EXPLORING CAVE: USING IMMERSIVE ENVIRONMENTS FOR DESIGN WORK

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Providing complex health and care infrastructure brings with it demanding design requirements. Information Modelling (BIM) is increasingly used as a solution to managing the complexity of the design process, and coupled with collaborative virtual environments, offers the potential to mediate design activities in ways not possible with traditional CAD models and drawings. This paper describes early analysis of the use of virtual environments for performing design. The project being studied is the design of a new hospital in the UK with all patient accommodation in single rooms. There are particular client requirements around the size of the rooms, and the visibility of patients from nursing stations. Models of the single rooms were imported from CAD models into a CAVE – a 1:1 scale 3D immersive environment set up in a UK University lab. The design teams then used the CAVE to review the design against the client requirements. The methodology for the research consists of both direct observation of these review meetings and analysis of video and audio data captured during them. Early analysis is revealing three emerging themes around the practicalities and utility of this immersive technology. The first is around the work done by users to initially orient and familiarise themselves with the technology and virtual space. The second is the way the environment allows things to be noticed about the design which have previously not been identified. The third is the way users shift between their role as designers, and imagined roles as client viewing the model.

Keywords: CAVE, client engagement, design practice, immersive environments.

INTRODUCTION

Providing complex health and care infrastructure brings with it demanding design requirements. Information Modelling (BIM) is increasingly used as a solution to managing the complexity of the design process, and coupled with collaborative virtual environments, offers the potential to mediate design activities in ways not possible with traditional CAD models and drawings. The study is based on the design of a new hospital in the UK with all patient accommodation in single rooms. There are particular client requirements around the size of the rooms, and the visibility of patients from nursing stations. The study focuses on understanding how the design

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process is being performed in an immersive environment and on distinguishing particularities of this experience.

LITERATURE REVIEW

Existing research around understanding new technologies in building design work point out the complexity of implementation and highlight how unpredictable ways of interacting with new technologies may generate 'hybrid practices'; where new tools and technologies are incorporated into, rather than replace, existing ways of working (e.g. Harty 2005; Harty and Whyte 2010). It is also noted that the effects of implementation may “spill beyond a single sphere of influence” (Harty 2005: 515) and function at an inter- organizational level. This presents a challenge in anticipating and predicting the outcomes of utilising new technology which may, as Harty states, bring about “not only transformation of practices, processes and systems, but also the potential transformation of technologies themselves” (Harty 2005: 512).

Taking into account this idea of tracing the dynamics of innovation in design practice and the various patterns that are established through interaction, this paper sets out to understand how immersive virtual reality environments (IVRE) as non -traditional technologies might impact on both design work and on the way design is communicated to stakeholders. The capabilities of virtual reality (VR) technologies for supporting design processes have been discussed. For instance Whyte describes the potential of this “interactive, spatial, real-time medium” (Whyte 2002: 4) to “augment and extend” (Whyte 2002: 54) the use of CAD packages. Similarly, studies around hybrid design environments examine circumstances of immersive and non-immersive architectural design (e.g. Okeil 2010), building on VR’s features of providing “the feeling of presence in a three dimensional computer generated world” (Okeil 2010: 204) and emphasizing on “the user’s ability to interact directly and in real time with the virtual environment” (Okeil 2010: 204).

Other research around developing technologies for design and construction looks for new methods to support the end-user’s involvement and to set up an intuitive way of collaboration and sharing information in all stages of design process (Christiansson 2011). This context is complementary to studies exploring the interdisciplinary use of 3D object models to improve interactions inside and outside design teams (Moum 2010), or developing platforms for spatial interaction management (Lertlakkhanakul 2008). Potential uses of VR within specific construction design process have also been studied, such as supporting the collaborative design review (e.g. Wang and Dunston 2008) or for other stages of architectural design, like conceptual design (e.g. Anderson, Esser and Interrante 2003).

