AN EMPIRICAL STUDY ON DESIGNERS' PERCEPTIONS OF AUGMENTED REALITY WITHIN AN ARCHITECTURAL FIRM

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SUMMARY: *Nowadays the design sector takes account of collaboration among design team members as seriously as the geometric and spatial features of the design itself. Effective collaboration should appreciate the difference in perceptions between design practitioners. Productivity in design heavily depends on how effectively design ideas can be communicated to other design team members. Augmented Reality (AR) technology, which can insert digital information into the designers' physical working environment, is envisaged to be a promising solution to the collaboration problem faced by design practitioners. Rather than focusing on Augmented Reality system development and application, the work presented in this paper is more focused on the strategic and organizational issues of Augmented Reality and it's role in the existing design sector. Specifically, this paper presents an analytical framework to identify and investigate potential issues of facilitating Augmented Reality technology transfer into the existing visual practices in design firms. Based on this analytical framework, this paper also implemented an empirical pilot study on the perceptions of using Augmented Reality technology for architectural design activity. The interviewees for this study were invited from a well-recognized Australian architecture company. The paper also presents the findings with a discussion of the application of AR technology in the design sector to achieve higher design efficiency.*

KEYWORDS: *Virtual Reality, analytical framework, Augmented Reality, empirical pilot study, questionnaire, architectural design, user acceptance*

1. INTRODUCTION

Nowadays the design sector takes account of collaboration among design team members as seriously as the geometric and spatial features of the design itself. Effective collaboration should appreciate the difference in perceptions between design practitioners. Productivity in design heavily depends on how effectively design ideas can be communicated to other design team members. Although visualization aid from computer simulations (e.g., CAD and desktop Virtual Reality) facilitates design understanding to a certain extent, it was found that they are not sufficiently effective in supporting collaboration, as those technologies confine design individuals to traditional computer screens (the immediate environment). Beyond such confining and traditional visualization interfaces, Otto et al. (2005) deployed immersive projection-based VR systems and applications in support of architecture design studio education and research in the Immersive Environments Laboratory (IEL). The lab has been developed as a test bed and proving ground to assess the value of immersive VR for day-to-day teaching and research in architecture, engineering, design arts and other disciplines.

Architectural design professionals are increasingly looking toward various computing technologies to facilitate collaborative tasks. Design firms are not only users, but also form part of the wider sectoral patterns for the innovation, adoption and use of these technologies (Whyte, 2003). Augmented Reality (AR), which appears in the literature usually in conjunction with the term Virtual Reality (VR), is a technology or an environment where the additional information generated by a computer is inserted into the user's view of a real world scene (Milgram and Colquhoun, 1999; Azuma, 1997; IWAR, 1998; ISAR, 2000; ISMAR, 2002). AR can create an immersive augmented workspace by inserting the virtual space in which we store and interact with digital content into the physical space where people work. In the late 1990's, several conferences specializing in this area were started, such as the International Symposium on Mixed and Augmented Reality (ISMAR) (2006). Another noteworthy avenue which is geared towards industrial settings of AR is the Industrial Augmented Reality Workshop (2006) which is a one-day event associated with ISMAR. More fundamentals regarding AR concepts and technology can be found in (Barfield and Caudell 2001).

AR technology is envisioned to improve the current state-of-the-art for architectural visualization, design process, building construction processes and engineering management systems. Augmented Reality technology holds great potentials to reduce costs, shorten design time, and avoid errors in collaborative design activity. Recent advances in computer interface and hardware power have fostered AR prototypes for various design applications. However, most of these prototypes were investigated by computer science/engineering societies which picked design as a lab-based testing area for proof-of-concept. Due to the lack of in-depth understanding of design practices, these efforts could hardly progress beyond the lab-phase to eventually become a usable system for practical operations. AR has actually matured from a pure research field into certain practical industrial applications, but until now it has not been implemented as a real product in architectural design. Augmented Reality has had a relatively slow transition into the architecture design sector. Military, advanced manufacturing and entertainment users have been comparatively early adopters of Augmented Reality. Lab-based applications of Augmented Reality in the design area include: early architectural design stage (Seichter, 2003; Aliakseyeu et al., 2006), urban design and planning (Seichter, 2004; Broll et al., 2004), individual mechanical design detailing (Dunston et al., 2002; Dunston and Wang, 2005), architectural design (Dias et al., 2002), steel erection planning (Yabuki et al., 2006), collaborative design (Wang et al., 2003; Schmalstieg et al., 1998; Schmalstieg et al., 2002), and multiple use planning tool (Rauterberg et al., 1997). Tracking is also a critical technical issue in developing effective AR applications, especially outdoor systems. In an outdoor urban area, there are many easily recognized artificial features that can be used as pseudo-fiducial markers. For instance, Behringer et al. (2002) have developed a system that is able to track windows on a building and to obtain user location and attitude, which can be used for a closely registered AR overlay.

