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Is VR an effective communication medium for buildings design?

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Abstract

This paper is concerned with the effectiveness of the use of Virtual Reality (VR) to inform the early design stages of construction projects. The investigation has developed a new experimental methodology for assessing building designs and an enabling tool "ASSET". A first VR model of a building has been produced as a vehicle for evaluating the methodology and ASSET and, incidentally, influencing the design of the building. An experiment has been completed to assess if design constraints have been fulfilled.

Introduction

Construction projects are complex and involve large numbers of organisations and individuals, all of whom may be regarded as "stakeholders" in any particular scheme.

A proposed construction project is defined by large amounts of complex, three-dimensional information. Effective communication between members of the design and construction teams, their clients and other indirect stakeholders is a key issue for the industry.

In this paper, the authors have focused their attention in the relation between designer (architect) and end-users. Architects (designers) commissioned to design new buildings for larger organisations such as universities are likely to be buffered from the actual end-users by a client committee or even a full time buildings department. On balance such organisational barriers make the designer's task of understanding the problem more difficult. Even if there are not barriers there are what Zeisel (1984) has called "gaps". He showed that while there might be good communications between designers and paying clients, both have a gap in their communications with the user (figure 1). In a more recent study Cairns (1996) provides empirical evidence, not only to demonstrate the existence of these gaps, but also that neither architects nor their clients were always aware of these gaps. The decisions which are most 'permanent' in the design process –relating to building footprint, structural form and construction- are those which are made at the earliest stage of development. Therefore it will

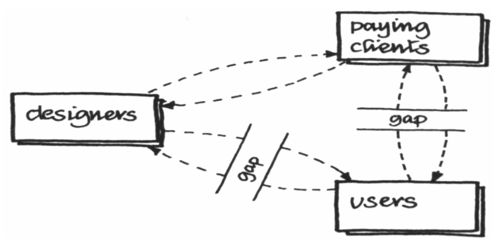

Figure 1. Zeisel's user-needs gap model

be the case that building users, who have had no input to the early stages of briefing and performance specification, may have had little or no involvement in the determination of these most permanent decisions. If they have no involvement in the design and construction processes, they will find their first opportunity for comment only after occupation (Cairns, 1996). At this stage only superficial changes can be made and it is well known that the opportunity to make changes reduces over time as costs increases. VR technologies, in their different variations, can help to bridge the gap between designers and users by channelling the communication between both parties through a more effective communication medium. It is believed that this improvement in the communications amongst the parties will be translated into an early "frozen" design and subsequently will make the design process at its briefing stage more efficient.

The use of VR in the construction process

Prior to setting up the experiments, the authors reviewed the existing research and applications of Virtual Reality (VR) in construction. Different applications of VR were explored and documented according to their use within the construction process (Pre-project phase, Pre-construction phase, Construction, Post-construction). The authors concluded that apart from a series of interesting proof-of-concept exercises (table 1), the commercial use of Virtual Reality in the construction industry is at present, *ad hoc*.

Table 1. VR research in construction.

Stage in the construction process	Research project
Pre-project phase	▪ VOX DESIGN (Donath et al., 1996) ▪ COVIRDS (Tushar et al., 1995) ▪ SCULTOR (Schmitt et al.,1996)
Pre-construction phase	▪ Onuma & Associates (VR News, 1997), ▪ Heng and Love, (Heng and Love, 1998), ▪ UCL and "space syntax" (http://www.vrl.ucl.ac.uk), ▪ TVS (Opriessing and Beer, 1998) ▪ The Depart. of Architecture. and Urban Design at California University (http://www.multigen.com/Sucess%20Stories%20(sp)/ucla.htm)
Construction 1. VR as an interface between designer and constructor	▪ SPACE (Alshawi et al., 1997) ▪ OSCON (Aouad et al., 1997) ▪ VROOMS(http://vrooms.watkins.co.uk) ▪ Opdenbosch's prototype (Opdenbosch, 1994) ▪ The Virtual Construction Simulation Research Group at Strathclyde University (Adjei-Kumi, T 1997)
2. Training tool.	▪ Wakefield and O'Brien prototype (Wakefield, R and O'Brien, 1994) ▪ SSV (Finkelstein, 1998)
Post-construction	▪ Dr Khosrowshashi's prototype (Rad & Khosrowshashi, 1997)

Indeed, commercial applications are developed, by mainly "down stream" process, to visualise completed schemes and allow walk-throughs by using expensive stand alone software packages.
As mentioned above, decisions taken during the early stages of the process are vital due to their possibly dramatic effects on the final project in terms of timing and costs. Therefore, it was concluded that VR technologies should be used early in the design process. However, before applying VR as an enabling technology for building design (the authors chose buildings as an application domain) a design methodology, that will help to merge VR technologies with daily construction practice, should be developed. This is not an easy task since VR is not a fully understood technology and the design process is very complex.

