# THE EFFICACY OF REALISTIC VIRTUAL ENVIRONMENTS IN CAPTURING USER EXPERIENCE OF BUILDINGS

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## ABSTRACT

Virtual models can offer early and inexpensive proxies of how the real environment will be experienced by its users. However, until relatively recently, the usefulness of virtual models has been constrained by the technological limitations of the software and hardware. Games engines now offer the industry a way to import multiple 3d formats to streamline workflow, with far greater realism and complex interactions with the created virtual environment. In order to be accepted as a reliable tool for design development and problem solving in architecture, engineering and construction, these virtual experiences must be capable of producing user-feedback that is credible. The assumption that a model of human experience from a virtual environment can be a dependable representation of how the real environment will be experienced needs to be tested. Such tests have hitherto offered inconclusive results and the paper reports on the early stages of a current project that aims to redress this. The use of equipment familiar to cognitive psychologists, such as lightweight head-mounted eye tracking systems, should enable comparisons to be made between user-experiences of real environments and their realistic virtual counterparts. Should the virtual environments be shown to communicate similar physiological responses from the participants and deliver similar experiential qualities when compared to the real environment, then it can be argued that they offer realistic visual representations and accurate representations of experience.

**Keywords:** Architectural design, Games, User experience, Virtual environments

## 1. INTRODUCTION

The relationship between architectural design and computing is usually dated to the appearance, in 1963 of the Sketchpad computer tool (Sutherland,1965). Over the next forty years computer tools were developed or adapted to aid designers in their work on layout, scale, visualisation and documentation. A brief résumé of the development of Computer Aided Design (CAD) and Computer Aided Architectural Design (CAAD) within the building industries of a number of countries worldwide can be found in Greenwood et al. (2008). In that paper the authors noted that Virtual Reality (VR) technology was increasingly being used by and between the different parties in the building process, and for different applications within it: in summary, VR technology had become a ‘rapid means of transferring and translating information and improved communications’ and ‘helping towards understanding of a project’ in cases where a prototype can be usefully visualized before construction begins (Greenwood et al., 2008). Outside the realm of construction design-interactive VR has become not only a more economical, but in some instances (e.g. hazard awareness and safety training) a much safer alternative to the experience of real-life situations, according to Johnson et al. (2009) who have listed areas such as the Military, Safety Services and Health as beneficiaries of its use. There is a perceptive classification, by Kähkönen (2003), of CAAD - related research into three categories: enabling technologies; applications; and process. By the 1990s the first of these, the enabling technologies (i.e. the hardware and software that support visualization) appeared to have fallen behind expectations, as noted, for example, by Akin and Anadol (1993). However, more recent advances in both hardware and software, and equally importantly, their reduced cost, have now created the prospect of ‘new generations of CAAD’ (see, for example, Reffat, 2006; Styliadis et al., 2008). Amongst the most important reasons for these advances are developments from the Games Software industry. Here, major improvements have been made both in photorealism and in the real-time rendering that enhances the user experience and makes it more genuinely interactive. The enhanced experience available from these developments means that 3D gaming engines have become a real source of potential improvement, particularly by enhancing the immersivity of so-called ‘serious games’ such as VR applications within CAAD.

**Software developments: the infiltration of gaming software**

Smith (2007) in presenting a useful historical overview of the topic, recognises the ‘powerful products and technologies’ that the computer gaming industry has begun to export to “serious” industries/sectors (including defence, medicine, architecture, education, city planning, and government). He also notes that, in each of these, game technologies are beginning to displace other ‘established industry-specific hardware and software’. More specifically, Trenholme and Smith (2008) concentrate on the opportunities for using computer game technologies for the creation of virtual environments, and proceed to offer an overview of currently available game engines that are capable of, and suitable for their prototyping. Of particular interest to the current paper, and the project it relates to, is Crytek GmbH’s games engine – CryENGINE®. According to Trenholme and Smith, the CryENGINE3 ® ‘supports a number of features that are useful for creating immersive and realistic games and virtual environments, such as a real-time editor, bump mapping, dynamic light[ing] …networking … an integrated physics system, shad[ing], shadow support ... ’ and produces ‘very high quality graphics and visuals’. Importantly, as Trenholme and Smith recognise, creating virtual environments from scratch is ‘complex, expensive and time consuming’ and this being the case an attractive alternative option is the ‘reuse of computer game technology’. This, together with the established commercial pre-eminence of the CryENGINE ® presented a convincing argument for its adoption as part of the current research project.

