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Blended reality and presence

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Human experience of public space is changing as virtual space blends with real space and technology provides increasingly hyper-immersive virtual environments. The purpose of this study is to reformulate the framework within which our virtual experience of location and self might usefully be considered, and this is articulated in terms of presence. We review the distinction between immersion and presence, illustrate various facets of immersion using a current virtual reality system specific to architecture and construction, and consider the key features of prominent presence theories. The results of an empirical study to evaluate the utility of a widely adopted survey instrument (the Slater-Usoh-Steed presence questionnaire) are presented and discussed. Incongruously, results indicate that users reporting their experience of virtual reality score that experience higher in presence terms than users experiencing the physical world. New perspectives drawn from emerging brain theory are required.

Keywords: virtual reality, hyper-immersive, presence

1 Introduction

The Internet of Things (IoT) references a pervasive extension of information and communication technologies (ICT) from specific computing devices to everyday things such as buildings, automobiles, washing machines, pharmaceuticals, posters, pot plants and potentially every other object in our world [34]. Recent advances in sensing devices, wireless network connectivity and display hardware mean that individual everyday objects with integrated ICT capabilities will gather data and connect to monitoring/control devices including other ‘wired’ machines via the Internet. A recent report forecasts that the IoT will include 26 billion units installed by 2020, compared to the projected use of smartphones, tablets and PC combined of only about 7.3 billion units [13]. People are also contributing to this network of data streams through increasing use of personal data tracking and smart mobile devices. Digital technology, and the data capture that goes with it, is being embedded in the very fabric of everyday life [15].

At the same time there is a movement towards making much of the huge collection of data held by various government agencies more available and open to the public as part of the recent push towards encouraging technology-enhanced forms of participatory government and public service delivery (see, for example, data.gov.au and data.london.gov.uk). Open data is “data that can be freely used, reused and redistributed by anyone - subject only, at most, to the requirement to attribute and share alike” (opendefinition.org). Of course the complement to this public data is the vast array of data routinely now being collected by private agencies and commercial organisations, both general business operations and specialist data service providers and analysts. There can be little doubt that the collection, storage and processing of data is increasing at a compounding rate [19].

The potential application of this vast data resource and increasing technological integration to the urban context is broad and substantial [11]. In particular, rendition of the data is no longer restricted to output in the form of text on a screen or to interaction limited by a computer keyboard and mouse. Human experience of data, and in our context the public space to which such data refers, stands on the verge of a technical revolution: a technically driven revolution in how we emotionally and cognitively experience the built environment [68]. Traditional distinctions between the real and the virtual and between virtual reality and augmented reality are being dissolved [23]. A critical consequence of this human-technological integration is how the further blending of real space with virtual space might impact our notions of location and self [5, 26]. The effective design of future spatial realities (actual, digital and blended) will be contingent on these emerging concepts of location and self [35]. It is a timely juncture to reformulate the framework within which location and self might usefully be considered in the development of digital systems that make sense of spatial data, particularly in the context of the emerging virtual reality technologies that sit directly at the confluence of blended reality.

In this paper we review the literature on how virtual reality is experienced by distinguishing between immersion and presence. A hyper-immersive VR system (The Situation Engine) is specific to architectural and construction and is used to illustrate various facets of immersion. A number of theories relating to presence are considered and key features identified. The term presence, as generally understood, is about the subjective nature of being in the world: the feeling of 'being there' [16]. However, as with many philosophical questions rooted in a notion of reality, this general consideration of presence begins to fail in the context of virtual reality [35]. Critical to presence is how it might be measured and an empirical study is undertaken to evaluate the utility of a widely adopted survey instrument: the Slater-Usoh-Steed (SUS) presence questionnaire [65]. The results of this study challenge the utility of both the instrument and the broad concept of presence on which it relies: defined as a two-dimensional construct of perceived self-location and perceived action possibilities. Incongruously, results indicate that users reporting their experience of VR score that experience higher in presence terms than users experiencing the physical world. The basis for this result and alternative directions for

2 A review of how virtual reality is experienced

To consider how people experience virtual reality (VR) it is important to distinguish between immersion and presence [57]. Immersion is generally considered as an objective description of the technology involved in VR, specifically in terms of how effectively (realistically) the system is able to represent a virtual world to the user [60]. According to Bystrom et al [6] the sense of immersion is determined by quantifiable features of the VR technologies used and relates to the broader sensory fidelity of the user experience. Sensory fidelity, in this context, is the degree to which the experiences within a virtual environment are equivalent to those in the real world in terms of spatial, auditory and haptic information. The intention is to deliver, as key factors, an inclusive, extensive, surrounding, vivid, matching and coherent sensory experience to the user. Slater and Wilbur [61] explain these factors as follows: inclusiveness indicates the extent to which the immediate physical reality is locked out of the user experience; extensiveness is a measure of how comprehensive a range of sensory modalities are incorporated into the VR; surrounding refers to the extent to which the VR is panoramic in a spatial sense; vividness is concerned with the resolution and richness of each sensory modality; matching requires an effective feedback loop between user actions and the VR response; and autonomy (or what is also referred to as 'plot') which is the extent to which the VR is able to present a story-line and independent behaviour within the VR that is plausible, self-contained and distinct from the immediate physical reality.