In the young discipline of VR only a few reports are available about the effect of VR technologies on the design process:

- Virtual Reality in Early Design: the Design Studio Experiences (Achten et al., 1999a)
- What Virtual Reality offers to the Designer (Achten et al., 1998),
- The Impact of Virtual Reality on the Design Process (Dorta et al., 1998),
- The Comparison between Visual Thinking Using Computer and Conventional Media in the Concept Generation Stages of the Design (Won. Peng-Whai, 1999)
- Using Immersive Virtual Reality Systems for Spatial Design in Architecture (Donath. D, 1999).

However, none of the efforts mentioned has produced a systematic approach to the design process to evaluate and implement VR technologies to the design process.

Because it is not possible to simulate the physical world in all its detail and complexity, an assessment tool is needed. So for a given task we need to identify carefully what must be provided to evaluate construction environments for human use, e.g. by building users. What needs to be identified includes: the information about the world to be represented, its representation and the interaction with the world. Determining the operational parameters inevitably involves many tradeoffs among cost, performance, and efficiency (Zelter, 1992).

Aims and objectives of the research

Many pathways to the future are open for exploration and defining the potential for VR technologies. However, the most notable challenge lies in finding a new paradigm for co-ordinating technology, user interface and user (Achten et al., 1999b).

The main aim of this research is to investigate the potential of VR technologies (from desktop VR to fully immersive environments) as an aid to visual cognition instead of traditional methodologies such as CAD drawings or artistic impressions.

This ongoing research project attempts to address four major issues:

- The need for an effective/efficient approach to use VR technologies (VE) for different stages in the design process.
- The identification of a first set of requirements for the future implementation of these technologies as a standard practice within the design process.
- The need for techniques which provide discriminatory power to evaluate VR technologies versus other graphics applications.
- Provide the first steps towards a design philosophy for designing Virtual Environments at different stages in the design process.

At this stage, this paper reports on the development of an assessment tool (ASSET) to examine whether or not desktop VR can be an effective way of channelling the end-user's input at the briefing stage.

Research Methodology

When using VR to assess building designs three different variables need to be considered (figure 2): level of detail (LOD) of the VR model of the building, immersiveness of the VR technology used and the type of stakeholder participating in the assessment.

By using the assessment tool (ASSET) described later in this paper, it is intended to manipulate these three variables so that we can explore other goals .

- Assess the level of detail needed (in the VR model) by the user, to analyse the effectiveness of VR as a communication medium for building design
- Comparison between highly, medium (wrap-around screens) and low immersive environments (desktop)
- Compare how the different parties (designers, clients, users) involved in the design process perceive the building through a Virtual Environment.
- Assess the effectiveness of a VR combination (i.e. desktop VR+ users + a specific LOD) as a communication medium for building designs in comparison with traditional methodologies (drawings, artistic impressions, CAD systems, 3D Models).

Figure 2. Variables in the use of VR for assessing building designs.

Level of Immersiveness (LOI)

Since one of the objectives of this research is to investigate how various VR technologies (that provide different LOI) could influence the building design process, it is necessary to clarify what we understand by LOI and how this fits into the definition of Virtual Reality.

Immersiveness can be seen as one the technological variables that influence presence or telepresence which is one of the three axes –the other two, are interaction and autonomy- in the API cube. This provides a conceptual tool for organising our understanding of current VR technology. In this scheme "virtual reality" is an unattainable node in which the value of the three components is unity.