The justification of investments in AR is one of the many challenges facing CAD/system managers in the architectural design industry today, as there is an ever-increasing demand to improve their performance and productivity. Rather than focusing on Augmented Reality system development and application, the analytical framework presented in this paper is more focused on the strategic and organizational issues of Augmented Reality's role in the existing design sector – an area which remains relatively unexplored for these issues. Such a technology acceptance study has been rarely conducted by researchers mainly because most AR researchers are from a computing society and lack the motivations and background for implementing this kind of study. Furthermore, these technological experts and researchers contribute little in the way of providing upper management with a framework for determining the exact benefits and associated costs of adopting AR technologies into their routine design practice. The above arguments lead us to think that the next logical step within the development of AR is to start exploring how well they are likely to integrate within existing design work practices. The ambition should hence be to deploy these systems beyond laboratory testing and within the hands of users who have little or no relationship to the technical details of these systems. The feasibility and success of such a deployment is likely to depend on a number of factors which the analytical framework presented in this paper investigated. The analytical framework identifies and investigates potential issues of facilitating Augmented Reality technology transfer into the existing visual practices in design firms. More specifically, a pilot study was also conducted based on the analytical framework that aimed at: (1) obtaining more insight into how well an AR system could be used within the design sector alongside existing design tools from the perspectives of industrial practitioners; and (2) revealing existing technical and user-interface issues that need to mature further in order to move the discussion beyond usability towards usefulness. We consider the pilot study an important intermediate step in bringing the system characteristics closer to end-user

requirements before releasing the system to a larger audience. Meanwhile it also helps to identify both specific remarks for improving the AR system and general issues that are likely to also be of interest for developers of other AR systems.

2. COLLABORATION IN DESIGN PRACTICE

Design has often been described as a reflective practice. According to Schön (1983) reflective practice refers to design as a learning and exploration process where iteration is the interesting part. While designers can conduct such reflective practice on their own, the complexity of design projects and the influence of the global economy have made such cases very rare. In practice, designers collaborate with other designers within the discipline as well as other experts outside the discipline. Collaborative design is a process of dynamically communicating and working together in order to collectively establish design goals, search through design problem spaces, determine design constraints and construct a design solution (Lahti et al., 2004).

In current literature, design collaboration is often studied in the early design phase - conceptual design. The early phase of the design process is concerned with understanding the problem and making general, rather than specific, decisions about a solution (Edmonds and Candy 1993). Bowman and Cooper (1994) characterised the task of the conceptual designer as, "to understand the customer's need, analyse it and produce a model of the possible solutions and present these for the customer's choice/acceptance". The conceptual phase in architectural design has often been one person's responsibility (Lawson, 1996). In most empirical studies of collaborative design, the process usually takes place when the participants are in geographically distant locations. Common foci of these studies are to examine the communication acts of the participants in different communication channels, to analyse the components of collective thinking and team behaviour; and to investigate social behaviours such as sense of community, open participation, and level of participants' awareness in the computer media.

The research into computer and digital technologies for supporting collaborative works started in the 1960s with the early work at Stanford Research Institute into interaction techniques. In the early 1990s, a sub-discipline of Human Computer Interaction (HCI) developed into the research area of Computer Supported Cooperative Work (CSCW). Similar to HCI, CSCW is a multi-disciplinary field that has made significant contributions to collaborative design technologies, which have changed the practice of many fields such as science, art and design. Nowadays, the use of collaborative design technologies mainly includes video conferencing, shared drawings and models, and virtual worlds. The development, and common use of computer and digital technologies, have brought fundamental changes in the way Architecture, Engineering, and Construction (AEC) professionals design and collaborate, partially because the technological developments have led to computer and digital tools that are technically and financially feasible to use in practice. In addition, technological developments have not only provided new opportunities and possibilities for design, but they have also contributed to the complexity of various design and communication processes (Bellamy et al, 2005). Such complexity has required better coordination of design and building-related activities which align technological, economical, political and other developments (Archea 1987). Thus, effective communication has become very crucial in the AEC arena. In addition, the AEC arena increasingly needs large design teams to work collaboratively in the production of large-scale or complex projects. Collaborations within large design teams are understandably more complex yet essential for the success of the entire project life-cycle.

3. ANALYTICAL FRAMEWORK

This section presents an analytical framework to identify and investigate potential issues of facilitating Augmented Reality technology transfer into the existing visual practices in design firms. This framework is an initial step to identify the strategic implications of using AR in a design organization and can be used to compare the use of the resulting AR-based visualization practice with existing practices. The following theoretical and practical issues and question are critical to understand in order to successfully transfer AR technology into the design sector and they could also be explored through empirical studies based on this analytical framework:

1. New AR visualization technologies should only work as part of existing visual practices in design firms. Therefore, the visual practices (e.g., sketches, drawings, annotations, visualization technologies, simulation tools, and prototyping tools) of design firms should be understood.

2. How could engineers and designers integrate AR tools in their process and product design?

3. How do design firms deal with the costs, risks and uncertainties that AR visualization technologies raise?

The following sections discuss Augmented Reality's role in design innovation, factors that impact effective adoption of AR, technical requirements, cost structure of building AR, and a research method to validate the analytical framework.

