtual museum experience. TAM results were further investigated for intercorrelations using Pearson's correlation coefficient. The results revealed significantly strong correlations between Perceived Usefulness (PU) and Intentions to Use (ITU) (r=.877, p=.001) and Perceived Enjoyment (PE) with Perceived Usefulness (PU) (r=.869, p=.001). These results suggest that as participants perceived the environment to be useful, more intentions to use such technology for the future was expressed. Furthermore, participants perceived the environment and the experience as very useful and enjoyable, and this can indicate that the more the meaningfulness of the experience, the more enjoyment can be achieved. Strong correlations were also revealed between Perceived Enjoyment (PE) with Intentions to Use (ITU) (r=.760, p=.001) and among Perceived Ease of Use (PEOU) and Perceived Enjoyment (PE) (r=.755, p=.001), indicating that participating in enjoyable VR experience can lead to behavioural intentions of using such technology in the future, and that the easier the environment is to use, the more enjoyment is achieved. Moderately strong correlations were also revealed among the users Perceived Ease of Use (PEOU) and Perceived Usefulness (PU) (r=.679, p=.004) and with Intentions to Use (ITU) (r=.645, p=.007), suggesting that the easiest the environment usage is to the user, the more useful is the experience and the higher the intentions to use in the future. The correlations between the Personal Innovativeness (PI) and the rest of the TAM constructs were weak, indicating that the individual traits and willingness of participants to try out new technology did not affect any of their perceptions regarding the enjoyment, usefulness, ease of use and intention to use of the system.

The PQ was analysed next using descriptive statistics. The results revealed that users have experienced high degree of Presence (M=5.2, SD=.86) reporting high overall Presence score (M=98.5, SD=16.34) within the virtual environment. Users have reported good control over the environment (CF, M=5.1, SD=.85), with high perceptions towards Sensory (SF, M=5.45, SD=1) and Realism (RF, M=4.93, SD=1.03) and low Distractions (DF, M=5.27, SD=.96) that could have impacted their experience. The Environment evaluation questions were then investigated (Table 1). Overall, participants have positively evaluated the environment (M=3.73, SD.4), and found it easy to navigate and interact (M=4.1, SD=.5). They also found the ability to see the real world through the eyes of the robot quite compelling (M=4.37, SD=.62), and have positively commented on the video quality of the live stream from the physical museum as the robot was navigating during the study (M=4.37, SD=.62), with some relative delays however (M=3.3, SD=.5). The participants have perceived the interactions with the robot in the virtual world as moderately easy (M=3.3, SD=.6) and have expressed some difficulties utilising the textual chat to communicate with others during the experience (M=3, SD=1).

Question:	Mean	SD
1. Navigating in the virtual world was easy	4.1	.5
2. Interacting with elements in the environment through the reticle (the white dot that expands) was easy	3.7	.68
3. Using the text chat to send messages to others was easy	3	1.
4. Following the robot around was easy	3.5	.8
5. Seeing the real world through the eyes of the robot was compelling (attractive, inspiring)	4.37	.62
6. The quality of the video feed was good	4.3	.6
7. There was no delay in video synchronisation	3.3	.5
8. Interacting with the robot was easy	3.3	.6
Overall Environment Evaluation	3.73	.4

Table 1 – Environment Evaluation Questions and Results

The data was further analysed for correlations between Presence and the Environment Evaluation results with the TAM constructs. The results revealed significantly strong correlation between Presence and Perceived Enjoyment (PE) (r=.818, p=.001), suggesting that developing the immersive feeling of presence can contribute towards the enjoyment of the experience, and moderately strong relationships between Presence and Perceived Ease of Use (PEOU) (r=.682, p=.004) and with Intentions to Use (ITU) (r=.667, p=005). These findings may suggest that the easier the environment is to use, higher degree of Presence can be achieved during the virtual experience, and consequently, the more achieved Presence, the higher intentions to use the environment in the future may be reached. The Personal Innovativeness (PI) was strongly positively correlated with Environment Evaluation (r=.745, p=.001), indicating that the willingness to try out the technology may relate to a more positive perception of the overall environment design. Furthermore, moderately positive correlation between Perceived Ease of Use (PEOU) and the Environment Evaluation was also revealed (r=.541, r=031.) suggesting that the easier use of the environment, the higher perceptions towards its general evaluation are reported.