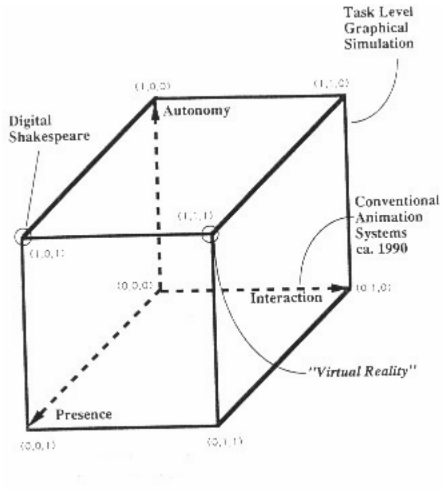

Figure 3. The AIP cube (Zelter, 1992).

Autonomy is a qualitative measure of the ability of a computational model to act and react to simulated events and stimuli(virtual actors capable of reactive planning, and ultimately more powerful knowledge-based behaviours and physically based models). *Interaction* is the degree of access to model parameters at runtime. The *presence* dimension provides a measure of the degree to which input and output channels of the machine and the human participant(s) are matched.

Therefore, in this study the authors are not interested in trying to explain, measure or even find evidence of presence. This investigation is meant to provide empirical evidence of how LOI influences the briefing stage of building design in order to create a new methodology.

Level of Detail (LOD)

As the authors are investigating what LOD can be presented in VE whilst still achieving the "right" impression building for a particular stage of the design process, it is necessary to explain the meaning of LOD. LOD of a VR model is a composite of its object LOD and its scene LOD:

LOD of a VR model = Object LOD + Scene LOD

Object LOD consists of geometry (polygons and vertices), textures (none, colour, surface reflection coefficients, bump mapping,...), shading mode, sound and behaviours. *Scene LOD* consists of amount of objects, scene illumination and accuracy of the scene.

Experimental Methodology

We hypothesised that any form of VR might outperform traditional methods and that different VR systems are suitable for different purposes. The basic concept is that, because of the way "the brain correlates from the visual system" (Mizell & Jones, 1995) that VR might give a human a better understanding of the design of the building. While there is little agreement about what constitutes VR, VR environments seem particularly well suited to spatial learning (Wilson et al., 1996). Regian et al. (1992), showed how simulations of three-dimensional space can be used as tool for transferring "skills" from a simulated task to a real version of the task.

It is often assumed that presence* (the sense of being in one environment "there" when physically in another environment "here" (Witmer & Singer, 1994)) improves performance, although this statement is debatable (table2).

Table2. Central features of technological approaches to telepresence. (Draper et al.. 1998)

Approach	Relationship to Performance
Akin et al.. (1983)	Telepresence* improves performance
Sheridan (1992a, 1992b, 1996)	Telepresence improves performance.
Steuer (1992)	Telepresence improves performance.
Zelter (1992)	Telepresence might improve performance, but might make tasks more difficult and fatiguing.
Slater and Usoh (1993) Slater et al.. (1994)	Telepresence improves performance.
Witmer & Singer (1994)	No clear relationship.
Schloerb (1995)	Performance must reach some minimum level before Telepresence can occur; relationship not established beyond that.
Mühlbach et al.. (1995)	Performance improves telepresence

*Presence is defined as the sense of being in an environment. However, when perception is mediated by a communication technology is more adequate the use of the telepresence. Telepresence is defined as the experience of presence in an environment by means of a communication medium (mediated perception of an environment).

If presence is associated with better performance, then VR systems that foment "this sense of being there" should produce a better understanding of building design for laypeople and possibly professionals accustomed to reading technical drawings.

Our own experience of attending ***briefings*** and witnessing how clients representing end-users of the future building reacted to the presentation of bespoke VR models, suggested that VR technologies should be used in this context, at briefing stage. Dorta and Lalande (1998) have confirmed that initial intuition in their experiments. They showed that non-immersive VR is a more effective way of communicating (design concepts) than traditional tools. However, a limitation of their research is that the results are based on a questionnaire designed to measure the comprehension of the spatial and formal characteristics of a finished model.

Understanding the ***radical constraints*** of the building, because our target group were the potential end-users, was considered the key element to identify an appropriate set of tasks to carry out the assessment. Radical constraints are those which deal with the primary purpose (Lawson, 1997) of the building and need users' monitoring and eventually approval. We obtained these constraints by means of a structured interview with the architect and one of the user's representatives.

The next step was to develop a series of assessments to test a ***desktop VR model*** of a commercial building (£4.5M) produced in collaboration with the architects. It was agreed with them the ***level of detail*** needed for the stage in which we were and to be presented to ***the end-users*** of the building.