3.1 Augmented Reality's role in design innovation

The potential use of AR within the design sector can be examined using the analytic lenses provided in the literature on generic technologies and sectoral patterns of innovation (Whyte, 2003). Augmented Reality used to be investigated for medical, gaming, and military industries and can be considered as a generic technology because it can be used widely outside its original sector of production.. Such generic technologies are instantiated in similar, but not identical, applications within the complex and idiosyncratic production systems of different sectors and industries (Rosenberg, 1963).

AR can innovate the way that designers design. Innovations rarely arrive fully fledged, able to bring about a rapid reduction in the costs of user organizations (von Tunzelmann, 2000). They are altered, refined and reinvented throughout the diffusion process (von Hippel, 1988). It is therefore envisaged that users of AR technologies can be active participants in this innovation process even though those thechnologies typically provide visualization aids that are not directly involved in production,

The organizational context of design innovations differs significantly from many other forms of manufacturing innovation (Slaughter, 1998). Design can be regarded as a project-based sector, and design firms usually conduct innovation within projects. Such a project-based nature is critical to understand innovation processes within this sector. Design firms usually design a wide range of different types of projects. Firms in the housing industry often do small projects, but with extensive design re-use. In these firms, each individual project may only require intermittent staff attention and staff may simultaneously work on a number of projects that are in different stages of development (Whyte, 2003). Some design firms concentrate on very large projects. These projects, may involve the collaboration of a number of different specialists and organisations over an extended project lifetime (Gann and Salter, 2000). Such projects can benefit from the reuse of modelling efforts, either by reusing Augmented Reality infrastructure on many different design activities over the entire life cycle of the project, or by reusing it across similar projects.

3.2. Factors impacting AR adoption

The factors that impact the adoption of AR in design firms are identified in this section. Problems of AR technology evaluation, particularly benefits and costs, are important. Considering the unique characteristics of the design sector, it is suggested that the evaluation of AR investments in the design sector should consider costs, technical issues and requirements, methods of implementation, risk analysis, technology acceptance, modeling efforts, potential benefits, etc. Factors impacting the adoption of AR include:

- Cultural, technological, educational, and communication environments

- Design firms organizational risk, definition uncertainty, technical uncertainty, infrastructure risk

- Project size, duration, complexity, structure, and reusability

- Modeling ability and preparation of reality model to build an AR environment

- Project management

- Past experience with implementing information technologies

- AR devices and tools

- AR technological limitations

- Employees' skills, expertise and learning ability

- CAD management's motivation towards the short-term limitations

- Virtual model rendering issues

- Extraction of industrial domain knowledge

Among those factors, technological limitations remain the major obstacle for AR systems. For instance, AR requires highly accurate trackers because even tiny tracker errors can cause noticeable mis-registrations between real and virtual objects. Rendering of the virtual model is also quite critical because a poorly displayed model might hinder a user's understanding of the augmented scene. It is also important to apply the appropriate level of realism with which virtual objects are rendered into the real world. For example, in some cases, real-world, high-fidelity physical and behavioural representations may be desirable in applications which attempt to provide a high degree of realism, such as in simulation, training, architectural design and planning, etc. However, such high fidelity settings can cripple systems when the virtual information is very large and requires the rendering of a very large number of polygons. Significant modelling (2D to 3D) and integration efforts are required to construct an AR-compatible database with appropriate formats. Thus, modelling, integration, and extraction efforts may be required and should be taken into consideration when building an AR application.

There might also be political and organizational reasons for not understating the cost implications of an AR infrastructure investment; the main one being the need to gain support for, and acceptance from senior managers.

3.3 Technical requirements

Augmented Reality systems should be integrated into the existing technological infrastructure. This includes the following three main aspects: (a) data integration: the data brought into the meeting and the results of the meeting should fit into the firm's existing technological environment. Types of data include text documents, images, and 3D geometry. The geometry is derived from CAD systems and should be integrated seamlessly into the environment; (b) process integration: the data selection process should utilize the same tools as the ones used by the designers during their daily work; and (c) AR infrastructure integration: AR systems should be set up on top of present technological infrastructure such as network and telecommunication infrastructure. AR should be optimal for a three-user and/or two-user setup, which covers 56% of the use cases for videoconferencing (Aaby, 2003).

One of the most critical technical requirements is moderate bandwidth consumption. Additional criteria include: connectivity and compatibility with existing systems, especially, network and telecommunication infrastructure, accessibility to conferencing and other communication services, accessibility to chat and whiteboard, robustness and accountability, and bandwidth efficiency.

3.4 Cost structure of building AR systems

The following direct and indirect cost items need to be considered and built into a justification costing structure.

Initial direct costs are often determined by the performance characteristics established by CAD managers during the system requirements planning stage. Those cost items include AR hardware and software, database, installation and consultancy support, training costs, and maintenance costs. It should also be recognized that indirect costs associated with the adoption of AR might be more significant than direct costs. Indirect costs are not simply restricted to humans, but encompass organizational issues as well. Organizational costs can be due to the transformation from previous to new work practices based on the impact of the new AR systems. A temporarily low design productivity may be experienced, as firms to adapt to new AR systems, procedures and practices. There may also be some constraints on available resources that maximize the potentials of AR technology through integrating information flows and increasing information availability, which might be another source of costs. The costs of organizational restructuring are also considered to be high, particularly if certain groups within the firm resist changing and making the planned transition.