The most sophisticated interactive VR simulation environments with practical application to first person experiences are to be found in video game engines. The most powerful game engines are now typically free to acquire for personal or non-commercial use and recent announcements confirm that even commercial use is now very affordable at the entry level. To illustrate the immersive qualities possible with such VR technologies, a particular system developed specifically for the construction industry is briefly outlines. The Situation Engine is an application that provides for specific and adaptive practical experience to be made available to users in a hyper-immersive digital rendition of a real world construction context. The system is inclusive by virtue of having the option for head-mounted stereoscopic displays that incorporate full 3D surround sound headphones. This largely blocks the immediate physical world, although the tactile qualities of floor finishes and variations in ground-level (walking up an incline or stairs) are still present to the user. The head-mounted display does provide a wide, 130 degrees of horizontal field of view and the head-tracking allows the user to scan the VR world in any direction. The VR worlds are also extensive in that they model entire blocks of urban settings which allow users to wander and explore. A variety of construction sites have been modelled and each includes various workers, plant and equipment, facilities and materials – as seen through the eyes of the user avatar. What is true of the spatial sense is also true in other modalities. For example, there is an extensive range of different object properties, actor behaviours and context variables (such as weather, time-of-day and shadows) available in the system. The core game engine provides extremely high resolution graphics, sound, physics and other key modalities, but does not provide haptic feedback. There is no discernible lag when the system is implemented on a laptop computer with reasonable graphics capabilities, notwithstanding current limitations in the available head-mounted display technologies. High-end video game engines are impressively efficient in responding to user interactions in terms of autonomy and plot. The models and scripting in The Situation Engine provide for a realistic rendition of typical construction site activities (including the operation of plant and equipment). Users get to see how the work at different stages of construction has been prepared, measure and check sizes and distances, operate plant and equipment, assess details against building codes and best-practice guides, identify key features, diagnose problems, rearrange work practices, etc. The same site can then be used to present alternative situations, at different stages of construction, with different activities and other configurations of material storage, signage, waste management, security, etc. Multiple users can be included at the same time and experience the situation collectively. At various points a user can interact with the building as it is in the process of being constructed – measuring the dimensions of a structural timber member, the tread size of a staircase or the spacing of reinforcement bars, for example. Providing high information content in this way and enabling the user to configure the virtual environment and modify their visual, aural and haptic senses, all relate directly to the three interactive properties identified by Sheridan [53] as being critical for immersion.

The Situation Engine represents an effectively hyper-immersive system in most regards, but the general lack of haptic and tactile feedback is a definite limitation. The recently added ability for a user to move their head with 6-degrees-of-freedom provides for new and increasingly hyper-immersive user experiences to be included, such as peering around a corner and leaning in to get a closer look at objects. Other recent improvements include the ability for a user to virtually walk by really walking and have all physical body movements correspond to virtual movements in The Situation Engine. The new interface device incorporates an RGB camera, an infrared sensor, an infrared emitter, an array of microphones and an accelerometer. Using the infrared emitter to project a prescribed pattern of dots onto a scene and using the infrared sensor to record how those dots are deformed across the surfaces on which they project, it is possible to determine a real time depth map of the scene. Each individual depth map can then be used to calculate the geometric structure of the scene and express the geometry in the form of a 3D mesh or point cloud. Comparing depth maps between scenes identifies the movements of the objects within that geometric space. The system is then able to interpret movement in a scene against the approximated skeletal framework of a user. Skeletal tracking data for 21 user-to-virtual bones is currently available, including: head, arms, legs, hips, neck and spine. Data on the movement and position of each virtual bone is parsed in real-time by specially developed detection algorithms within The Situation Engine. The detection algorithms interpret sequences of movement against a register of prescribed gestures. New gestures can be prescribed and added to the register where they are monitored against the tracking data and where specific gestures are identified then specific user protocols can be enacted. Some of the gestures currently detected include turning, jumping, leaning in any direction and pacing at speeds on a continuum from walking to running. Such gestures are used to control the positioning and movement of the user avatar within the virtual space. For example, as the user leans then the view-point and avatar adjust accordingly. Other, more context-dependent gestures have also been developed for The Situation Engine. These include composite gestures such as extending the arm and twisting the wrist to open a door, clenching the fists and pulling downwards to enter the cab of an excavator and reaching down with one arm and clenching the fist in order to grab a small hand tool from the ground.

Control of this kind is termed ‘gestural control’. Gestural control is an important aspect of immersion because gestures are often more intuitive for users, particularly those inexperienced with established gaming interface technologies and protocols. Established gaming interface technologies and protocols are also rather limited in scope. For new actions and interface protocols the use of familiar gestures can be significantly more viable than having to create and memorize potentially complex new combinations of mouse and keyboard sequences. However, a low to zero level of latency is required in order to ensure that gestures are interpreted into actions in The Situation Engine with the same immediacy as the gestures themselves. This demands highly efficient communication between the base-level game engine code and the interface device. To implement this in The Situation Engine a multiplexer class was created in the base-level (C++) coding of the game engine such that data retrieved from the interface device could be served out to an arbitrary number of gesture detection algorithms with minimal impact on the memory footprint and real-time performance. Gesture detection algorithms were implemented at a higher coding level, as nodes in the game engine control flow graph. Each gestural detection algorithm also defined the related actions in The Situation Engine that the particular gesture was intended to initiate. Noting that many gestures could be limited to the tracking and analysis of upper arm, forearm and hand movements only, relevant pre-filtering of those body parts specific to particular groups of gestural detection algorithms provided further performance optimization.

Implementing the gestural detection algorithms at the higher coding level as nodes in the control flow graph also means that the system monitors body movements for all and any registered gestures in parallel. This enables multiple combinations of gestures and movement to be accommodated collectively. For example, walking, while turning, while leaning and while swinging a hammer are all captured at the same time in the Situation Engine's gesture control system. This additional complexity further develops the immersive qualities of the virtual experience. These advances in gestural control and the broader improvement in the quality of physical engagement in virtual environments are being complemented with a variety of technology developments: multi-user environments where other avatars actually represent the behaviour of other users in the same virtual experience and there is direct verbal communication between players; mobile deployment that locates experiences in the immediate location of the user; improved integration between the base-level game engine, external software, data streams from the internet and interactive web browsing from within the game; rapidly improving artificial intelligence coding and behavioural representation; and the use of sensors able to tune into electrical signals produced by the brain to detect user thoughts, feelings, and expressions. Such increasing scope, scale and quality of immersive potential, from both perspectives of the virtual and of the real, are potent evidence that the virtual world and the real world are blending, and blending within affordable and readily available digital technologies.

As the technical (immersive) qualities of VR improve and can now be reasonably tested in relevant applications such as The Situation Engine, a critical counterpart to immersion is becoming more and more apparent. As the level of technical immersion has improved then so the user's perception of being actually (physically) present in a virtual (non-physical) world has also improved. The psychological sense of being in a real world when physically in a virtual world is termed presence. Presence is traditionally conceived as being the subjective measure of how conscious a user is that the virtual world they are experiencing is not to all other intents and purposes an actual physical world. Essentially, it is argued, the less a user perceives a virtual environment to be virtual, the greater the suspension of disbelief in the fact that it is actually a virtual environment and the greater the sense of being there in the virtual environment [6]. Thus presence is the experiential counterpart of immersion.

