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MIXED REALITY AT THE SKETCH DESIGN STAGE

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Abstract. We discuss the use of multiple design representations to enhance decision making at the early stages of design. Our particular interest is in the way in which context can be extended by two interrelated approaches: (1) the incorporation of the temporal; and (2) through the concurrent evaluation of qualitative representations and quantitative information. Outcomes from a practice survey are used to formulate approaches to the use of mixed reality (MR) technology that reflect design-specific modes of working. We propose two approaches – studio MR and site MR – reflecting the distinction between the act of design and the process of a design review. The implementation of a studio MR application and illustrative design project are presented.

Keywords. Design representations; mixed reality.

1. Introduction

Our previous research in the field of design representations has explored the potential of hybrid approaches to support design conception and review. Mixed reality technology that combines real time context with digital models, offer the potential to further this research agenda. Our particular interest is in the way in which the representation of 'context' can be extended by two interrelated approaches: (1) the incorporation of the temporal; (2) through the concurrent evaluation of qualitative representations and quantitative information typically relating to functional performance. In relation to the temporal aspects of design context we distinguish between two approaches. The first builds on a long tradition in which architecture is conceived in terms of temporal sequence, as celebrated in the Villa Savoye where architecture is best appreciated, according to Le Corbusier "on the move" (Bois and Shepley, 1984). Here time is considered from the viewpoint of the mobile observer where architecture is surveyed as a temporal sequence of form, space, surface

and the event of occupation. The second considers multiple time scales and the capacity of architectural experience and performance to be transformed within a dynamic environment. Central to both the peripatetic and scalar aspects of temporal context is our interest in the concurrent evaluation of the qualitative and quantitative attributes of a design. Our previous research in multiple design representations, and evidence from a recent survey of practice, suggest there is much to be gained by the co-presence of visualisations that capture the formal attributes of a design alongside quantitative measures, such as environmental and structural performance.

Currently there is growing activity within the CAAD community and beyond in 'performative architecture,' which typically maps functional data directly to digital models. This trend has been facilitated by the recent availability of graphics programming interfaces where performance data can be mapped to geometry variables. While it is encouraging to see the development of designer orientated programming interfaces, there has been criticism of performative architecture as a return to functional determinism (Pellitteri et al., 2008). Clearly it would be naïve to ignore the qualitative aspects of a design when evaluating designs, in particular the impact of design proposals in a wider design context. It is with this agenda of temporal context and concurrent evaluation that we are exploring ways in which mixed reality technology can be integrated into design practice at the early stages of design.

The research is based on a method of practice survey, the specification and prototyping of technology and strategies that respond to current practice evident or implicit in this survey, and an evaluation of the potential benefits that may arise out of adoption of such technologies by design practices. The practice survey has been undertaken and the next section summarises observations from the survey transcripts and examples of work collected. A subsequent section summarises the range of mixed reality technologies and articulates two approaches that we consider offer potential for practice: a studio-based and on-site configuration. The second part of the paper reports on the technical development of a prototype studio system. In order to partially illustrate the potential of this approach, the prototype has been used to enable the sketch design of dynamic sun shading for a high rise tower.

2. Practice survey

As has been reported elsewhere, the practice survey involved 22 Melbourne-based design practices of various types and sizes (Dave and Moloney, 2009). Using the format of a structured interview the designers were asked to respond to a series of questions relating to the use of design media to incorporate temporal context. In addition practices were requested to provide examples of

projects in which consideration of temporal context informed design development in the form of sketches, photographs, drawings or writing. The survey revealed a full range of analogue and digital media with design representations ranging from abstract lines and figures to the highly detailed and photorealistic. This overlaying of abstract and 'real' representations evident in the survey, to our minds, foreshadow functionalities that would be desirable in future mixed-reality applications.