ASSET consists of a very detailed *experimental procedure* and an *analysis tool* to interpret the data obtained by video –taping the sessions.

The *experimental procedure* was divided into three parts:

Part 1: to screen human and technical factors

1. A series of background information questionnaires are handed out to the participant:
   -1.1 General state of health, age, confirmation of visual capabilities (colour discrimination, spatial resolution, depth perception), amount of weekly computer use, and extent of spatial navigation and training experience.

      1.1.1 Confirmation of visual capabilities and amount of weekly computer use.
      1.1.2 Pre-Exposure Background information
      1.1.3 Pre-Exposure Physiological Status Information

   -1.2 Participants are also required to complete this background and pre-symptom checklist portions of the SSQ (Simulator Sickness Questionnaire) (Kennedy et al., 1993). This questionnaire has been successfully used by Lampton (Lampton et 1995) to measure the incidence and severity of simulator sickness in virtual environments. Lampton showed a relation between high ratings on the SSQ and performance decrements (Bliss et al., 1997). Witmer and Singer also demonstrate that increasing levels of presence tend to occur with decreased levels of VE sickness (Witmer and Singer, 1994).

2. Apart of the considerations mentioned above, a series of technical requisites were set to assure that none technical factor influence the user's performance (table3).

Table 3. Technical requisites

Technical factor	**Minimum optimum standard**
Graphics refresh rate	Vertical 60 (U.S)/50 (U.K.) Hz Horizontal 70 Khz
Frames per second	24-30 fps (Goiffet et al., 1994)
Latencies	No greater than 100 msec to avoid dizziness and sickness (Goiffet et al., 1994)
Resolution	1024 x 768 pixels, 24 bits (true colour) depth.

Part 2: The participant is asked to carry out a series of tasks with an interactive 3D model of a building, while doing this they are required to think aloud; a procedure that has proven to be very useful to analyse usability problems of new software (Nielsen, 1993). Prior to carrying any task, the participants are prepared to make them aware of what they are required to do in order to produce "rich" verbal protocols, both passively by watching a video and actively through practice tasks.

Part 3: the participant is asked to answer further questions regarding his/her experience within VR model of the building. After that he or she is debriefed.

The analysis tool comprises a coding scheme for verbalisations and physical movements that allow assessing the participant's input regarding the radical constraints of the building.

The use of ASSET is illustrated in Figure 4.

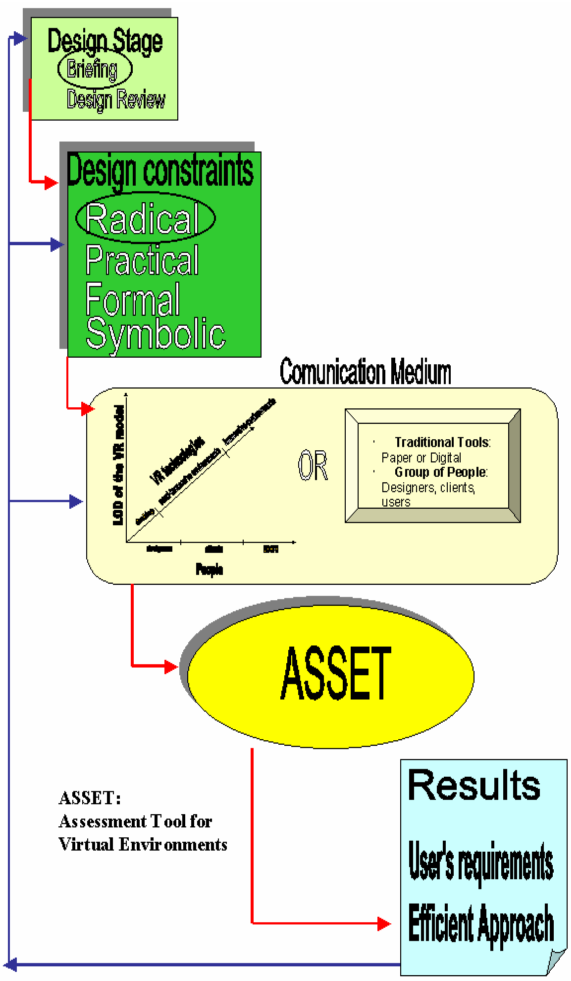

Figure 4. The use of ASSET in the building design process.