The potential and use of VR technology for mediating work on health and care projects has also been explored. Both the HospiTool project developed by VTT in Finland (Nykanen, Porkka, and Kotilainen 2009), and the CAVE-CAD software created at the University of California (Palmer 2011) developed an interactive user – orientated and performance based design process, and looked at how testing the virtual spaces experientially enabled monitoring and measuring psychological feedback from users.

METHODOLOGY

The aim of this research is to investigate the potential of CAVE technologies to mediate design activities in ways not possible with conventional CAD models.

The case study is based on an on-going project for designing a new hospital in the UK. One of the requirements is that all patient accommodation is in single rooms, rather than traditional wards. Single room only accommodation is rare in the UK, and so a key issue for the client was ensuring that the rooms were of sufficient size. At the time of the research, the project was still in bid preparation stage. The project team opted to augment the traditional design and client engagement procedure with the use of a CAVE (an immersive virtual reality environment) at the University of Reading. This was to be used to demonstrate to the client that the rooms were of an appropriate size.

The CAVE (Cave Automatic Virtual Environment), is a multi-person, room- sized, 3D multi-display medium that provides an immersive environment for simulating and viewing at full 1:1 scale virtual models (e.g. CAD). It offers the user (equipped with 3D glasses and a head mounted tracking device with location sensor) an active and real-time interaction with the model. The CAVE at the University of Reading has three vertical projection screens (3m by 2.2 m) and a floor projection screen (3m by 3m).

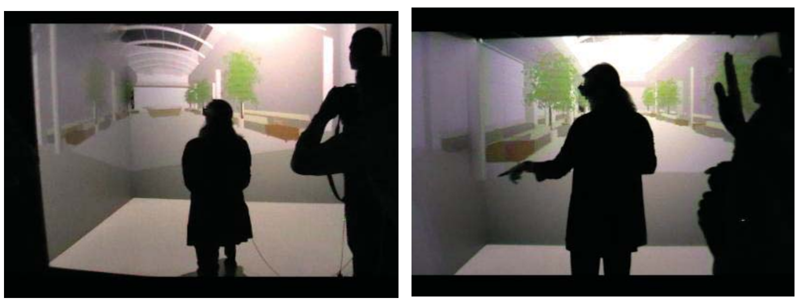

Figure 1: the CAVE

The research used video recording and direct observation of a series of six sessions held within the CAVE, involving project and design managers, architects and designers, and modellers and visualizers, in various combinations. These were spread across five months, between November 2011 and March 2012, culminating in a session with representatives of the client. These sessions produced 11 hours of audio-video recordings. Various combinations of video cameras have been used to capture the design meetings: one hand-held camera, a second camera fixed on a tripod, positioned in one corner of the CAVE and a third camera fixed on the CAVE's ceiling to offer an aerial top down view.

For this paper we were most interested in the processes of design reviewing occurring in the CAVE, the activity around presenting the models to the NHS client and their use in demonstrating particular design requirements, such as the size of the single rooms and the visibility of patients from nursing stations, and more generally how design teams and contractors are exploring a new work setting. The data was sifted to select particular episodes which are examined in detail below. This approach draws on video ethnography based studies of workplaces and of interactions (Heath and Luff 2008; Heath, Hindmarsh and Luff 2010). The transcripts presented in the paper have been produced using a simplified transcribing system provided by Silverman (2006).

EMERGING THEMES

Theme 1: Orienting to the technology and virtual space

The first theme examines how the immersion in the CAVE requires certain ways of movement in the setting and navigation of the model. Although the virtual space is large, the physical dimensions and technical aspects of the CAVE are always present. To explore the model, participants shape their behaviour by adjusting their body positions (they put on 3D glasses, hold joysticks or connection wires in their hands), and by changing their shoes (to protect the sensitive floor projection screen), and through limiting the motion within the physical space of the CAVE (to avoid collision with the rear projection screens).