**Hardware developments: the choice of peripherals**

In terms of their delivery to the individual(s) experiencing them, VR displays can take a variety of forms. Milgram et al., (1994) usefully locate these on a reality-virtuality continuum that ranges from a real environment, through mixed reality, to a virtual environment. Matching the different points on the continuum, and the different levels of immersivity required, is the use or non-use of a variety of hardware peripherals. The most common devices for attempting near-total immersion are head mounted displays (HMDs) for individual experience, and ‘cave’ environments for multi-user or collaborative experience. Additional peripheral hardware can be used to involve other senses, for example ‘haptic’ devices to invoke the sense of touch. At the simpler end of the scale is the monitor-based display.

## 2. RESEARCH CONTEXT

The opportunities afforded by such software and hardware developments bring their own research questions. Normally, the prime purpose of VR, as with any other representation, is to convey a model of reality that is as realistic as it can be, or needs to be. For example, when a user’s experience of an aspect of the built environment is being interrogated, the usefulness or otherwise of a VR representation crucially depends on how close the virtual experience is to its real-life counterpart. The question ‘how close?’ is one that can be best addressed by measuring the response of the user.

**Measuring experience in real and virtual environments**

Recent work on differences in perception of real and virtual worlds has been summarised by Johnson et al (2009). Acknowledging the possible limitations of VR in simulating real life experience (as, for example, pointed out by Campos et al, 2007), the particular interest of Johnson and her co-researchers was to seek evidence of differences between perceptions of distance, ‘route acquisition’, ‘task performance’ and ‘goal urgency’ in experiments conducted in real-space and virtual mazes. Their initial findings suggested that the two compare favourably in terms of the similarity of experiences they produce.

**Two measures of 'realism'**

The efficacy of 'realistic' virtual environments can be assessed on two separate levels: visual realism and experiential realism. Visually the virtual environment that is offered should present as true a representation of the real environment as is necessary and technologically possible. For example, the quality of real-time lighting should be of high fidelity; and the software used to create an environment should be able to represent a specific environment in various different forms to suit the requirements of different user groups: for example, architects and planners may wish to experience the environment in a white massing-model style; engineers may wish to observe a more schematic style of visual; clients and other stakeholders may require a near-fully realistic representation in order to make informed decisions. Accordingly, studies by Bishop and Rohrmann (2003) and Daniel and Meitner (2000) have identified the critical need for realism when studying human perception and behaviour.

The second, deeper assessment of realism is on the level of experiential realism or 'presence'; a shortened form of the original term 'telepresence', which originated in theorizing about reactions to cinema films (Bazin, 1967). Lombard (2000) refers to presence as,

> a psychological state or subjective perception in which even though parts or all of an individual's current experience is generated by and/or filtered through human-made technology, part or all of the individual's perception fails to accurately acknowledge the role of technology in the experience. Except in the most extreme cases, the individual can indicate correctly the s/he is using the technology, but at 'some level' and to 'some degree', her/his perceptions overlook that knowledge and objects, events, entities, and environments are perceived as if the technology was not involved in the experience.

A more recent and perhaps neater definition, by Freeman et al. (2005) refers to presence as 'a participant's sense of being there in a mediated environment, arising from a perceptual illusion of non-mediation'. A particular feature of this concept of presence is that the person experiencing the virtual / mediated environment will recall it as a 'place' or a 'locality' that was visited rather than merely as a set of pictures seen (see, for example, Slater, 1999).

**Measuring 'presence'**

The measurement of experiential realism or presence, as it has been described, has conventionally been a subjective matter, with user responses being gathered by the use of questionnaire. These questionnaires have generally been based upon rating scales (e.g. Likert, Thurstone, and other Semantic Differential scales). Sheridan (1992) argues that 'subjective report is the essential basic measurement'. Objective measurement is not entirely dismissed, but 'presence is a subjective sensation or mental manifestation that is not easily amenable to objective physiological definition and measurement' (Witmer and Singer, 1998). Accordingly, until recently the measurement of presence has been almost exclusively through administering questionnaires (see also Slater, 1999; Lessiter et al., 2000, and Slater and Steed, 2000).

