From abstraction to being there: mixed reality at the early stages of design
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Abstract

We discuss the use of multiple design representations to enhance decision making at the early stages of design. Our interest is how the context in which design decisions are made can be extended by two interrelated approaches: (1) the incorporation of the temporal; (2) through the concurrent evaluation of qualitative representations and quantitative information. Outcomes from a practice survey and observations from design studios are used to inform the development of mixed reality (MixR) technology, to enable the applications to reflect architecture specific modes of design praxis. We propose two approaches - studio MixR and site MixR - reflecting the distinction between typical studio based design process and the requirements of a formal design review by the design team and stakeholders. Prototype applications have been implemented and a number of projects have been undertaken to illustrate some of the potential of mixed reality for architecture and urban design. These focus on the early stages of design, from the abstraction of parametric design to on site design reviews undertaken with augmented reality visualization.
I. INTRODUCTION

Our previous research in the field of design representations has explored the potential of hybrid approaches to support design conception and review. These have included using videogame technology to develop collaborative virtual environments, [1] the social aspects of hybrid urban spaces [2] and mixed media in the design studio, informed by the concept of digital craft. [3] 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: the incorporation of the temporal; and through the concurrent evaluation of qualitative representations and quantitative information on functional performance. In relation to the temporal aspects of design context we locate two interrelated modes of engagement. 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”. [4] 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 insight from a recent survey of practice, suggest there is much to be gained by the co-presence of visualizations 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. The proliferation of this strategy has been facilitated by the recent availability of graphics programming interfaces, which enable performance data to be mapped to geometry variables. While it is encouraging to see the development of designer orientated programming interfaces, there is a concern that the rubric of performative architecture suggests a return to the functional determinism of design science. Clearly it would be naive to ignore the qualitative aspects of a design, 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 incorporates a practice survey, the specification and prototyping of technology and the undertaking of illustrative design projects. The first section reflects on the survey outcomes and our previous...
experiences with digital technology. A subsequent section summarizes 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 two prototype systems. In order to explore some of the potential of these approaches, illustrative projects have been undertaken. These include a dynamic sunshade for a high rise tower and a medium density docklands promenade development.

2. PRACTICE SURVEY

The practice survey involved 22 Melbourne based design practices of various types and sizes. [5] 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 was not intended to be definitive but rather it provided a snapshot of activity in leading local practices. In general the outcomes correlated with our observations of digital design studios undertaken at Melbourne and elsewhere. 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 we make is that for new digital technologies such as mixed and augmented reality to be effectively integrated into existing practice, there is a need to compliment and integrate existing media techniques. Secondly, designers require a continuum of representation fidelity, from the abstract to the photorealistic and ideally, to be able to integrate visualization with functional performance simulations. Below are some more specific observations 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 modeling 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 1A-D: Observations on the range of techniques evident in the practice survey.

3. MIXED REALITY: TWO SCENARIOS FOR DESIGN

The practice survey, in combination with our experiences of teaching design studios over the last decade, has informed the proposition of two scenarios for incorporating mixed reality into the early stages of design. In order to support 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 allows a wide range of technologies and the consideration of appropriate technology is central to our research inquiry. The taxonomy of Millgram and Kishino 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”. [6] 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 virtualized reality. [7]

This established taxonomy enables us to locate opportunities along the virtuality continuum for the particular focus of this research – the concurrent evaluation of qualitative and quantitative representations in a
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. [7] usefully clarifies the issue of suitability of technology for specific activities. Their review evaluated technology along the continuum in terms of two factors: the correlation between perception and action; and secondly the level of interaction with real artefacts. The first factor is based on human computer interaction research, which demonstrates the more we can use our every day motor activities in interacting with virtual objects, the better the performance. [8] The second factor is based on research in activity theory that, in contrast with earlier cognitive theories of human computer interaction, takes into consideration the impact of traditions with non-computer tools and the social context in which digital tools will be used. [9] 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 internalized conversation 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 MixR. The second is directed towards undertaking a design review in context, and which we refer to as site MixR. 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 in 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 visualization. The emphasis is on co-locating multiple views and data types and has some resonance with the research of Lee et al. [10] 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 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 synchronized with the design model.
4. STUDIO MIXR DEVELOPMENT

The objectives of the studio based mixed reality system is to provide a design interface that allows the evaluation of design options in a temporal context and in relation to the concurrent evaluation of the qualitative and the quantitative. Towards these ends, 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 visualization 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. Implementation

The technical implementation was initially attempted using open scene graph and some progress was made in developing a prototype application.
that meets the above requirements. However one of the factors that became more obvious from the survey outcomes was the need for a visualization 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 utilize 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 utilized 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 MixR and to identify areas for more detailed evaluation, an illustrative 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.