4. PILOT STUDY

In order to identify potential issues in the development of techniques for using Augmented Reality as a visualization tool, a pilot study was conducted to obtain a shot/picture of AR technology acceptance and attitudes from the design practitioners and a list of suggestions/wish-lists for AR system. Investigating designers' perceptions on using AR in design collaboration, the pilot study also aimed to identify the driving forces (i.e. improvement in design quality, cost/time effectiveness, etc.), and propose possible implementation solutions and strategies for future AR in design practice.

More specifically, the pilot study presented in this section focused on addressing cultural, technological, and communication environments, the effectiveness of AR devices and tools, the AR technological limitation, employees' expertise, and virtual model rendering issues, as listed in section 3.2. The pilot study used a questionnaire to assess designers' reactions to, and ideas for the future application of, AR technology based on hands-on usage.

Two Augmented Reality systems developed in the authors' lab were demonstrated to design professionals (architects, interior designers and urban planners) of a large Australian architecture company in this study. The first system demonstrated to design professionals was the Mixed Reality-based Face-to-Face Conferencing System (Wang and Dunston 2005), a collaborative virtual environment that creates a face-to-face scenario to support design review collaboration (see Fig. 1). The system consists of a central server with CAD application, a client computer with AR rendering software, a head-mounted display (HMD) with a colour video camera (real environment sensor) attached, multiple tracking markers, and a tangible interface. The HMD, hi-Res800$^{TM}_{PC}$Headset, was used to project 3D digital images at a resolution of 800 x 600 with $\pm$ 26.5 degree diagonal field of view. Thus, virtual images were overlaid directly on a view of the real world using a see-through HMD.
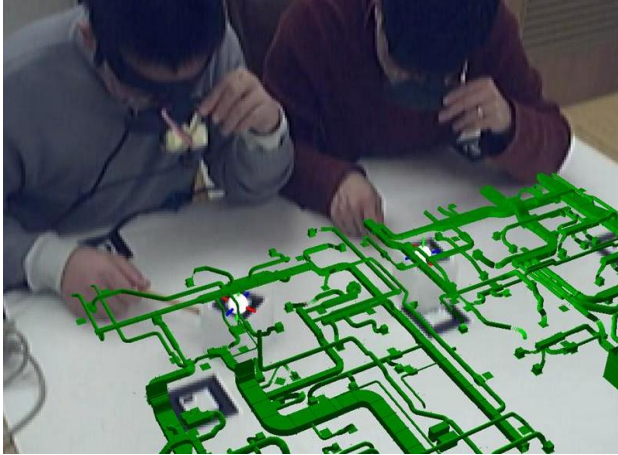
FIG. 1: Augmented Reality system for mechanical design review (Wang and Dunston 2005).

The second prototype demonstrated was the Augmented Reality-based Urban Design System (*ARUDesigner*) (Wang 2007) as shown in Figure 2. *ARUDesigner* was designed to reduce the possibility of misinterpretation among team members by providing more detailed visual information on design objects, and encourage group collaboration and communication in order to improve the design group's overall efficiency and productivity. Currently the *ARUDesigner* consists of a PC, a HMD, a video camera as sensing device, and tracking markers. The virtual objects are pre-modeled in ArchiCAD.

FIG. 2: Augmented Reality system for urban planning proposal review

All participants attended the workshop to gain an understanding and "hands-on" experience of AR technologies through presentations and on-site trials. For on-site trials, they attended two trials using each of the AR systems respectively. In the first trial session, the interviewees tried the Mixed Reality-based Face-to-Face Conferencing System. They were able to see the same virtual duct model and real marker together via the head-mounted display. They viewed and browsed the design which was from an industrial partner, BMW Constructors, Inc. They could review and inspect the design model. More specifically, they could also point, locate, and navigate any item in the design model. They also tried to change viewpoints by either moving around, or manipulating the real tracking marker underneath the virtual model. In the second trial session, the interviewees tried the system *ARUDesigner*. The trial scenario was an urban design proposal at Millers Point in Sydney that focused on re-establishing a new residential area in conjunction with a commercial district. They tried to move around the tracking markers with virtual buildings to see how the proposed building locations fitted to the existing neighbourhood represented by the 3D paper drawing and the wood blocks. They also tried to see if certain design objectives could be accomplished in such a setup. For instance, a virtual building can be moved around to ensure that its location allowed adequate connectivity for pedestrians and local communities in the design solution.