**An alternative (experimental) approach**

Sheridan (1992) has noted that physiological methods of measuring presence, obtained experimentally rather than by questionnaire survey, are not straightforward. However, researchers are also aware of the limitations and subjectivity of *post hoc* questionnaire surveys and accept that objective physiological metrics have a role to play. Meehan et al. (2002) for example, have used skin temperature, heart rate and skin conductance to measure aspects of presence, and their results show reasonable correspondence with parallel measurements taken by questionnaire. Another option for physiological measurement of a subject's experience is eye-tracking. Human eye response can be deconstructed into a number of separable forms. At the most basic level, pupil diameter has been found to vary due to different emotional states (Partala et al, 2000) and to increase in line with cognitive demands (Beatty and Lucero-Wagoner, 2000). In terms of the current project, however, the most viable metric would appear to be the actual movement of the eye. In an experiment involving internet users, Salojarvi et al. (2005) proposed a relationship between eye movements, attention and perceptions of relevance. Duchowski (2002) has recognised that participants 'eye movements are generally recorded to ascertain users' attention patterns' and indeed eye tracking methodologies are used widely in multiple disciplines such as psychology, neuroscience, computer science, and marketing. Detailed inspection of a scene is carried out in a sequence of 'saccades' (rapid eye movements) through scan paths, with occasional 'fixations' (where the eye remains relatively motionless). Rayner and Pollatsek (1992) observed that in scene perception much information regarding the scene is extracted during the initial fixation, and that during fixations, the eye can exhibit the 'tremor', 'drift' and 'micro saccades' all of which, according to Engbert and Kliegl (2003) have some relation to cognitive processes.

## 3. RESEARCH RATIONALE

In their paper 'Perspective on Computer Aided Design after Four Decades' Mark et al. (2007) identify eight 'approaches to design'; in fact these can also be seen as representing eight possible avenues of CAAD research. It is the last of the eight approaches, Design and Cognition that is most relevant here. According to Mark et al. this approach 'bridges the disciplines of cognitive science, artificial intelligence and computer based methods. Research methods include capturing and observing human design activity… providing insights into human interaction with design tools or architectural places' (Mark et al. 2007, p. 6).

**Overall research aims and objectives**

To begin with, we can assume that no artificial representation of a real environment can completely recreate it, nor can it reasonably be expected to elicit exactly the same response from the observer. Nevertheless, all design processes (including that relating to the architectural design of built environments) are predicated upon the use of representational forms – sketches, drawings, photographs, and physical and electronic models - to carry information and to elicit 'realistic' (and therefore useful) responses. As Rohrmann and Bishop (2002) observe '[t]he crucial question is therefore, how valid is a representation? Is it realistic enough to induce responses which are sufficiently similar to the evaluation of the real environment?' (Rohrmann and Bishop, 2002: p. 319).

The overall aim of the project reported in this paper is to establish the 'validity' (as defined above by Rohrmann and Bishop) of virtual representations of real environments. Underlying this aim is the practical question, namely whether virtual environments offer an effective CAAD tool for capturing user experience of buildings at their design stage.

To accomplish the aim, and offer an answer to the question, a series of more focused objectives have been adopted, namely:

- To design an experimental method that permits the comparison between real and virtual constructed environments;
- To research, review and refine measurements of user experience appropriate to the area of interest;
- To specify the appropriate hardware and software and to carry out experimental work using this method;
- To obtain robust data from the experimental work that can be of use in assessing whether patterns of visual behaviour and visual experience in a virtual environment approximate to the patterns of visual behaviour and visual experience in a real environment.

**Research methods**

Empirical data collection is based upon an experimental method is proposed that will gather data from a mobile eye tracking device on visual gaze, points of interest and duration of gaze. Subjects are randomly selected to form two groups of participants, each of which in turn, experience both a real environment and a virtual environment created using the CryENGINE3® game engine software.