Performance measures and design modeling

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 modeling and environmental simulation (Ecotect, IES) we decided to use the open database approach of Energy Plus. At present commercial applications such as Ecotect 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 the design has to be re-modeled to meet this requirement. A clear outcome from the practice survey is that designers work across a range of modeling 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 than 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 by 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 visualization. A simple script automates the production of plan views which are analyzed to produce the percentage of floor area receiving acceptable luminance.

Qualitative evaluation and visualization

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 explored in the practice survey, there needs to be a range of visualization approaches from the abstract to the photorealistic. Moreover, the above factors require visualization 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 visualization for these factors two visualization 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 visualization in an abstract ‘clay’ model. In addition a time lapse feature linked to sun paths was incorporated, to allow visualization 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 visualizations used a combination of baked in ambient lighting and real time shadow projection to provide a quasi-realistic visualization of the impact of external dynamism.
Web Portal

A web portal was developed to allow designers to submit design models and review design visualization and performance. Designs from typical modeling 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 visualization / performance simulation. Using a render farm and a scripted interface to energy plus, designs were processed to produce the range of qualitative visualizations 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 that summarizes relative merits of design iterations in one interface. Selecting particular design iterations loads the relevant virtual environment, which is accessible as a 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 MixR portal: text forum and qualitative ranking (top left), environmental performance data (top right), composite video (bottom left) and interactive virtual environment (bottom right).
5. SITE-MIXR DEVELOPMENT

The objective of the second prototype is to facilitate design review on site, after a short list of design options had been established via the design portal. It was anticipated that the ambience of the actual site context would enable a greater sense of the visual presence and focus the design team and stakeholders to enable a consensus to be made on the relative merits of designs. There have been a range of projects that utilize head mounted displays to enable compositing of computer models and site context in real time. [11] For the purposes on an onsite review involving several stakeholders, a screen based system that facilitates dialogue and eye contact as naturally as possible, is in our opinion preferable. For this prototype these were the key development requirements.

- **Hardware:** → LCD screen suitable for daylight viewing; touch screen interface; live streaming video from co-located camera; wireless network allowing additional distant cameras to be broadcast; portable power supply; work station capable of real time high resolution graphics.
- **Tracking:** → Pan and tilt; pre-calculated locations allowing multiple camera inputs to centrally located LCD screen; camera calibration.
- **Interactivity:** → Touch screen interface; model loading; translation, rotation and scaling of models; capacity for parametric modification of geometry and textures; saving of scene states.
- **Lighting:** → pre-calculated sun paths; real time ambient lighting based on site conditions.

5.1. Implementation

Significant work was undertaken to develop the required functionality with Open Scene Graph. However this did not prove feasible within the time scale for the project and the final implementation was undertaken using a commercial virtual environment (Esperient Creator). Plugins for the camera inputs were developed in C+ to enable the real time display at full frame rate and resolution (dependent on the camera source). These were accessed within the application as texture maps, enabling full screen or picture in picture. Python was used to develop the real time calculation of ambient lighting levels through analysis of the streaming video signal. Windows media server was used to broadcast alternate cameras through a wireless network, which resulted in a 5 second lag to the remote camera signals. Implementation of pan, tilt and zoom controls was integrated to enable control of these remote located cameras via the touch screen interface. The co-located camera was mounted on the LCD screen, with pan and tilt of the screen / camera tracking enabled by using a bluetooth linked Wii game controller. The remaining functionality was developed using the scripting interface of the virtual environment. This enabled quick
development of a graphic user interface to enable model loading, camera calibration, controls for ambient lighting and the animation of pre-calculated sun paths. The animation capability of the VE was also exploited to enable touch screen control of translation, rotation and scaling transformation and full texture map control of design models. This also provides the capacity to integrate simple parametric editing based on animating model assemblies.

5.2. Illustrative Project

The design scenario for initial evaluation of the site MixR prototype is the design of an urban promenade incorporating retail and gallery space in conjunction with outdoor performance space and recreational areas. This was loosely based on a project brief from one of the participants in the practice survey, which entailed the concept of an urban ‘verandah’ activating a new docklands open space. In order to test an alternate work flow using parametric modeling, the sketch design was for this project was undertaken using Rhino / Grasshopper. This enabled us to test the adaptability of the automation layer for an alternate working paradigm where designers used a shared parametric description. The design focus was to find the right mix of retail space, semi-enclosed and open public urban spaces, explore alternate ways of addressing site access points, sunlight orientation and the addressing of the water edge. To assist the designer the parametric model incorporated feedback on floor area, as parameters were adjusted. The parametric design representation was diagrammatic, an appropriate abstraction at this early stage where designers were quickly developing a range of alternate ideas. When the design parameters were manipulated to produce a viable option, an instance of the parametric model was ‘baked’ and uploaded to the server.