This pilot study is based on the responses to the questionnaires completed immediately following the trials, and interviews with architectural design practitioners. There were ten design practitioners from an architecture/interior design/urban planning company that were invited to this study. The questionnaire was designed and administered to reveal how a change in the technology used can bring changes in the way designers collaborate in design activities. The questionnaire was designed to achieve two objectives: (1) to investigate the designers' perception on technological innovations - AR technologies in the design industry with the help of cognitive psychology science, and (2) to see what effect the changes in technology can impose on designers in their current work practice. There were 16 questions in total. Questions were organized as product-related (6 questions), process-related (4 questions), and open essay (6 questions). Specifically, process-related questions were used for CAD managers, and product-related questions were used for senior management personnel. The post-trial questionnaire was designed to be completed based on the subjects' experience and feelings during the experiment. Ratings were made based on five different scales: from Totally agree (scale 1) to Totally disagree (scale 5). The five category rating scale is intentionally used to force respondents into partial agreement or disagreement instead of sitting on the fence. Following each question is a blank space allowing respondents to add information that could inform the interpretation of this question.

5. FINDINGS AND DISCUSSIONS

The 10 respondents for the survey were professionals employed in the industry. Most of the respondents were architects (one was a psychologist). All participants attended the workshop to gain an understanding and "hands-on" experience of AR technologies through presentations and on-site trials. They then completed the following questionnaires.

5.1 Section 1: design process-related questions

Section 1 has 6 questions divided into 2 categories that are related to the design process. Questions 1 to 3 asked the participants to evaluate the performance of AR technologies in terms of design communication. Questions 4 to 6 are about design development. In general, participants responded positively towards the impacts of AR technologies in design collaboration and design development. In terms of design collaboration, they agreed that AR technologies would help them to better convey their ideas to the team; help them to better understand other team members' inputs; and motivate interdisciplinary design collaboration. Regarding design development, respondents believed that AR technologies would potentially benefit spatial cognition; concept development and decision making; as well as design modifications and refinements due to the support for viewing and "touching" the design. The data for each question in the section 1 is plotted in Figure 3.

Question 1 asked "Compared to current CAD tools, physical sketches and models, do you agree that the use of Augmented Reality (AR) technologies will better facilitate design communication and design information sharing, and therefore helping to convey your ideas to the design team?" 80% of the participants agreed (scales 1 and 2), and 60% totally agreed (scale 1) that AR technologies would better facilitate design communication and design information sharing and therefore help them to express their ideas to the team. The other 20% remained neutral (scale 3). For these respondents, AR can make contributions to supporting multi-user group activity. AR can act as a platform to enable effective team working where interchange between participants and conveying of information can be improved. The explicit intervention of participants that is typically required in the design process can be facilitated by AR so that participants can more effectively apply their expertise to synthesize information and render it useable by the group.
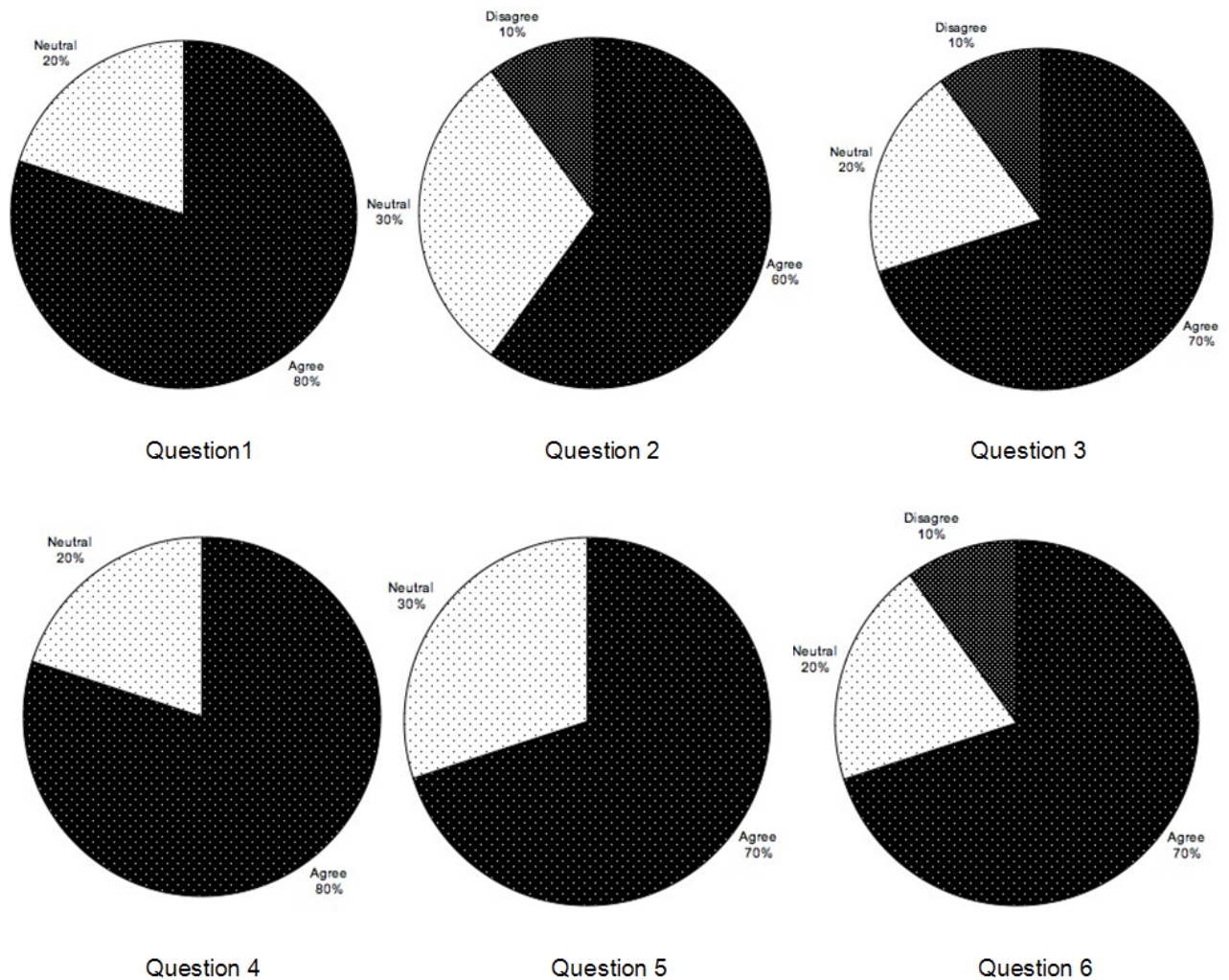
Figure 3. Questionnaire data plot for the 6 questions in the session 1.