The central observation is that for new digital technologies such as mixed and augmented reality to be effectively integrated into existing practice at the early stages of design, they need to enable the concurrent use of analogue media and a range of digital techniques. Secondly designers require a continuum of representation fidelity, from the abstract to the photorealistic and ideally, to be able to integrate visualisation with functional performance simulations. Below are some more specific observations from on the use of digital technologies within the surveyed practices.

- **Peripatetic movement.** The classic strategy of key-frame sketches in context is carried through in the form of fixed path animations, and interactive 3D exploration (e.g., VRML, game engines, etc.) (figure 1A).
- **Site- and time-dependent changes.** Continuous phenomena such as light, shadows, sound propagation, energy and wind flow, etc. are used in design to both inform and evaluate design alternatives. Whereas discrete representations at one spatial frame of reference (as sketch, graph, etc.) were the traditional vehicles, various digital modelling tools now support analysis and reading of these changes over space and time (figure 1B).
- **Situated view cones.** This is a way for designers to locate themselves at a point in space to see what is visible as a way to confirm the fit between spatial elements and qualitative experiences (view, protection, continuity, etc.) (figure 1C).
- **Volumetric morphing between points.** Complementary to the above design explorations is the strategy of morphing spatial changes between situated view cones or animating parametric assemblages (figure 1D).

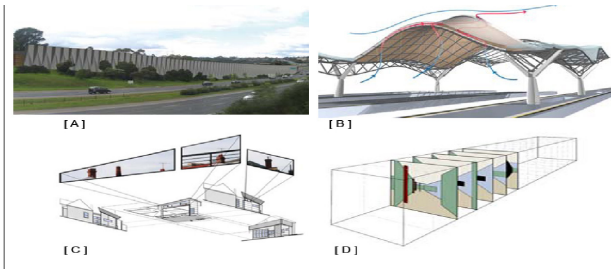

Figure 1 A–D. Sample projects from practice survey.

3. Mixed reality: two scenarios for architectural design practice

In order to support such fluid inquiries and augmentation of design process, mixed reality applications need to integrate and support functionalities that reflect discipline-specific modes of working. Mixed reality as a term allows a wide range of technologies and the consideration of appropriate technology is central to our research inquiry. The taxonomy of Millgram and Kishino (1994) is a robust classification that articulates soft boundaries between fully synthetic digital space and the video display of real environments using what they term a "virtuality continuum." This allows a distinction between displays that combine the real and the synthetic, of which there are two primary types – augmented reality (AR) and augmented virtuality (AV). Within the primary distinctions of AR and AV are a number of other approaches that have been classified along the continuum including amplified, mediated and virtualised reality (Schnabel et al., 2007).

Building on observations from the practice survey, the second stage of our project is to locate opportunities along the virtuality continuum for the particular focus of this research – the concurrent evaluation of qualitative and quantitative representations in a temporal context. What mix of technologies will enable design ideas to be evaluated in relation to a dynamic context, from multiple motion paths, and at the same time allow the superimposition of functional performance data? Perhaps more importantly for design practice, how might these technologies be implemented in a studio design environment? In relation to these questions the survey of Schnabel et al. (2007) usefully clarifies the issue of suitability of technology for specific activities. Their review evaluated technology along the continuum in terms of two factors: (1) correlation between perception and action; and (2) level of interaction with real artefacts. The first factor is based on human computer interaction research that demonstrates the more we can use our everyday motor activities in interacting with virtual objects, the better the performance. The second factor is based on research in activity theory that takes the perspective "that the computer is just another tool that mediates the interaction of human beings with their environment" (Kaptelinin, 1996). In contrast with earlier cognitive theories of human computer interaction, activity theory takes into consideration the impact of traditions with non-computer tools and the social context in which digital tools will be used. These factors are of particular importance to architectural design at the early stages. In this regard, we should be clear on the distinction between the individual act of *designing* – the formation of early ideas on paper, and with physical and digital models – and the process of *design review* in which these sketch designs are evaluated. Typically designing is a reflective activity, the individual designer(s) developing ideas as an internalised conver-

sation with a range of media. The design review by contrast is a group activity, in which design options from different designers, are compared and discussed in relation to a range of issues.