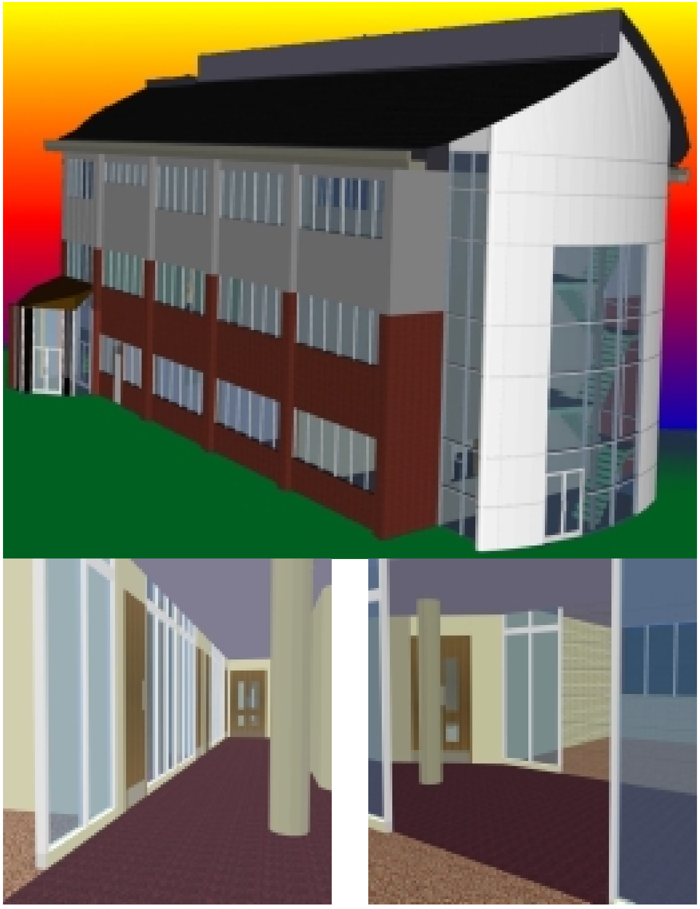

Figure 5. VR model of the CE.

Case study

Project: Centre for Enterprise (CE). Budget: £4.5M. Architects: The DEWJOC partnership

The model was constructed from the CAD drawings and in collaboration with the architects. The project had been alive for six months and therefore a great number of decisions had already been made, especially regarding the exterior of the building.

The CE project took one developer (the first author) seven weeks to produce the VR model (figure 5). This time included a training period in the software applications: MultiGen, 3D Studio Max 3.1 and Adobe PhotoShop 5.0. There are approximately 35,000 polygons in the model and it uses approximately 4 MB of texture memory. The model attains a frame rate of 30 frames per second in almost all areas.

During the development of the model a few inconsistencies were found in the "final" design, the most significant being the roof of the lobby area (white circle in figure 5 and also figure 6). As a result of the VR model, it was completely redesigned.

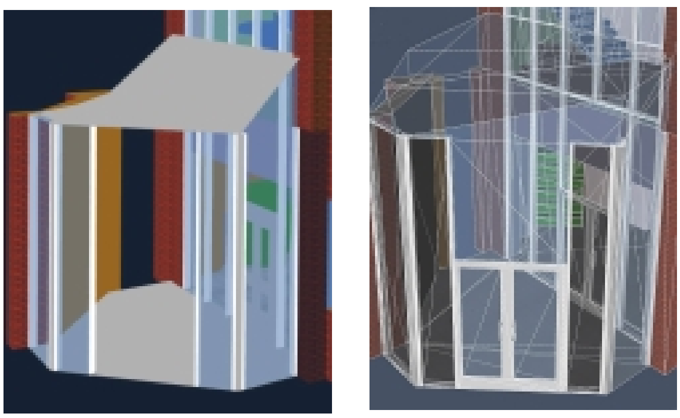

Figure 6. Roof of the lobby area before and after.

The desktop system used in the experiments is presented in figure 7.