When entering the real environment participants wear a head mounted video camera with integrated mobile eye tracker. All ambient sound is excluded to ensure that the only active variables in the environment will be visual. Data collected from the eye tracker is overlaid onto the video footage showing participants' visual behaviour, and analysed on a macro level in terms of *areas/regions of fixation*, and on a micro level in terms of the *point of first fixation*. Visual scan paths are also considered. Participants then are asked to orally convey 'immediate self-report data', describing the visual information they have gathered. Upon completing the experiment the participant exits the space and is asked to respond to standard questions/statements on a visual analogue scale (similar to that used by Imamoglu, 2000) and to re-count what they can remember of the environment they have experienced. All of this is documented in video and audio recordings.

A virtual counterpart of the real environment has been created. To achieve high quality realistic virtual environment a game engine has been identified that allows the creation of realistic virtual environments. Selection was based on the software specifications and reported capabilities. The virtual environment has been created using the game engine software CryEngine3 from the developers Crytek. The real environment was photographed and surveyed to ensure that the virtual environment was dimensionally accurate. Participants enter this environment (instructions on how to navigate within it having been given prior to entering the experiment). The virtual environment is navigated with a controller with two analogue sticks (the left will offer full $360^0$ body rotation in the virtual environment and the right the appropriate head rotation). Participants wear a head mounted display with integrated eye tracker, data from the eye tracker are analysed in the same way as data collected from the real environment. Participants convey 'immediate self-report data' as before. Upon completing the experiment the participant exits the space, completes the questionnaire, as before, and then re-counts what they can recall of the environment. Participants in the virtual environment also complete a 'presence questionnaire' compiled from established examples (Slater, 1999; Freeman et al., 2005, and Slater and Steed, 2000). As before, all activities are documented in video and audio recordings, and as in the case of the real environment all ambient sound is excluded to ensure that the only active variables in the environment will be visual.

Pilot experiments will be conducted in a 'simple' environment (for example, an empty room or office space). The pilot experiment will serve to calibrate the experimental equipment, familiarise participants with the technology, and establish a baseline for participants' visual behaviour in a conventional setting with limited stimuli. In both the real environment and the virtual parts of the experiment, the participant will be placed in the corner of a room. When the experiment begins the participant will be free to scan the room with full head movement whilst remaining stationary. Data obtained from this experiment will be: fixation positions in the x, y and z axes, gaze duration, and regions of interest (ROIs).

The environment to be used in the main research experiment needed to be an architectural space with a particular function. Numerous possibilities were considered, including hospital wards and school classrooms; though these were considered as presenting the participant with too many stimuli and too many subconscious sub-routines relating to function and prescribed perceptions. A more suitable space was an art gallery. An art gallery is normally designed with 'the visual experience' at the forefront of its brief; indeed its prescribed function is that of visual experience. Considerations of light/shadow, material textures and layout all have a direct impact upon the function and the success of such a space, making it a very suitable environment in which to run the final experiment.

Participants follow the same routine as in the pilot experiment: they will be stationary in one corner of the space and will be allowed full head movement. Data are collected through integrated head-mounted eye tracking devices to provide objective and quantitative data relating to participants visual and attention processes in both virtual and actual perceptions of the space. Following this, subjects are presented with a questionnaire survey so as to compare experimental results with the more traditional subjective responses elicited in this way.

## 4. SUMMARY

The goal of the research is to test the efficacy of realistic virtual environments, created with game engine technology, in capturing user experience. Within this broad target there are two issues that are of immediate interest. First, to compare subjective (questionnaire response) and objective (physiological) measurements taken from subjects in real environments with measurements taken in response to virtual environments; and secondly, to compare responses within virtual and real environments that are elicited both by subjective (questionnaire response) and objective (physiological) measurements. At the time of writing these experiments are underway: data are currently unavailable but it is envisaged that these will be forthcoming in time for presentation.

This work incorporates theory from multiple research areas; it is a progressive investigation into the correlation between data gathered from a real environment and a virtual recreation of that environment. The novelty of the research can be ascribed to: (i) its use of photo-realistic simulations created with games engine technology in built environments; (ii) its contribution to the current debate on the relative validity of subjective and objective measurement of visual and experiential realism; and (iii) its input into current thinking about the efficiency and effectiveness of using virtual environments in practical situations involving decision making and problem solving within Computer Aided Architectural Design.

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