In recognition of these two modes of design activity we propose two approaches to mixed reality applications in architecture. The first is orientated towards designing that we refer to as studio MR. The second is directed towards undertaking a design review in context, and which we refer to as site MR. In both systems we reject the use of head-mounted displays as they restrict the incorporation of analogue media and interaction between designers. As illustrated below (figure 2A) the studio-based system is envisaged to allow designers to integrate design models with a database of site video, more abstract virtual environments and integrates quantitative analytical simulations with the visualisation. The emphasis is on co-locating multiple views and data types and has some resonance with the research of Lee et al. (2008). The second system (figure 2B) is intended for a design review on site. A large-scale LCD incorporating a touch screen interface is mounted on a mobile platform. Design models are superimposed onto streaming video with ambient and directional lighting been updated by sampling the video feed and accessing a database of sun paths. As the location on site can be pre-calculated there is no requirement for full motion tracking. Instead a motion sensor allows pan and tilt and the video camera zoom is synchronised with the design model. The level of interactivity is under review. Prior to the survey we had envisaged interactively substituting design models with simple transformations (move, rotate, scale). However with the growing uptake of parametric computer models evident in the survey, we are considering the capacity for more model interactivity to enable more on site editing of design options.

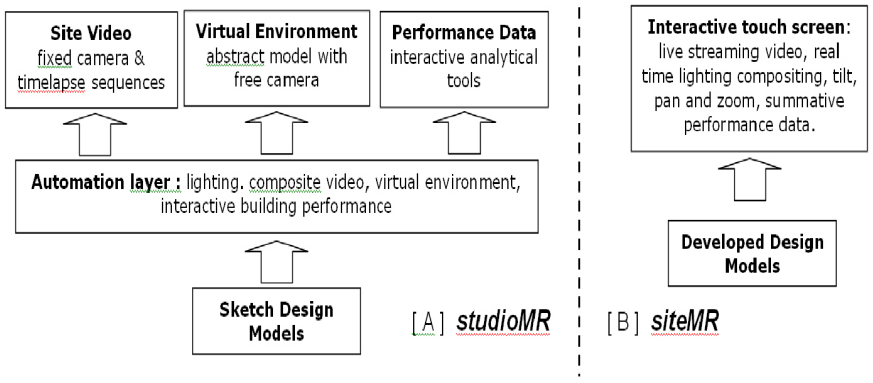

Figure 2 A–B. Overview of studio- and site-based mixed reality.

4. Studio MR development

The objectives of the studio-based mixed reality system is to provide a design interface that allows an understanding of temporal context in relation to qualitative and quantitative data. Below are what we consider key requirements for a studio-based mixed reality system

- **Navigation.** Provide both real time navigation and multiple camera paths that align the digital model with pre-recorded site video. This requires the combination of AR and AV in the one visualisation environment.
- **Dynamic environment.** Develop a database of site video taken from key viewing points. Link design models to environmental performance software that considers a range of time scales. In real time (AV mode) animate lighting and skybox relative to range of time scales.
- **Concurrent evaluation.** Develop an export module that converts the design model into a format compatible with environmental performance software. Import the performance data and store in local database to enable continuous update of performance.
- **Interactivity.** Enable users to swap between the navigation modes (real-time or via pre-recorded camera paths). Design models should be able to be swapped in and out on-the-fly, and entities should be editable in terms of translation, rotation and scaling.
- **Lighting.** Export module that automates the lighting of design models in external graphics animation software in relation to the pre-recorded video; supplement this with interactive lighting in real-time mode.