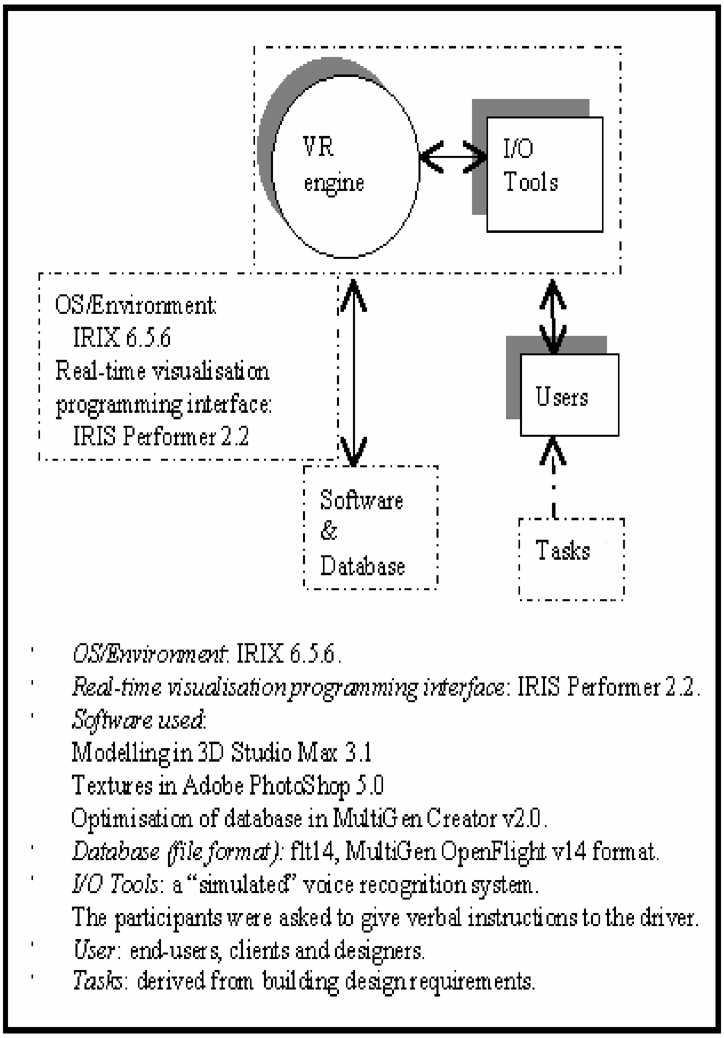

Figure 7. Detailed description of desktop VR system used for the experiments

Results and conclusions

Based on Nielsen's mathematical model of the finding of usability problems, the authors decided to test the new interface with 7 different end-users. Although, the curve clearly shows that you need to test with at least 15 users to discover all the usability problems in the design, Nielsen recommends testing with smaller number of groups: three iterations (test-redesign the interface) with groups of five. The main reason is that it is better to distribute your budget (efforts in our case) for user testing across many small tests instead of blowing everything on a single, elaborate study. After the first study with 5 users, according to Nielsen's experience you will have found 85% of the usability problems, you will want to fix these problems in a redesign and test them again. However, Nielsen's formula only holds for comparable users.

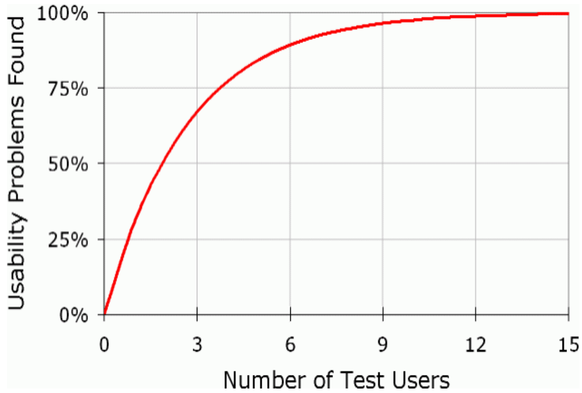

Figure 8. Nielsen's problem of finding usability problems.

So far the research has achieved the following results: (1) a new experimental methodology for assessing building designs has been developed; this can be used not only to assess if design constraints have been fulfilled, but also to compare different communication media; (2) a tool "ASSET" has been developed to enable the methodology; (3) a first VR model of a new development in the University of Teesside campus has been produced as a vehicle for evaluating the methodology and the tool ASSET and, incidentally, influencing the design of the building; (4) an experiment with seven participants, has been carried out and data collected. The results of the experiment will be reported in future publications and presented at the conference.

Plans for future work will include a second version of the model, with a higher LOD. This model will be tested using a more immersive VR immersive technology, with different groups of people.

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