Even as the counterpart of immersion, various theoretical models of presence still regard presence as some form of direct outcome or function of immersion [52]. The classic theories of Slater and Wilbur [60, 61] explicitly measure presence in terms of objective technical features. The correspondence between increased immersion and increased presence is an obvious consequence of that choice of measurement. However, it is now clear that cognitive processes mediate the impact of immersion on the development of presence in a fundamental way [56]. Individuals experience different levels of presence even in the same immersive environments [30]. Presence is a more complex phenomenon than originally conceived. Even the basic notion that presence involves the suspension of disbelief is now largely discounted on the philosophical grounds that it is unreasonable to define something as manifestly complex as presence by what it is not or by the failure of someone to notice something [10].

Presence is now being shown to range across multiple levels and requires multiple affective, cognitive, motivational and peripheral physiological perspectives in order to frame the complexity [51]. Specifically, in the context of The Situation Engine and the blended space between the real and the virtual that hyper-immersive systems are beginning to occupy, the notion of presence as a sense of being there is being challenged [5]. In the first instance the rationalistic distinctions between subject and object and the recourse to mental representations that inhere to the notion of a being there can be questioned philosophically [75]. The potential for a user to experience something akin to being there is contingent on the user having some sense of being here. When the ‘there’ and the ‘here’ are merging and the distinction between virtual and real is being dissolved, then presence should be an expression of the blended space that results. The illusion of non-mediation and the sense of being in another location are false goals in the context of that kind of blended space [5].

According to van den Hoogen et al [21], the degree of technical immersion can be measured and controlled, and this might influence the level of presence, but ultimately presence is a subjective response to the immersive experience. In the context of digital technology, presence is considered from a number of different perspectives. These include: telepresence, which is the sense of being co-located to somewhere physically remote using a teleoperating or similar device [9]; mediated presence, employed in communication studies to “confine the concept of presence strictly to the realm of mediated perception” [28:29]; social presence, where the salient properties are the interpersonal relationships afforded by the technology [54]; and spatial presence, which is where the location is entirely simulated within a VR technology [25].

Specific to spatial presence, Witmer and Singer [73:225] defined presence as “the subjective experience of being in one place or environment, even when one is physically situated in another”. Witmer and Singer [73] sought to use the measure of perceived spatial presence to indicate the effectiveness of the VR experience. Along similar lines, Steuer [67:2] defines presence as “the extent to which one feels present in the mediated environment, rather than in the immediate physical environment”. In contrast, Lombard et al [31] focus on what is not noticed. They define presence as “the perceptual illusion of non-mediation”. More explicitly, Lee [28:32] summarises presence as “a psychological state in which the virtuality of experience is unnoticed”.

Definitions of spatial presence tend to distinguish between: the sense of the user in another location; another location being brought to the user; and several remote users sharing a virtual location together. Wirth et al [72] characterise these spatial aspects of presence in terms of a two-dimensional construct: the perceived location of the self as the core dimension, and the perceived possibility for action as the secondary dimension. Along with Slater and Steed [59], spatial presence is defined as a binary experience during which perceived self-location and perceived action possibilities are connected to a mediated spatial environment. Wirth et al [72] argue that this generalised model of spatial presence is particularly useful because it is based on related psychological concepts such as attention and involvement.

In summary, there is general consensus that the concept of presence refers to the subjective perception of an individual. It is also recognised that a range of factors can influence the sense of presence. Those factors can be external to the user and particular to the technology (such as the visual resolution and richness of the display, system interactivity and other immersive qualities of VR), or internal to the user as cognitive states and personal concerns. This particular combination of external and internal factors makes it difficult to isolate specific factors for evaluation. Indeed the evidence available from previous studies in this regard is mixed and often conflicting. For example, a study by Slater et al [63] found that users in a head-mounted-display achieved much higher presence than those who used a desktop monitor, where Mania and Chalmers

[33] reported no significant difference in the sense of presence between these two pieces of technology. Hendrix and Barfield [18] and Dinh et al [8] found that spatial sound contributes significantly to a sense of presence, where the results of Lessiter et al [29] demonstrates that audio quality makes no difference. There are several possible reasons to account for these contradictions. Firstly, those presence studies were conducted in different years and the immersive quality of the technologies used in each varied considerably. Secondly, the instruments used to measure presence were not always the same. Most studies rely on self-reported questionnaires and there have been many different presence questionnaires adopted in this field. Finally, presence itself is a complex concept to define and measure directly because it deals with cognitive processes and subjective feelings that have no obvious benchmark. Measuring presence is a challenge that many researchers have sought to address.

3 Measuring presence

Vorderer et al [70] draw together a broad scope of presence definitions to construct a process model on the formation of spatial presence. The model aims to establish connections between presence, relevant concepts from psychology and communication, and cognitive theory. Combining existing presence concepts and the work of Gibson [14] on perception of the visual world, Vorderer et al [70] concludes that spatial presence is an experience with a two-dimensional construct – a sense of self-location and a perceived set of possible actions. Schloerb [49] and Slater et al [64] came to a similar conclusion, distinguishing between subjective presence (a perceptual judgement of self-location) and objective/behavioural presence (a measure of task performance and observations of how users respond to events presented within the VR). Thus there is a common agreement that a measure of presence should consider the user perception of self-location along with either the user perception of possible actions or an external observation of behaviour. As a consequence there are two main approaches to measuring presence. One approach uses entirely subjective measures, which include the use of self-reported questionnaires, content analysis and interviews. The alternative approach is to use more objective measures, which include psycho-physiological, behavioural and task performance appraisals. Despite the obvious limitations of using a subjective measure in terms of benchmarking and consistency, the self-reported questionnaire continues to be the most widely used survey instrument in presence research.