Evaluating the model (dimensional geometry, perceived volumes) requires aligning the review process to the particular physical capacities of the setting and of the technology. Prior to the design meeting session, participants familiarise themselves with the spatial perception (perspective angles, dimensions, geometry) allowed by the technology and with features of lighting, colours and textures, in the CAVE as compared to the CAD models geometry, and computer screen representation. The technician introduces them to the limitations of imagery in the CAVE (inaccurate representation of light and textures), as well as to capacities such as objects' motion and animation. The participants evaluate the geometry perception, while testing various viewing angles allowed by the stereoscopic glasses and the head trackers. To make sense of the immersive virtual environment across several sessions in the CAVE, the teams' members learn particular ways of directing the patterns of the design review process and a certain way of communicating between themselves.

Episode 1 (E1)

Designer 1 (14:14):	It's totally out of perspective for me, I can't tell anything.
CAVE technician 1(14:16):	Do you want to swap head trackers over there?

During an episode of discussing textures in the patient room, one designer expresses her difficulty in evaluating the space because of the distorted perspective (E1, 14:14). The CAVE technician invites them to swap glasses, so that each team member can see the model whilst wearing the head tracker, to get the most accurate perspective (E1, 14:16).

Designer 2 (14:23):	It's odd (.) It's something to do with the point you sit.
Designer 3 (14:25):	It's got to do with me ((laughs)) yeah:
Designer 1 (14:27):	'Cause you have the head trackers on.

The designer wearing the head trackers moves through the CAVE to swap the glasses, but hesitates and stops to explore the model, displayed on the surrounding projection screens, as she notices that by her movement, the model is offering a different perspective. Such a reaction suggests the impact of the reality-like effect of moving within the CAVE space, provoked by perceiving different perspective images as viewing angles change continuously to correspond with the observer's position and orientation (E1, 14:25). Another observer points out the correlation between the glasses and the visualised projections (E1, 14:27). This episode suggests how participants learn the rules of navigating the 3D virtual model in the CAVE, acknowledging that navigation is led by one person at a time and the other participants have to follow his movements and within the containing space and the generated projections.

Episode 2 (E2)

Designer 4 (23:13):	That's good. This is very successful.
Designer 4 (23:29):	But I think they seem a bit smaller spaces.
Designer 5 (23:32):	Do they seem obviously smaller?

Designer 4 (23:33): No.
Designer 5 (23:33): So that's good!

One member of the designer's team expresses his appreciation of the model as presented in the CAVE. The examination entails a positive impression (E2, 23:13) and even though the appearance of the space as 'small' is noted the overall impact is a satisfactory one. The above fragment reflects how the design meeting participants establish through discussion a shared way of understanding and interpreting the perception of the 3D model's representation, based on the specificity of the technology.

Episode 3 (E3)

Designer 1 (14:52): It seems like you see a corridor when you put head trackers on. It looks like the window is far away. 'Cause the window really is far away.
Designer 5 (15:05): Yeah: It does actually.
Designer 5 (15:06): It's quite interesting:, isn't it? 'Cause this space is so tiny(..)
Designer 5 (15:15): Well: that is part of the problem with our rooms.

When one designer takes the head tracker, another designer who knows the geometrical features of the room, utters her impression of how the spatial perception is about to become different. The user is forewarned about how the depth of the patient's room will appear augmented from the previous perspective that she could perceive just with 3D glasses. It is pointed out that even though the room has a small area, which conflicts with the client's requirement, the 1:1 scale perception in the CAVE presents a satisfactory spatial sensation.

Summary theme 1

The episodes above address issues of perception experienced by the participants when exploring the model of the hospital and navigating within the real space of the immersive environment. Examining their perception of perspective, size, volume, geometry and dimensions, the observers remark differences between representations of the model as visualised with the head trackers and as observed with 3Dglasses. The observers point out the distortion effect of the viewing perspective, depending on the angle and on the type of glasses they are wearing. They notice that not all of them are able to see the same image at one time (they have to change glasses), and particularly the person who is leading the discussion at each time is being offered the head tracker to have a clear judgement of the undistorted perspective. It is suggested that the interior space of the patient room is perceived to be slightly smaller as projected in the CAVE than the dimensions of the precise geometry of CAD layouts. Building on these observations, the group members establish a particular way of performing the design review in the environment and establish a contextual code of using the technology for their objectives.