Question 2 asked "Traditionally, information exchanges are made verbally, together with sketches or models. Do you agree that AR systems will help you to understand and interpret the inputs of your design collaborators?" 60% of the participants agreed (scales 1 and 2) that AR technologies would help them to understand their team members' inputs better. 30% remained neutral (scale 3), and 10% disagreed (scale 4).

The notion of "interdisciplinary" is of more importance because of the increased volume of design activity taking place by distributed participants and the inherent teamwork nature of designing among discipline specialists. The goal for AR in design might be to support higher levels of 'interdisciplinary collaborative working where participants are empowered to explore and negotiate meaning and generate conjecture. Question 3 asked "Compared to current CAD tools, physical sketches and models, do you agree that the use of AR technologies will motivate interdisciplinary design collaboration among different domain experts?" A majority of 70% agreed (scales 1 and 2) with the statement. The remaining 20% were neutral (scale 3) and 10% disagreed (scale 4). This experienced group of practitioners clearly considered themselves to be involved in interdisciplinary team working, and in open discussions, they indicated a simultaneous increase in the number of different disciplines represented in the teams with which they had been associated. The result reveals that the existence of pressures to achieve close integration between team members, to achieve greater efficiency, and to improve the quality of the output of the team motivates them to consider AR as a potential effective tool.

Question 4 asked "Compared to current CAD tools, physical sketches and models, do you agree that the use of AR technologies will better facilitate spatial cognition during the design process when the design can be viewed

and "touched"?" Once again, 80% of the participants agreed (scales 1 and 2) that AR technologies would better facilitate spatial cognition compared to traditional tools. The other 20% were neutral responses (scale 3).

Question 5 asked "Compared to current CAD tools, physical sketches and models, do you agree that the use of AR technologies will better facilitate concept development and design decision-making when the design can be viewed and "touched"?" There were 70% positive responses (scales 1 and 2) agreeing on the statement. The rest of the 30% indicated neutral (scale 3). Edmonds and Candy (1993) have noted the significant influence that computer-based media have on creative thinking and, particularly, the emergence of ideas. Based on the above result, it was also observed that AR can potentially support and improve design creativity and problem solving.

Question 6 asked "Compared to current CAD tools, physical sketches and models, do you agree that the use of AR technologies will better facilitate design modifications and refinements during the design process when the design can be viewed and "touched"?" A majority (70%) of the respondents once again agreed (scales 1 and 2) on the positive impacts of AR technologies in facilitating design modifications and refinements. There were 20% remaining neutral (scale 3) and 10% disagreed (scale 4).

5.2 Section 2: design product-related questions

In this section, the survey moves away from process-related questions and begins to request respondents to make judgments regarding the potential impacts of AR technologies on the quality of design product. The four questions of section 2 were intended to survey the participants' responses towards the impacts of AR technologies on design quantity; design quality; design presentations; as well as operational expenses and environmental factors. The responses received confirm the positive impacts of AR technologies on the above design product-related issues, in particular, design presentations, receiving a 90% positive response. The data for each question in section 2 is plotted in Figure 4.

Question 1 asked "Do you agree that Augmented Reality (AR) systems will increase the quantity of work within a given amount of time?" A majority of 70% agreed (scales 1 and 2) that AR technologies could potentially increase the quantity of design production. There were 10% remaining neutral (scale 3) and 20% did not answer this question. The result shows that AR seems to increase the quantity of the work that the respondents get through, and the rating is predominant.

Question 2 asked "Do you agree that AR systems will increase the quality of work within a given amount of time?" 50% of the participants agreed (scales 1 and 2) that AR technologies would help to increase design quality. 40% of the participants however provided neutral responses (scale 3) and 10% did not respond. There is a belief that AR can increase the quality of the respondent's contribution to design projects and the overall quality of output from teams. Future studies may seek to investigate whether this is a consequence of successful team working enabled by AR or due simply to AR-based working with its access to AR resources and tools.