Figure 4: Parametric design abstractions linked to area calculations
In a similar process to the earlier tower project, a 3D MAX script automated the application of detailed textures and correct UV maps and produced the composite video and analytical shading renders. Animation camera paths were automatically produced by tracking the respective configurations of the chain of retail and open space. The design options were collated on the design portal with key quantitative factors displaced as relative bar graphs, in this case floor areas of retail and semi-covered public space and the effect of solar gain on internal temperature. In a manner similar to the previous tower project, the composite video animation and real time virtual environment enabled the concurrent evaluation of qualitative aspects, in particular the urban presence of the promenade, and typical circulation paths.

The design options were evaluated using the web portal and two options were selected for evaluation on site. The transfer of model data was expedited by simply removing the site context from the virtual environment model and setting up a range of strategic camera positions for the site review. As the day of the site visit was known in advance, the sun path was calculated and the resultant animation path assigned to the key light in the virtual environment. Position along the animation was linked to the computer clock enabling exact matching of virtual and actual sun position. Arriving on site the hardware set up was quite simple, as all the required equipment was wheeled onto site using a custom designed trolley. As can be seen from Figure 5 this was designed to be reasonably unobtrusive.

![Figure 5: Hardware setup for mixed reality evaluation of designs on site.](image)
The computer, voltage regulator and small power generator were concealed within the trolley and the touch screen placed on a simple tripod allowing it to be the focus of attention. For this evaluation only one distance located camera was used, consisting of a tripod mounted camera, laptop and wireless router to broadcast the video signal. For both cameras the viewing positions were pre-calculated, with fine tuning undertaken with the touch screen controls, using translation and rotation sliders to correct the camera lenses distortion. The ambient lighting calibration allowed adjustment of the location and strength of fill and backlights, again based on matching the model and video by eye. The virtual environment software enabled real time direct sun shadow casting, which was animated to track the exact sun position. As the site conditions changed from direct sunlight to passing cloud or overcast, the scene lighting was updated: video frames were analyzed in terms of RGB values and this changed the strength of the virtual lights; in synch with the pre-baked lighting of the model materials being animated through a range of shadow conditions.

By the time the camera and lighting calibration was finished, the review participants had arrived and the subsequent review process was reasonably seamless. The two design options could be interchanged on-the-fly from the two camera locations and the design team could also experiment with subtle changes in location, orientation and scale, using the touch screen editing tools. The LCD screen could be panned or tilted by the participants, which enabled focus on different parts of the design. While discussion focused on the screen mounted camera, the position of the

\[\text{Figure 6: Site MixR touch screen interface enabling on site calibration of cameras and lights, and transformation editing of design options.}\]
distance located camera was changed to pre-specified positions, enabling the participants to stay in one place and swap viewpoints, thus maintaining the continuity of the discussion.

6. OBSERVATIONS AND FURTHER DEVELOPMENT

The feedback from the trial participants (academics and part-time practitioners) has been generally positive. The care taken to distinguish between different stages in typical work flow at the early stages of design was well received. As was the range of design representations and the presentation of calculative performance data as simple bar graphs. There was less interest in the actual data result, with the focus being on the relative performance of one design option over another. The text forum on the web portal included the capacity for participants to rank the qualitative aspects of each design, which were averaged and also presented as a bar graph. This transcription to ‘data’, alongside the calculations from energy plus caused some discussion (as was intended). When it was pointed out by a specialist energy consultant that in his experience, there was a general margin of error of up to 20% for environmental analysis, the quasi-objective representation of qualitative assessment was better received. The reaction to the video documentation of the site MixR was less engaged. There was a clear difference between the participants who had experienced the trial on site and those who were seeing the video documentation. Those who were on site, reported the capacity to assimilate a range of ambient site conditions enabled a heightened level of engagement: soundscapes of water, birds, café conversations and passing vehicles; the capacity to see and experience the site while referring to the design on screen; the facility to switch between different camera positions and edit design options. In summary, viewing and discussing the design options while being there, heightened perception and enabled insight beyond that typically available with composite video.

In relation to further work, there are some obvious ways in which the prototypes can be improved and adapted to facilitate alternate design scenarios such as urban streetscapes and city skylines, or tracking designs as they are perceived from public transport. This would require the incorporation of foreground video occlusion and camera tracking in real time, for which there are increasingly mature solutions. Since starting the project the iPad has arrived on the market and we are considering using this to enable handheld versions of the prototype. Ideally these would have the capacity to record a personal exploration and the various journeys by participants could be uploaded to the web portal. No doubt there will be further technology developments that can be considered, which may provide opportunities to further improve the fidelity and range of visualization and simulation, and hence improve decision making at the crucial early stages of design.
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References


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