Theme 2: Drawing attention to detail

The second emergent theme looks on how the representation of the design in the CAVE affects the design review process. The focus is on distinguishing specificities of the design's representation in the CAVE versus its representations in other traditional media and looking for particularities of the review process, which these differences might bring about. It is examined how the designers teams are using the CAVE technology to verify how the design is complying with the functional flow and with the aesthetical and technical requirements of the hospital programme and, particularly, with the client's expectations.

The distinctiveness of an immersive and navigable simulation of the 3D model, at more real scale, and experienced as an extension of designers' more familiar and perhaps mundane setting and tools, serves to explore the work they had previously created in their offices. Expectations and assumptions on spatial effects, intended through their design solutions, were either confirmed by the visual perception enabled by the CAVE, or in some cases there were not as noticeable as wished for. The fragments selected address issues of comparing the perception of the 3D model visualised (with 2D-3DCAD) on desk computer screens and its visualisation allowed by the CAVE technology in the immersive, 1:1 scale environment.

Episode 4 (E4)

Designer 2 (25.27):	You don't get the perception of the curve, as you do on the plan:.
Designer 5 (25.35):	No.
Designer 2 (25.39):	'Cause we do [get it] with the bird's eye view all the time.
CAVE technician 1 (25.39):	Yeah, I believe that. 'Cause when you zoom out-in you have different perception.

Performing the review process, team members examine how spatial effects at a real scale and the perception allowed by the CAVE match the assumptions of the conceptual design and the expected associated visual representation. The design session illustrates how these can be either confirmed (e.g. "One (), two (.), three! We can see three beds", (20:40), in verifying the client's requirement for visibility of the patient rooms) or, can be not confirmed ("You don't get the perception of the curve", (E4, 25:27), in the sequence of discussing the visual perception of the hall).

The episode of checking the curved shape of the hallway, the designers are disappointed to observe the lack of the curved effect, as previously noticed in the 3D CAD model on the desk computer screen. Even though they would have had the possibility to observe the same effect on the desk computers, the context of evaluating geometry of a large area within a screen space (set up at a desk's height) is more likely to prefer an aerial perspective (bird's eye view), rather than using the human eye line of sight. The differences noticed between perceiving the spatial geometry using the CAD simulation on computer screens, and the perception of the 3D model simulated in the CAVE, might suggest differences of performing the design process in traditional work settings and in the CAVE.

Episode 5 (E5)

CAVE technician 1 (24:20):	So how does it compare from when you look at it in Revit?
Designer 1 (24:25):	Oh: (1) Hum:: (.) It's not really comparison: I mean the views in Revit are always stretched, because of perspective cameras (.) You do walkthrough in Revit, you have the path, but you don't have that feeling of space.
CAVE technician 1 (24:57):	So do you find it useful?
Designer 5 (24:59):	Yeah:. Specially people that don't understand the scale of spaces that we're showing them (…). So they might

	think we're completely lying when we're showing them perspectives.

It is pointed out the usefulness of the CAVE (E5, 24:57 and 24:59), as allowing a better understanding of the design compared to conventional design presentation interfaces. The design session participants indicated the 1:1 scale and the feeling of space (E5, 24:25 and 24:59) as elements specific to the CAVE, that might better communicate the design, especially to a client who may lack the knowledge of spatially interpreting conventional visual representation.