The earliest self-reported questionnaire specific to presence was developed by Steinfield [66] to test the impact of computer-mediated communication (the use of emails) on co-presence. It contains 30 items on user experiences and 11 items covering background and demographic information. Barfield and Weghorst [3] developed a presence questionnaire concerning visual display and auditory parameters. This questionnaire contains only two 5-scale items. Later, Hendrix and Barfield [18] extended this questionnaire to 5 items, still with a focus on visual and auditory parameters. The following year, Hendrix [17] changed some of the questions to address 5 different parameters: field-of-view, stereo visual display, head-tracking, sound quality and general user experience.

Slater and his colleagues Usoh and Steed developed a six-item questionnaire, known as the Slater-Usoh-Steed (SUS) presence questionnaire [65]. It has become the most influential and widely used survey instrument for measuring presence [2, 32]. Developed by researchers with a psychology background, the questions are independent of technical (immersive) parameters and focus purely on the psychological states and experiences of the user. A review by Lombard et al [32] concludes that the SUS presence questionnaire correlates with objective measures of presence identified in many studies, which is taken as providing strong evidence of its validity. However, the sensitivity of the instrument across different domains has been questioned after Usoh et al [69] published the results of a study which found no significant differences when real and virtual environments were compared. One implication of this study is that the use of this questionnaire should be limited to measuring presence in immersive virtual environments.

Another influential instrument is the Presence Questionnaire (PQ) developed by Witmer and Singer [73]. Also widely used, the PQ contains 32 items all of which are on 7-point scales. The items address four factors concerning virtual environments: control factors, sensory factors, distraction factors, and realism factors. A series of studies were conducted to test the validity and sensitivity of this instrument, and results indicate that the PQ has achieved high levels of both validity and sensitivity [41, 73]. There have been ongoing debates between the lead authors of the SUS and PQ questionnaires. Slater [57] challenged the PQ from a fundamental perspective, pointing out that Witmer and Singer [73] had mistakenly interpreted the term ‘presence’ as dealing with technical factors rather than psychological states of being. The PQ questions seek user opinion on the technical settings of the VR systems and consequently only reflect the immersive qualities and not the sense of presence. In response, Singer and Witmer [55] admitted that the PQ is designed to measure involvement and immersion. They emphasise that individual PQ items are significantly correlated with the PQ total score and that the PQ is a reliable and valid measure of what they deem to be presence.

The position of Slater [57] does have some substance however and the Witmer and Singer [73] concept of presence is difficult to distinguish from immersion. In the experiments that validate the PQ, participants are usually assigned to different immersive conditions and are then asked to report on the qualities of those conditions. It is not surprising, then, that significant correlation is found between immersion and presence because the two concepts appear to be measuring the same phenomenon but from different perspectives.

Another popular instrument is the ITC-Sense of Presence Inventory (ITC-SOPI) [29]. This questionnaire contains a rather unwieldy 63, 5-point scale items in the original version and 44 items in the revised version. It tests four factors: sense of physical presence, engagement, ecological validity and negative effects. Studies have demonstrated the validity and reliability of this instrument and have shown that the results of the ITC-SOPI are strongly correlated with those of the SUS presence questionnaire and PQ.

The Igroup Presence Questionnaire (IPQ), developed by Schubert et al [52] is based on the PQ, the SUS presence questionnaire and the Hendrix and Barfield [18] questionnaire. It is a 14-item instrument concerning three factors: spatial presence, involvement, and realness. Tests have shown that data gathered using this questionnaire is both reliable and sensitive.

Finally, the MEC Spatial Presence Questionnaire (MEC-SPQ) was proposed by Vorderer et al [70]. The development and application of MEC-SPQ is particularly relevant to the spatial presence model proposed by the authors. However, it also contains a rather unwieldy 64, 7-point scale items to measure spatial presence in seven dimensions: attention allocation; spatial situation model; spatial presence (self-location and possible actions); higher cognitive involvement; suspension of disbelief; domain specific interest; and visual spatial imagery. There are 8 items in each category, including spatial presence. Shorter versions of MEC-SPQ have also been proposed, comprising 4 or 6 items in each category and reducing the total number of questions to 32 and 48 respectively. The full MEC-SPQ has been tested in a series of studies with high levels of correlation among items and strong reliability and sensitivity reported [38, 48].

The fact is there have been many questionnaires developed to measure presence. Van Baren and IJsselsteijn [2] reviewed 28 presence questionnaires and others continue to be proposed. Self-reported questionnaires are usually administered to users after the experience, but IJsselsteijn et al [24] use a continuous assessment method. In this approach, subjects are asked to move a slider along a scale to indicate their perceived level of presence while they experience the environment. McGreevy [36] used a combination of methods including open-ended questionnaires, unstructured interviews and observations. Retaux [43] applied auto-confrontation where the user is shown a video of their experience and is asked to explain their behaviour and feelings at the time. Rourke et al [47] used content analysis to code transcripts of online communication on the basis of a template that calculates a social presence density factor. Riva et al [45] applied experience sampling to assess the external situation and the personal states (consciousness) of the users. Participants carry a beeper during the experiment and are required to complete a questionnaire whenever they receive a signal.

Objective corroborative measures of presence have also been proposed. There are several categories: psycho-physiological measures, neural correlate measures, behavioural measures, and task performance measures [2]. Psycho-physiological performance addresses physiological processes such as heartbeat, blood flow and eye-movement using cardiovascular [62], skin [7], ocular [27], and facial electromyography measures [42]. Neural correlates study brain processes and activities using electroencephalograms [50] and functional magnetic resonance imaging [20]. The criterion for behavioural measures is based on the belief that the more people feel being present in a virtual environment, the more likely they are to respond in a similar way to how they would in the real world. A number of techniques have been used to measure behaviour including facial expression [22], reflex responses [39], and social responses [1].

Task performance is proposed as an objective corroborative measure by Barfield and Weghorst [3]. However, although many studies investigating presence and task performance have been undertaken, there remains a lack of compelling evidence to support this argument. The factors considered in studies specific to task performance include: completion time and error rate [4], number of actions taken to complete a given task [63] and the transformation of knowledge from the virtual world to real-world situations [74].

The veracity of measuring presence directly using self-reported questionnaires can only be estimated in broad terms using statistical analysis to establish the internal consistency and coherence, and how consistent the results are over time. Whilst the established methods have reasonable internal consistency results, there have not been longitudinal studies where the responses of particular individuals are monitored over time. More objective measures have been proposed in an attempt to corroborate and benchmark the self-reported questionnaires, but none have established themselves with broad currency or uptake. Of course much of the problem lies in the fact that presence is defined as a cognitive process and is being tested against a significant range of and rapidly changing immersive VR technologies.