V. Discussion

The results of this study indicate that users have accepted the environment as a technological mean to support their hybrid visit to the museum, revealing high enjoyment during the VR experience. Users perceived the environment as easy to use and useful, showing high degree of behavioral intentions to use new technology and such application for the future, addressing the posed RQ1. The results analysis further revealed that some of the TAM constructs were correlating addressing RQ2, with emphasis on how the participation in enjoyable, useful and easy to use VR experience may lead to higher intentions to use such system in the future, and how an easy-to-use environment can make the experience more enjoyable. The implications of these results highlight the importance of considering the meaningfulness of the experience during the design and development stage, and to ensure that the system and the VR environment is easy to use.

Users have also achieved high sense of presence within the virtual environment during the experience and have positively evaluated the design of the environment to support their virtual museum visit, addressing RQ3. Furthermore, users have positively evaluated the environment's design and the ability to see the real world through the eyes of the robot, finding it easy to navigate and to interact. However, users have indicated difficulties when interacting with the robot and using the textual chat to message each other (RQ4), which the authors of the system would take into consideration to redesign the environment's and robots interactions and functionalities.

To address RQ5 and holistically investigate the relationships between Presence and user's perception of the environment with the TAM constructs, statistical analysis for correlations on the results was employed. The results revealed the important role of the development of the feeling of Presence in a VR experience, and how it contributes towards the enjoyment of the experience, with the possibility of leading to higher intentions to use the environment in the future. Furthermore, the results revealed that the ease of use of the environment contributes towards a more positive perception towards the design and functionalities of the virtual world, again highlighting the need of designing easy to use systems and environment interactions to aid the user experience. Equally important however, the results indicated that users with more willingness to try out the technology may perceive the environment more positively, raising the important point that while VR can be an enjoyable and compelling mean of accessing virtual experiences, the technology developers and environment designers need to accommodate for people who may be hesitant to use such technology, especially in CPSeS systems where performance is crucial. Future work is on its way to redesign the environment by taking into consideration the user's feedback, to implement additional system functionalities and conduct further system and user evaluations. Functionalities such as advanced AI pathfinding, implementation of multiple robots in the real world and additional development of complex robotic capabilities are currently underway.

From the experience developed through this study and from the authors experience with previous CPSeS development and VR environments design and evaluations, several suggestions that can be taken into consideration when implementing such systems are proposed:

- Since a positive user experience is paramount to the success and effectiveness of such system, it is important that the design of the VR environments is easy to navigate and to interact with. User interactions with objects and elements in the environment should be simple, responsive, and easily anticipated, and the activities should be short and meaningful.
- When deploying CPSeS VR environments for smartphone VR, it is important to accommodate for the limited processing capabilities of the devices, to ensure a smoother visual experience for users when exploring and interacting with the VR world. To support a good visual experience, consider occlusion culling, spatial partitioning, potential-visible-sets and other relevant optimisation techniques (e.g. [40]), and low geometry design solutions. When implementing scripts and AI functionalities such as guide agents etc. consider optimisations such as switching off unnecessary scripts, running lighter version of AI when the agent is not on sight or near the user where appropriate, and other optimisation techniques, to ensure that resource intensive scripts would only run when necessary to save processing power.
- In CPSeS systems, synchronicity and speed of service is also important therefore it is crucial to ensure that enough bandwidth is available for the system to process multidirectional data stream and to also support a multiuser infrastructure to facilitate the social element of the system. Adjusting the data stream frequency, lowering the quality of live video and audio feed from actors, and other adjustments maybe necessary to ensure that the system would behave synchronously.

The domain of Intelligent Reality research is still at its infancy, and the development of complex computing systems that leverage the power and potentials of emerging disrupting technologies are starting to rise. This paper presented a proof-of-concept CPSeS system, aiming to seamlessly blend the real with a digital world using VR, Robots and AI. The system described and evaluated in this paper is an example of a new generation of systems with integrated computational, physical and visualisation capabilities, demonstrating how it can be applied to the context of a virtual museum, but it is also applicable to a plethora of other domains.

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