Question 3 asked "Do you agree that AR systems will improve design presentations and therefore have value-added marketing impact?" An absolute majority of 90% agreed (scales 1 and 2), with 70% totally agreed (scale 1) with the positive impacts of AR technologies on design presentations. The remaining 10% were neutral (scale 3). This is an important finding from this study that they saw Augmented Reality open up new markets for their services. They were specifically interested in using AR at the customer interface as a communication vehicle to convey design intentions to non-professional parties.

Question 4 asked "Do you agree that AR systems will help in reducing lead-time, costs, and environmental impact (without producing physical outputs such as drawings and models)?" Once again, 70% of the participants agreed (scales 1 and 2) that AR technologies would reduce lead-time, costs and environmental impact during operation. The other 20% are neutral responses (scale 3). The last 10% did not respond.
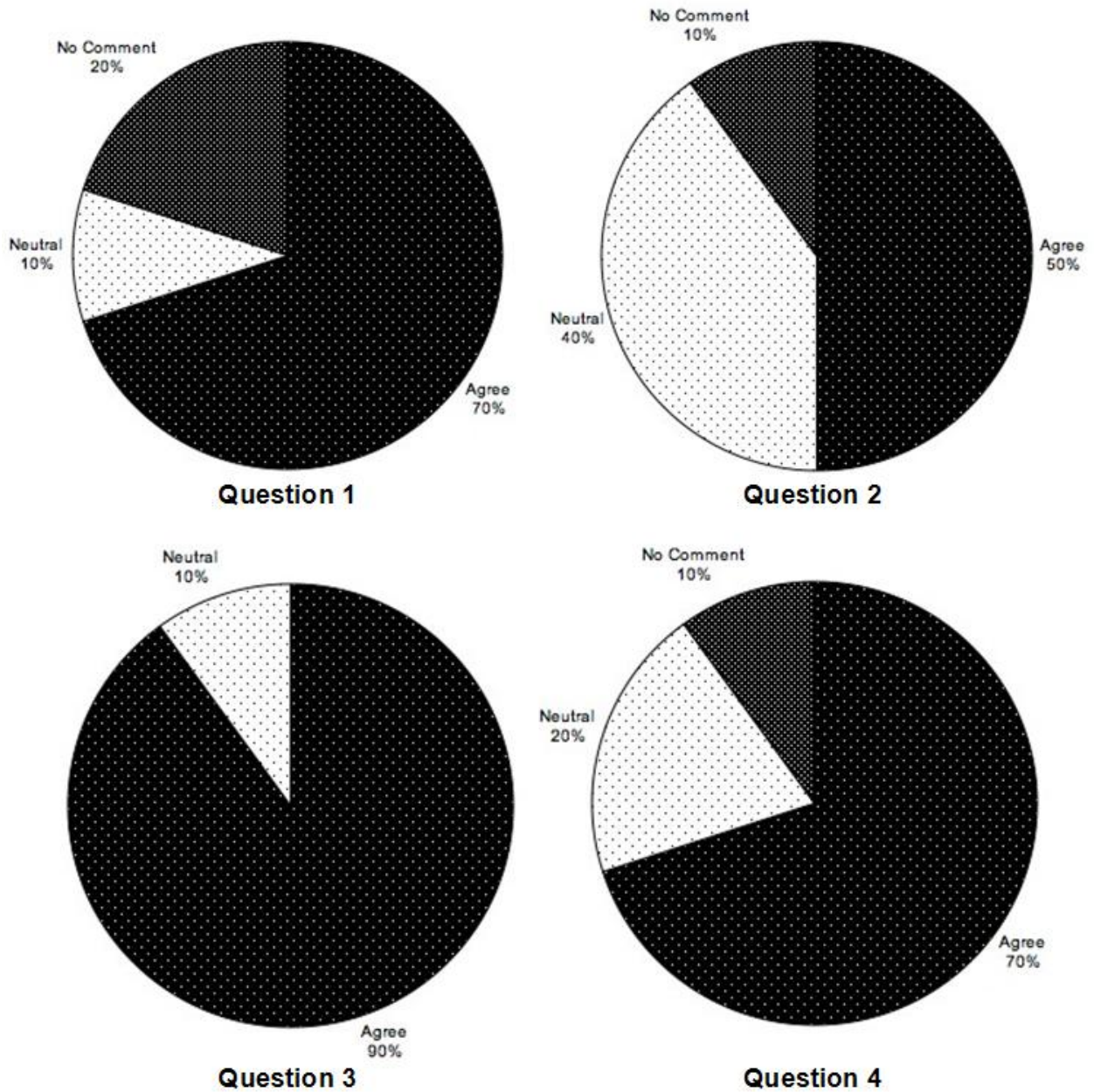
Figure 4. Questionnaire data plot for the four questions in the session 2.