4.1. TECHNICAL IMPLEMENTATION

The technical implementation was initially attempted using open scene graph and some progress was made in developing a prototype application that meet the above requirements. However one of the factors that became more obvious from the survey outcomes was the need for a visualisation environment with a wide range of file formats and the desirability of a networked design space to store and easily retrieve design options. For these and other reasons of expediency, a hybrid design environment that uses a web interface to utilise a range of commercial applications has been developed. The current implementation strategy is to link existing technologies with bespoke web and script interfaces: 3D Studio Max and Backburner to produce the composite video and rendered images; Esperient Creator provides a fully featured virtual environment with excellent file interoperability; Energy Plus is utilised for environmental performance analysis; the web interface is developed in Python allowing access to a large number of interface libraries.

4.2. ILLUSTRATIVE PROJECT

To illustrate some of the potential of studio MR and to identify areas for more detailed evaluation, a design project has been undertaken. The design scenario is the development of a sun screening system that is required to perform environmentally, but also act as a large-scale information interface and urban art work. This design scenario explicitly requires the concurrent evaluation of functional performance in tandem with the capability of the system to in effect act as a large scale 'display' screen that allows the embedding of information and abstract kinetic art. The design is for the re-cladding of an existing high rise tower located in a prominent position in the Melbourne CBD.

4.2.1. Performance measures and design modelling

For the purposes of the study the quantitative data from which functional performance is measured is the impact of sunlight on internal temperature. Clearly there are other variables that determine comfort levels for occupants (air movement, relative humidity, light glare), but the shading of glazed areas from direct sunlight is the primary functional requirement for externally mounted screens. After testing two commercially available applications that integrate geometry modelling and environmental simulation (Ecotech, IES) we decided to use the open database approach of Energy Plus. At the moment commercial applications such as Ecotech and IES provide poor file interoperability. Moreover, all environmental simulations requires the calculation of discrete volumes that dictate either the designer thinks in this way as they design, or it necessitates remodelling after a design idea has been developed. A clear outcome from the practice survey is that designers work across a range of modelling applications and require a workflow between idea and performance that allows this. For this illustrative project the key factor is the percentage shading produced by the sun screens and the impact this has on internal temperature. Rather then constantly translate the design model to an environmental model, we have developed an approach that evaluates the design model in terms of percentage shading. This percentage is then linked to the energy plus database and using weather history files for Melbourne the impact on internal temperature is calculated for daily and seasonal time scales. This approach allows designers to work in their favored design applications and obtain accurate feedback on performance, in this case impact of shading on internal temperature. In a similar way we also provide feedback on the impact of the external screens on internal light levels. The design model is imported into 3D Studio MAX which has the capacity to generate accurate luminance visualisation. A simple script automates the production of plan views which

are analysed to produce the percentage of floor area receiving acceptable luminance.

4.2.2. Qualitative evaluation and visualisation

There are three qualitative factors for this particular design illustration: (1) the capacity to embed information within the dynamics of the screen; (2) the capacity of the dynamic screen to support kinetic art works; (3) the visual impact of this dynamism on the internal spaces. As evidenced by the practice survey there needs to be a range of visualisation approaches from the abstract to the photorealistic. Moreover, the above factors require visualisation from multiple viewpoints and time scales. In terms of factor 1, this capacity to embed graphic or textural information will be dependent on viewing position within the Melbourne city grid. There is a similar requirement for factor 2 as kinetic artists will need to evaluate how their artworks are perceived from multiple viewing angles and distances. With factor 3, the visual impact on the screen dynamism on the tower interior spaces, there is less variability given the constraints of the internal plan area. None the less, it would be useful to be able to manipulate internal viewing position to evaluate the impact from different areas of the plan. In order to facilitate visualisation for these factors two visualisation environments were developed. A video survey was undertaken and eight strategic viewing positions within the city grid were established. Design models were superimposed on to these strategic viewing positions to enable evaluation in a photorealistic context. Supplementing this was a virtual environment which allowed interactive visualisation in an abstract 'cardboard-like' model. This allowed free camera movement and multiple speeds (pedestrian versus motorist). In addition a time lapse feature linked to sun paths was incorporated to allow visualisation from multiple time scales and seasonal lighting conditions. The virtual environment included the facility to view the dynamic screens from within typical floors within the tower. These internal visualisations used a combination of baked in ambient lighting and real time shadow projection to provide a quasi-realistic visualisation of the impact of external dynamism.