Summary theme 2

Possible differences between the design (review and visualisation) process in the alternative technological settings can be seen. Participants pointed out three issues. Firstly, the reported differences between perceiving the spatial geometry in the CAVE and in traditional design settings (such as CAD packages used on desk computer screens), by means of possibly revealing things that have not been previously noticed. Secondly, it has been highlighted the sense of presence (enabled by the interactive immersion, at a human scale perception) as distinctive feature provided by the CAVE's technology. Thirdly, it has been indicated the usefulness of the technology, particularly as instrument for presenting to the client, through providing more intuitively the sense of scale and enriching the non-specialists' understanding of the design.

Theme 3: Shifting roles as designers, and imagined roles as client

The third theme focuses on how participants simulate the experience of occupying the designed space. In addition to a "sense of being there" (as highlighted above) participants simulated different roles. In a game-like performance they were verifying spatial dimensions and viewing angles as though they were the non-expert client viewing the model, 'acting' as nurses, patients or clients by testing the lines of sight from the nursing station, adjusting their position, simulating sitting down on the patient's bed, or on the toilet). As a function of the immersion in the setting, body movements are perceived realistically, and gestures towards representations of the hospital's interior spaces (rooms, halls, atrium) such as pointing out with hands or fingers, are regularly engaged throughout the reviewing process, as well as navigating with the controller. Multiple changes of gazes (towards different sides of the rooms or corners of the CAVE), reorienting heads' directions, or physically moving around inside virtual rooms attempts to perceive the spaces in the way end users of the not yet built hospital might.

Episode 6 (E6)

Designer 5 (07:28):	This is totally blocking what is suppose to be there: ((pointing with the hand)), towards the atrium.
Cave Technician 1 (07:36):	But this is partly unknown yet. They just want to see what's happening.
Designer 4 (07:38):	But we don't want them to see that!
Designer 5 (07:39):	Yes, we don't want them ((the client)) to see that.
Designer 4 (07:41):	We don't want them to see, no, ((that)) you can't see that. ((the atrium))
Designer 2 (07:45):	Ok. 'Cause this is ((just)) a phase, no? ((of the design proposal))
Designer 1 (07:58):	((Speaking about the model)) It's good, though!

On examining the issue of visibility towards the atrium area, team members are observed as playing the role of the client. Imagining the client's feedback regarding the spatial perception of the model entails filtering the visual information through estimating the model's compliance with presumed expectations. Even though it has not been mentioned as a design requirement, and although this phase of the project is strictly meant to illustrate the spatial outcomes of the layouts discussed on previous stages (E6, 07:36, 07:45), the visibility towards the atrium area is assumed to be, preferably, accomplished.

Drawing on the previous theme of the analysis, which discusses how the technology allows things to be noticed, the episode illustrates how the model in the CAVE reveals a lack of visibility (E6, 07:28). In discovering this, they decide not to show this visual effect to the client, even though at this point the design is not fixed (E6, 07:38, 07:39, 07:41). The use of the CAVE as a 'marketing tool' is to be noticed in this episode, as only particular viewing angles will be selected for presenting to the client, those considered to be potentially advantageous for the bid, in terms of complying with the maximum possible requirements and presumed expectations.

Episode 7 (E7)

Designer 2 (08:56):	This is huge. ((pointing with the finger))
Designer 5 (08:58):	No, no. They have to. (be in here). Because they are all the imaging screens. ((showing with hands)) No, they're showing: (.) whatever imaging they're doing, to the patient that's on the table ((pointing with hands towards the on the left side of the operating theatre)). Will show up and then can look at different views on those screens. ((pointing towards the screens on the right side of the room))
Designer 2 (09:14):	But this room, is huge, but it doesn't look big.
Designer 2 (09:18):	It is a big room.
Designer 1 (09:20):	This is 80sqm.