As a further extension to the measurement of presence per se, recent work by Riva et al [46] and Riva and Mantovani [44] regards presence as the enabling neuro-psychological factor for translating internal intentions into actions in the external world. Within this framework, presence is the product of a metacognitive judgement that links spatial perception to bodily experience and action. In other words, presence is the critical factor that determines whether a person can successfully transform his/her internal intentions into actions in the external world: the cognitive gatekeeper for perception-action outcomes. Based on established psychological theory, if valid, the framework promotes presence as a necessary and critical factor for reasoning about and within VR. This possibility makes it all the more important that any relationship between (increased) immersion and (increased) presence is verified and a robust method of measuring presence is established.

Finally, it is worth noting that presence does not necessarily require high levels of user involvement and/or complete suspension of belief. Slater [58] argues that the two aspects of presence (perceived self-location and perceived action possibilities) translate directly into two forms of self-illusion when using an immersive VR system: the illusion of place and the illusion of plausibility. As evident, measures of presence typically focus on the illusion of place, in which users may experience the illusion of being in a virtual place but not necessarily involved with the events within that place [58, 62]. Slater [58] maintains that users will respond more naturally and authentically to a VR environment when both place illusion and plausibility illusion are achieved. Measures of presence must broaden to more directly address the perceived action possibilities.

4 Research method and results

The aim of the experimental study is to test the self-reported presence experienced by users of a hyper-immersive VR system: The Situation Engine. The study is part of a broader investigation of virtual environments and learning styles and was undertaken in 2013. A total of 253 participants were drawn from undergraduate courses in architecture and building construction. All participants were using The Situation Engine as part of their learning process, but to different extents. The sample was also relatively diverse in terms of study background, work experience, previous use of video game technology and familiarity with VR technologies in teaching and learning. The survey instrument used was the Slater-Usoh-Steed (SUS) presence questionnaire, slightly modified to suit the particular task context. The questionnaire included the following six questions and participants were required to circle a single point on a seven-point scale of responses for each question from low (1) to high (7):

1. Please rate your sense of being in the virtual environment, on a scale of 1 to 7, where 7 represents your normal experience of being in a place.

   (1) I was not there at all … (7) I was there

2. To what extent were there times during the experience when the virtual environment was the reality for you?

   (1) Not the reality at all … (7) It was the reality

3. When you think back to the experience, do you think of the virtual environment more as images that you saw or more as somewhere that you visited?

   (1) Images … (7) Somewhere I visited

4. During the time of the experience, which was the strongest on the whole, your sense of being in the virtual environment (VE) or of being elsewhere?

(1) Being elsewhere … (7) Being in the VE

5 Consider your memory of being in the virtual environment. How similar is the memory in the virtual environment compared to the memory of other places you have been?

(1) Not similar at all … (7) Extremely similar

6 During the time of your experience, did you often think to yourself that you were actually in the virtual environment?

(1) I was not there at all … (7) I was actually there

The experimental process involved a class announcement by the lecturer in charge to invite participation. Participation was entirely voluntary and there was no grading associated with the exercise. The volunteers were then invited in groups of six to a separate lab location where six independent copies of The Situation Engine were installed on six high-performance computers, each physically separate to the other. Participants were asked to undertake one of several possible short tasks using The Situation Engine, allocated at random. Each task related to their current field and level of study and took approximately 5 minutes to complete. Immediately following the task participants were asked to complete the survey questionnaire independently and without interaction with other participants. Survey responses were collected, validated and analysed.

There are two principal ways used in the literature to calculate the level of presence based on the SUS presence questionnaire: the presence average, where the average score across all six questions is calculated for each participant and this average is used to rank and categorise the responses; and the presence count, where the number of times each participant selects a particular score is recorded and various classifications are determined from the groupings. Using the presence count method, and as proposed by Slater et al [65], where a participant scores 2 or more high (6 or 7) responses they are classified as high presence, a score of 1 is deemed to be medium presence and a score of 0 is deemed to be a low presence response.

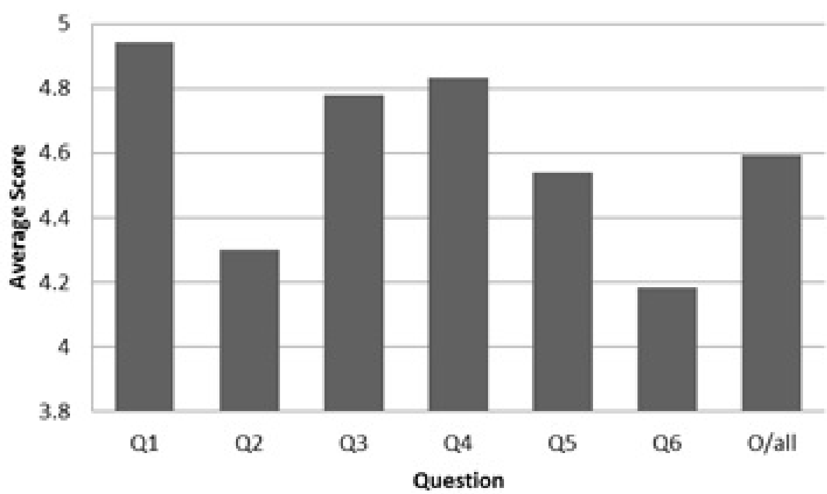

Figure 1 Average scores for each question and overall

Figure 1 shows the overall average score for each question along with the overall average score for all questions. These values indicate whether there is an overall sense of presence on average and how the responses to each question compare. An overall positive sense of presence on a 7 point scale would result in an average score of greater than 4. It can be seen that the average for each question and overall is greater than 4. The strongest response was for question 1 (average 4.94) which is the most direct question regarding the sense of presence. Questions 3 and 4 also had strong support, indicating that participants experienced the VR situation as a place and had a strong sense of being elsewhere (rather than in a VE). Only marginally positive responses for questions 2 and 6 indicate that participants were undecided about whether the VE was real or that they were actually in the VE.