4.2.3. Web interface

A web interface was developed to allow designers to submit design models and review design visualisation and performance. Designs from typical modelling environments identified in the survey (Rhino, Sketchup, Maya) were converted to a 3D studio MAX file which was then merged with a site file. The upload interface allowed users to select multiple days and times and choose

to run a partial or full visualisation / performance simulation. Using a render farm and a scripted interface to energy plus designs were processed to produce the range of qualitative visualisations and graphed representations of impact of shading on internal temperature and lighting. Given the number and range of design representations, a primary challenge is presenting this information to the designer. A review interface has been developed that allows a designer to easily access composite video animations, temperature and lighting graphs in one interface. Selecting a design iteration also automated the display of the relevant virtual environment, which is accessible as separate re-positional window with its own navigation interface and interactive controls for the dynamic shades and sun paths. Linked to each design is a scoring and comments interface that allows the input of qualitative assessment in relation to the three factors identified in the previous section. As various design options are processed and evaluated, a summary page tracks the progress with each option presented as a screenshot and summative graphs charting qualitative and quantitative assessment.

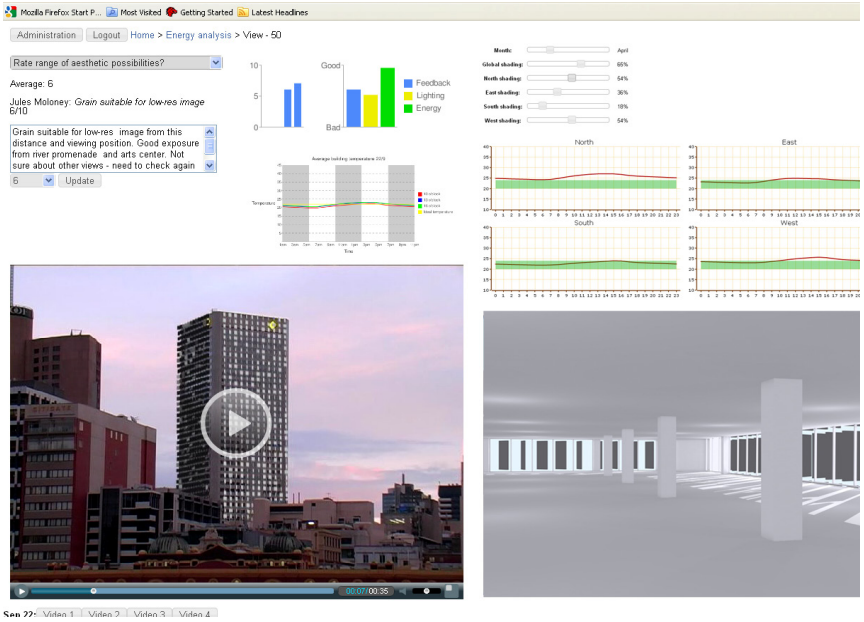

Figure 3. Screenshot from studio MR prototype web application, which allows the concurrent evaluation of data on environmental performance, composite videos, and a real time virtual environment allowing external and internal evaluation. In order to track design iterations and enable collaboration a comments and scoring interface summarises the evaluation of each design.

5. Further work

The project illustrates one specific example of how qualitative evaluation and quantitative information can be integrated into the early stages of design conception and review. Building from the practice survey, the primary drivers were to enable design to be undertaken in typical geometry modelling applications, automate the production of abstract and photorealistic representations and present these alongside key quantitative performance measures. The project is illustrative only as the 'designers' are at this stage are the project team. Clearly there is a need for evaluation of the approach by a wider sample of potential users (ideally including some participants from the survey), which will be undertaken in a subsequent project stage.

We are also making progress on the implementation of the site-based MR approach outlined in the first half of the paper and a preview of this work will be available for the conference presentation.

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