The episode of reviewing the operating theatre again illustrates simulating roles of end users. Several issues are to be noticed in this sequence: firstly, the impact of the spatial perception in the CAVE, secondly the analysis of technical equipment from the end user's point of view, and thirdly the frequency of physical gestures and body movements as part of the discussion. Despite certainty over the theatre's size, (E7, 09:14, 09:18, 09:20), the model in the CAVE reveals a perception of the operating theatre as small, and a disharmony between the "huge" volume of the equipment (E7, 08:56) and its placement in the room. The issue of perceiving spaces differently in the CAVE has been previously acknowledged (as presented on the first theme's discussion). The situation provokes questioning the dimensions of the imaging equipment (through considering that furnishing a room with too big or too many objects might create a crowded effect and an undersized look).

To explain, a member of the group proceeds to describe the equipment based on its subsequent use by the medical staff (E7, 08:58). The succession of actions related to particular parts of the equipment is presented with the support of visually illustrating each step of the medical procedure. The 3D model's examination is dynamically accompanied by observers' physical motion inside the space, while constantly reorienting their gazes and the direction of heads, and/or indicating different zones by making gestures with hands or fingers. This kind of dynamic exploration of spaces accompanied by a set of physical reactions of the participants while reviewing the design and experiencing occupying the space, may be distinguished as a particularity of the design process within the CAVE.

Summary theme 3

Simulating scenarios is a part of the design process, which is often testing the outcome of the spatiality inferred from the existing CAD models. Such scenarios are regularly being imagined, through associations between dimensions in the model and in the real life. Yet in this instance, arising from the immersion in the CAVE, enables a more physical experience of this simulation. Despite certain limitations (such as the lack of tactile feedback, or a restricted accuracy of detail), the CAVE provides the "sense of being there". This is a transition from conventional, static examination of the 3D model (which solely allows visualising it's representation on computer screens), to a more dynamic and physical investigation, through engaging the participants' bodies in exploring the designed spaces. In the CAVE, physical motion inside the space is enabling a distinct way of tracing the flow of activities meant to be performed in the spaces especially created to accommodate them. It also demonstrates a different way of exploring the compatibility between form and function, and the ergonomics of the spaces created.

DISCUSSION

The discussion around the three emergent themes reveals several observations concerning design meetings performed in the CAVE. As depicted in the first theme, aligning the CAVE within the design process requires learning or developing specific procedures for navigating the physical space of the CAVE and navigating the virtual space of the 3D model. The last implies understanding the spatial perception of the representation projected, as allowed by the technology. The second theme outlines two issues. The first addresses the particular spatial perception mediated by the CAVE and looks at how this allows design features to be noticed, not noticed, or juxtaposed with visual outcomes unexpected from perspectives based on CAD models. This relates to how the immersive translation of the layout's geometry is either confirming or not confirming design expectations. The second points out the usefulness of the technology, in terms of allowing an enriched spatial understanding of the design, by providing the "feeling of space" generated by immersion in the model. The third theme reveals how the immersion at the 1:1 scale of the CAVE enables a more dynamic exploration of the model, allows the physical motion of participants in the space, and provides a different way of making sense of the space. This entails a different experience of simulating roles of end users or clients.

CONCLUSIONS

Drawing on such observations, several conclusions might be outlined. Although conventional design simulations have the capacity to allow the perception of spatial geometry and dimensions, using such technologies seems to not reveal certain aspects as obviously and intuitively as the CAVE allows. The freedom of engaging in natural behaviour (moving; looking around) inside the virtual space suggests a different sort of review process, shaped towards a way similar to examining an existing building. It is a means of enabling a fluid and experiential simulation of the actions and activities meant to be performed within these spaces. The technology allows an enriched way of understanding the geometry of the layout as translated to realistic dimensions. The level of detailing the model and the chosen perspective angle might entail limitations or distorted visual effects but nevertheless such immersive, dynamic interaction provides a different sort of flexibility in understanding the space.

This study is built on data based on direct observation and audio- video recordings. Augmenting this data set with more reflective interviews with the various participants involved might enrich the understanding of the phenomenon. Tracing back (individually) the groups of designers, visualizers, contractors and clients, and allowing them to reflect on how they had perceived the impact and value of experiencing the CAVE, would be an interesting addition to the data.

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