Table 1 Statistical description of the average scores

Group	Q1	Q2	Q3	Q4	Q5	Q6	O/all
Mean	4.94	4.30	4.78	4.83	4.54	4.18	4.60
SD	1.14	1.22	1.35	1.27	1.18	1.30	0.84
Median	5.47	4.83	5.28	5.39	5.11	4.75	5.26
% above 4	67.98	43.87	56.52	62.45	53.75	41.90	73.12

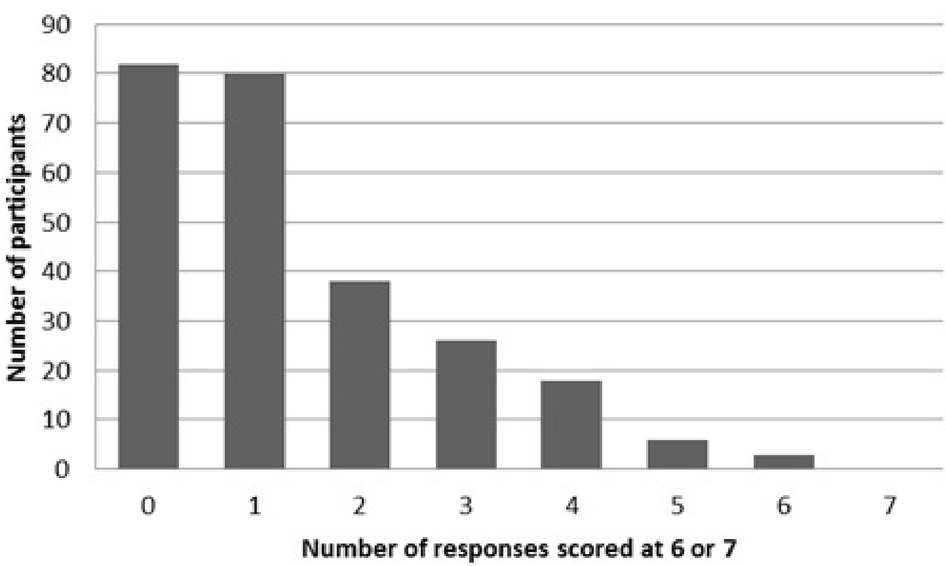

Figure 2 Count of responses scored by each participant

A summary chart of the average score statistics is presented in Table 1. Table 1 shows that the distribution of scores for each question is relatively tight (standard deviation measures of approximately 25% of the mean value) and skewed to the right (median higher than mean). This is particularly so for the overall score. Table 1 also shows that less than 44% and 42% of participants respectively ranked question 2 or 6 above a score of 4. By comparison, almost 68% of participants ranked question 1 above a score of 4 and overall, more than 73% of participants averaged above a score of 4.

Figure 2 shows the number of participant who selected high scores (6 or 7), on how many occasions. Using the presence count method, 91 participant (35.97%) scored 2 or more high (6 or 7) responses and they are classified as high presence, 80 participant (31.62%) scored only 1 and are deemed to be medium presence group, and 82 participant (32.41%) scored all questions below 6 and are deemed to be a low presence group. The distribution is remarkably even, with more than 67% of participants deemed to have recorded a medium or high presence score based on the method proposed by Slater et al [65].

5 Discussion and conclusions

This study is driven by the increasing integration of ICT in the fabric of everyday life: the Internet of Things. Digital data that can be stored, manipulated and transported is already representing the physical world to people in all manner of ways. This trend is accelerating and will have no less a fundamental impact on how people design, construct, manage and use the built environment as it is already having on society and culture more generally. Of particular interest to this study is how the rendition of the built environment using VR technologies might impact our notions of location and self, particularly in terms of how VR is designed and how it is used in architectural and building education. VR is a critical technology in the blending of virtual, augmented and physical reality. The effective design of future spatial realities (actual, digital and blended) will be contingent on the emerging concepts of location and self.

The aim of the study is to reformulate the framework within which our experience of location and self might usefully be considered. To begin this reformulation it is important to distinguish two significant aspects of VR technology that are often conflated in the literature: immersion and presence. Immersion defines a technical description of VR features and the broader sensory fidelity of the user experience. Presence is the experiential counterpart to immersion and defines the cognitive perception of the user experience. As the immersive qualities of VR technology improve, how presence is conceived and measured is becoming both contested and critical.

To demonstrate the current state and future potential of VR technology a hyper-immersive system specific to architecture and building, The Situation Engine, is briefly described. The Situation Engine provides an inclusive, extensive, surrounding, vivid, matching and coherent sensory experience to the user in the context of building construction technology, architectural design and workplace health and safety. An understanding of The Situation Engine and the extent to which the experiences it provides are equivalent to those in the physical world in terms of spatial, auditory and haptic information is relevant to this study as the system represents advanced VR capabilities and is used as the reference experience for the study. In a highly dynamic technical field, implementations of the latest developments in head-tracking with 6-degrees-of-freedom and gestural control (where physical body movements correspond to virtual movements) demonstrate the viability of The Situation Engine as an excellent exemplar of currently available VR systems.

Presence is the primary focus of this study. A review of the literature reveals a general agreement around the nature of presence being a subjective perception, but a variety of views in terms of the key factors and most effective frameworks to use to measure or improve the sense of presence. This study draws particularly from the work of Schloerb [49], Slater et al [64] and Vorderer et al [70] to frame presence as a two-dimensional construct comprising the user perception of self-location along with either the user perception of possible actions or an external observation of behaviour. As a consequence there are two main approaches to measuring presence. One approach uses entirely subjective measures, which include the use of self-reported questionnaires, content analysis and interviews. The alternative approach is to use more objective measures, which include psycho-physiological, behavioural and task performance appraisals.

An experimental study is presented that seeks to evaluate the utility and viability of measuring presence in the context of VR using subjective measures only. The particular aim of the experimental study is to test the self-reported presence experienced by users of a hyper-immersive VR system and benchmark these against other studies. Despite the obvious limitations of using a subjective measure in terms of benchmarking and consistency, the self-reported questionnaire continues to be the most widely used survey instrument in presence research. The SUS presence questionnaire is identified as the most popular survey instrument in previous studies of presence and this is adopted in the current study.

The experimental design worked extremely well, with no withdrawals or invalid questionnaire submissions by any of the 253 participants. There is no doubt that the interpretation of each question could have varied between participants, as some phrases and terms are somewhat ambivalent. For example, question 4 ("During the time of the experience, which was the strongest on the whole, your sense of being in the virtual environment (VE) or of being elsewhere?") is not clear as to whether the "elsewhere" refers to somewhere which explicitly is not the VE, or is the VE but feels like somewhere real (non-virtual). However, the large number of participants in this study would have offset that potential bias. Having 253 participants makes this one of the largest ever applications of the SUS presence questionnaire, when the majority of studies include less than 40-50 participants.

Table 2 Comparison of averages with results for Usoh et al [69]

Group	Q1	Q2	Q3	Q4	Q5	Q6
Virtual	4.3+1.5	3.6+1.3	2.6+1.6	4.6+1.3	4.4+2.3	3.3+2.2
Real	4.0+2.1	4.0+2.3	4.6+2.2	5.1+1.9	3.7+1.9	5.2+1.6
Current	4.9+1.1	4.3+1.2	4.8+1.3	4.5+1.2	4.5+1.2	4.2+1.3

The overall results are also encouraging. The SUS presence questionnaire is not proposed as an absolute measure of presence and is typically used in bimodal analysis to compare relative presence to other factors believed to influence presence. Where relevant measures have been provided from previous studies however, the average values reported in this study compare very well. Take for example the findings of Usoh et al [69], who compared the sense of presence in a real space with the sense of presence in a VR model of that space. The results of that questionnaire are reproduced in Table 2, along with comparative figures from the current study taken from Table 1. Results for each question are shown as the mean and standard deviation. “Virtual” refers to the Usoh et al [69] participants reporting on the VR experience, “Real” report on the real space and “Current” are the results from this study.

It can be observed that the current average presence scores are higher in every case other than Question 4 and one aspect of Question 6, and generally significantly higher and more closely distributed around the mean. This indicates that the sense of presence reported in this study is broadly and substantially improved over both the VR experience of Usoh et al [69] and, most notably, the real experience of Usoh et al [69]. That is to say that, on average, users of The Situation Engine reported experiencing higher levels of presence than others have reported in their use of a physical space. The only notable exception to this was for question 6 (“During the time of your experience, did you often think to yourself that you were actually in the virtual environment?”), which is not a surprising exception.

The first positive to draw from this result is that The Situation Engine provides a relatively high and consistent sense of self-reported presence across all measures. A strong sense of presence is particularly important where the virtual experience is intended to provide an authentic experience (of some real experience, for example). This intention is often the case in training and entertainment contexts where the focus is on behaviour development and modification [12]. For instance, health and safety training typically needs to promote good practice outcomes, not just to communicate information.

A second positive can be drawn from the results in Table 1, that for all measures the median is higher than the mean, indicating that the distribution of scores is skewed towards a higher sense of presence. This is confirmed by the significantly higher proportion of all scores being above 4, which offsets a modest number of responses with very low reported presence. An overall percentage of 73.12% of scores higher than 4 indicates that the significant majority of users are reporting positive experiences in presence terms.

The disturbing result is that users reporting their experience of VR score that experience higher in presence terms than users experiencing the physical world. Since there can be little apparent doubt that an individual in the physical world is present in the broad sense that the SUS presence questionnaire seeks to determine, the likelihood is that participants are reinterpreting the questions to suit the context. Thus, presence in the physical world may be reinterpreted as the level of engagement or interest, rather than the user perception of self-location and action possibilities it is intended to address. The ambiguity of how key questions in the SUS presence questionnaire can be interpreted was noted in previous sections. Self-reporting questionnaires are always susceptible to such error. However, the incongruity of a VR experience rating higher than a physical experience in presence terms points to the significant possibility that any cross-environment comparison (between the virtual and physical, immersive VR and desktop video games, etc.) could also be invalid using this approach. This is a more serious limitation and should govern the application and interpretation of results using a SUS presence questionnaire in the future.

A further issue raised by the results in Table 2 is what this says about the ambitions for VR design and development. There is a general implication that the goal of VR is to match the experience of the physical world exactly. Hyper-immersive technologies point in that direction and demonstrate the possibility of something approaching that ambition, but how much immersion is enough? Presence is often considered as some form of Turing-type test for hyper-immersive VR [49, 67]. One implication of the current study is that as VR technologies achieve increasingly hyper-immersive qualities then how the SUS presence questionnaire is being interpreted by study participants could also change. Whilst the current study shows a relatively high sense of presence being reported against a relatively advanced hyper-immersive VR experience, it is not clear if this score is still approaching a maximum, achieved the maximum or is falling from a maximum. Further studies where specific elements of the immersive technology are removed and/or improved are required.

Of course much of the preceding discussion is predicated on the definition of presence as a two-dimensional construct comprising the user perception of self-location along with either the user perception of possible actions or an external observation of behaviour. It might be argued that this coupling between perception and action is to some extent vacuous, given the hermeneutic view that perception without action and action without perception would be inconceivable [75]. It is also the case that recent developments in brain theory challenge the status of a concept such as self as the most effective or useful focus to describe and account for actions [56]. For example, the boundary between self and environment/other can range from particular areas of the brain, to the body, to the tools being used by the body, to the social networks in which the body/tools participate. There may be the presumption of self as a bodily agent, but there is no guarantee that any given participant will provide a user perception of self-location on that basis.

Brain theory is going to have increasing impact on how we understand learning in a general sense and on the design of VR experiences more specifically [71]. In the first instance, brain theory provides its own account of presence that relates directly to the generalised brain functions. This account offers a range of approaches to the objective (direct) measurement of presence in terms of cognitive load, brain patterns, etc. [37, 40] – presuming presence is defined in terms of its impact on the state of mind rather than in terms of action. The notion of cognitive synchronisation is important here as it may represent an equivalent brain theory term for presence. Cognitive synchronisation (presence) is an expression of the degree to which the external environment (VR or physical world) corresponds to the mediating mental model/simulation: the closer the correspondence, the greater the sense of presence [56]. The design of VR experiences can then be related directly to an increased sense of presence through a consideration of the predictability and familiarity of the VR situation specific to the user: familiarity breeds presence. In the second instance, brain theory provides a direct link to an array of other specific theories on behaviour, personality, cognition, etc. that each represent a rich source of empirical evidence to inform and improve VR design.

The aim of this study was to reformulate the framework within which our experience of location and self might usefully be considered, and this has been articulated in terms of presence. We have argued that an effective notion of presence is critical to the future design and development of hyper-immersive VR systems, and that prevailing notions of presence are overly simplistic. Key shortfalls in existing definitions and common measurement approaches to presence have been identified and demonstrated through empirical study. New perspectives are required.

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Design Sciences, Advanced Technologies and Design Innovations
Towards a better, stronger and sustainable built environment

Aims and scope

Today's design strongly seeks ways to change itself into a more competitive and innovative discipline taking advantage of the emerging advanced technologies as well as evolution of design research disciplines with their profound effects on emerging design theories, methods and techniques. A number of reform programmes have been initiated by national governments, research institutes, universities and design practices. Although the objectives of different reform programmes show many more differences than commonalities, they all agree that the adoption of advanced information, communication and knowledge technologies is a key enabler for achieving the long-term objectives of these programmes and thus providing the basis for a better, stronger and sustainable future for all design disciplines. The term sustainability - in its environmental usage - refers to the conservation of the natural environment and resources for future generations. The application of sustainability refers to approaches such as Green Design, Sustainable Architecture etc. The concept of sustainability in design has evolved over many years. In the early years, the focus was mainly on how to deal with the issue of increasingly scarce resources and on how to reduce the design impact on the natural environment. It is now recognized that "sustainable" or "green" approaches should take into account the so-called triple bottom line of economic viability, social responsibility and environmental impact. In other words: the sustainable solutions need to be socially equitable, economically viable and environmentally sound.

IJDST promotes the advancement of information and communication technology and effective application of advanced technologies for all design disciplines related to the built environment including but not limited to architecture, building design, civil engineering, urban planning and industrial design. Based on these objectives the journal challenges design researchers and design professionals from all over the world to submit papers on how the application of advanced technologies (theories, methods, experiments and techniques) can address the long-term ambitions of the design disciplines in order to enhance its competitive qualities and to provide solutions for the increasing demand from society for more sustainable design products. In addition, IJDST challenges authors to submit research papers on the subject of green design. In this context "green design" is regarded as the application of sustainability in design by means of the advanced technologies (theories, methods, experiments and techniques), which focuses on the research, education and practice of design which is capable of using resources efficiently and effectively. The main objective of this approach is to develop new products and services for corporations and their clients in order to reduce their energy consumption.

The main goal of the International Journal of Design Sciences and Technology (IJDST) is to disseminate design knowledge. The design of new products drives to solve problems that their solutions are still partial and their tools and methods are rudimentary. Design is applied in extremely various fields and implies numerous agents during the entire process of elaboration and realisation. The International Journal of Design Sciences and Technology is a multidisciplinary forum dealing with all facets and fields of design. It endeavours to provide a framework with which to support debates on different social, economic, political, historical, pedagogical, philosophical, scientific and technological issues surrounding design and their implications for both professional and educational design environments. The focus is on both general as well as specific design issues, at the level of design ideas, experiments and applications. Besides examining the concepts and the questions raised by academic and professional communities, IJDST also addresses the concerns and approaches of different academic, industrial and professional design disciplines. IJDST seeks to follow the growth of the universe of design theories, methods and techniques in order to observe, to interpret and to contribute to design's dynamic and expanding sciences and technology. IJDST will examine design in its broadest context. Papers are expected to clearly address design research, applications and methods. Conclusions need to be sufficiently supported by both evidence from existing research (reference to existing design research knowledge) as well as strong case-studies from any design discipline. A paper must contain at least one chapter on research questions, methodology of research and methods of analysis (the minimum length is 1500 words). The concluding chapter (the minimum length is 1000 words) will summarise the paper and its results. The concluding chapter also examines and discuss applications, advantage, shortcomings and implications of the investigation for both professional and educational design communities as well as for the people and the society. Also authors are also encouraged to include in this chapter a discussion of the possible future research that is required or is possible in order to enhance the research findings.

The papers considered for IJDST cover a wide range of research areas including but not limited to the following topics: Design research, design science, design thinking, design knowledge, design history, design taxonomy, design technology, design praxeology, design modelling, design metrology, design axiology, design philosophy, design epistemology, design pedagogy, design management, design policy, design politics, design sociology, design economics, design aesthetics, design semantics, design decision-making, design decisions, design evaluation, design sustainability, design logic, design ontology, design logistics, design syntaxis, design ethics, design objective, design responsibility, design environment, design awareness, design informatics, design organization, design communication, design intelligence, design evaluation, design education, design theories, design techniques, design methods, design operations, design processes, design products, design users, design participation, design innovation, design inspired by nature, design case studies, design experiments, etc.

International Journal of Design Sciences and Technology is devoted to further exploration of all themes and issues that are directly or indirectly relevant to the exploration, introduction, discussion of design sciences and technology, cross referencing domains and any other themes emerging in the future.

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[3] **Buxton, W** (1997) Living in Augmented Reality: Ubiquitous Media and Reflective Environments. In: Finne K, Sellen A and Wilber S eds, Video Mediated Communication, Erlbaum, Hillsdale N.J., 363-384

[4] **Dixon, N M** (2000) Common Knowledge: How companies thrive by sharing what they know, Harvard Business School Press, Boston, MA

[5] **Djenidi H**, **Ramdane-Cherif A**, **Tadj C** and **Levy N** (2004). Generic Pipelined Multi-Agents Architecture for Multimedia Multimodal Software Environment, Journal of Object Technology, 3:8, 147-169

[6] **Gorard, S** and **Selwynn, N** (1999) Switching on to the learning society? Questioning the role of technology in widening participation in lifelong learning, Journal of Education Policy, 14:5, 523-534

[7] **World Bank** (2002) Social assessment as a method for social analysis, World Bank Group [www.worldbank.org/gender/resources/assessment/samethod.htm]

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