5.3 Section 3: open questions

This section marks a shift in question design. The respondents are confronted with open questions in which they are asked to write down more details in an essay format. Respondents had to indicate one of four levels of agreement/disagreement. These questions were seeking to establish a foundation of AR-supported working practice within which the benefits of collaborative design could be investigated. The first question asked what elements in AR systems are essential for achieving good communications. Most of the designers invited believed that the quality of the virtual AR image and the ability to manipulate designs is critical in conveying design concepts. The second question asked about what mode of work AR technologies will better serve (collaborative or individual work; larger scale or smaller scale work). Most of the designers believed that the demonstrated AR systems better serve a collaborative and smaller scale work/project. The third question asked

them if they agree that AR systems will have positive impacts on the overall quality of design output. Most of the designers believed that AR tools are quite suitable as a presentation tool to clients and consultants as a key value-add to designer-client communication. The 3D effects provided by AR can help clients to better understand the designers' intentions. AR technologies can also better engage these non-professional parties into the designed 3D space. The fourth question asked about which Augmented Reality (AR) features they prefer the most. The designers believed that the ability to change their viewpoint of the virtual design in a natural and quick way is the most impressive feature - preferred to the traditional desktop-based constraining design space. Manipulation of markers by "touch" was also interesting for design review. The fifth question asked them to indicate a wish list of AR features (not limited to current developments) for their daily work. Answers were summarized as follows:

- add audio effects to assess the acoustic impacts

- AR developers collaborate with product and furniture manufacturers to create models of products

- easy section view

- show clashes

- less bulky headset

The sixth, and last ,question asked if they think that AR technologies might hinder project development in any way (e.g., in terms of design creativity, information overload, organizational and/or technical operation). No designers gave negative responses for this question. Examples of comments include "I cannot think of any negatives", "not more than real models do", "no , I do no think so", etc.

An important finding from this study is that they saw augmented reality opening up new markets for their architectural design skills, as dynamic and spatial media are incorporated into the built environment, and as spaces are designed and represented virtually in interactive, spatial, real-time media. They were also specifically interested in using AR at the customer interface as a communication vehicle to convey design intentions to non-professional parties.

6. TRIAL IMPLEMENTATION OF AR FOR REMOTE TEAM COLLABORATION

Based on the results of the above pilot study, a trial implementation has been planned to test a possible use of AR technologies in design practice. A team of researchers and design industry practitioners collaborated in the planning and implementation process. Based on this specific design firm's profiles and strategic plans of other industry partners, the following issues are identified:

- Remote team collaboration: the company is geographically located in multiple offices around the world, delivering projects by collaboration across multiple offices. The company has been flying people around the world for face-to-face meetings which is expensive. Or, the company has been using video conferencing technologies for managing remote project meetings. However, these technologies are not adequate and not tailored for supporting design-related activities. Suitable technologies for remote collaborative design are urgently needed.

- Client engagement: as shown in the pilot study, an absolute majority of designers believe in the positive impacts of AR technologies in engaging clients and other non-professional parties in the design process.

The proposed trial implementation of the AR system for remote team collaboration is described as follows.

6.1 System descriptions

The proposed AR system allows two or more participants at different geographical locations to communicate over a network in an environment simulating a traditional face-to-face meeting as illustrated in Fig. 3. Integrated into the AR environment are live video streams of the remote participants spatially arranged around a physical meeting table. 3D virtual design geometries (models) are visualized on top and middle of the physical meeting table (see Fig. 3 as an example). For collocated collaborators, a large real presentation screen can be used for design display and application sharing.

6.1.1 Application scenario

The AR system could be embedded into an existing global working environment. Members of a project team situated in different locations are provided with a communication platform to collaborate and coordinate on projects. This could provide a base platform to explore the full potential of AR in collaborative design in different perspectives.

6.1.2 Visualization of collaborative design data

The AR system provides a communication platform for the exchange of a broad range of design information. In this scenario, three designers are conducting a meeting. During this meeting, they collaboratively work on a design project by discussing changes and refinements made to the 3D design components derived from the CAD data.

Further, the virtual design can be discussed as a whole, and the focus of discussion can also be shifted to different components of the design or very specific design details. Like in a real face-to-face meeting, the following design information is needed for a comprehensive discussion. They are digitally represented via AR technologies for remote collaboration (see Fig. 3 for conceptual setup of this system):

- 3D modeling application sharing: an application that allows common 3D CAD models to be displayed and shared between remote collaborators;

- 2D documentation sharing: 2D design data such as drawings, text documents and spreadsheets; and meeting agenda and presentation slides.

All digitalized contents can be inserted into the participants' normal views of their local meeting place (similarly as in Fig. 3). Each meeting has a moderator who leads the session and has certain rights and obligations, depending on the purpose of the meeting, such as assigning tasks, choosing or manipulating 3D models to be displayed, and so on. Designers connect from their local offices, with access to their design data and computer systems. They can be invited to the virtual meeting by the moderator of the meeting through their normal IT tools. Like for a normal meeting, information about the meeting can be distributed through mail or shared information spaces in advance to all participants to prepare for the meeting. A virtual status "mirror" can be integrated onto the meeting table where names of the participants are displayed. This enables a user to check his or her own visibility within the meeting and is also available to the other participants (like a mirror).
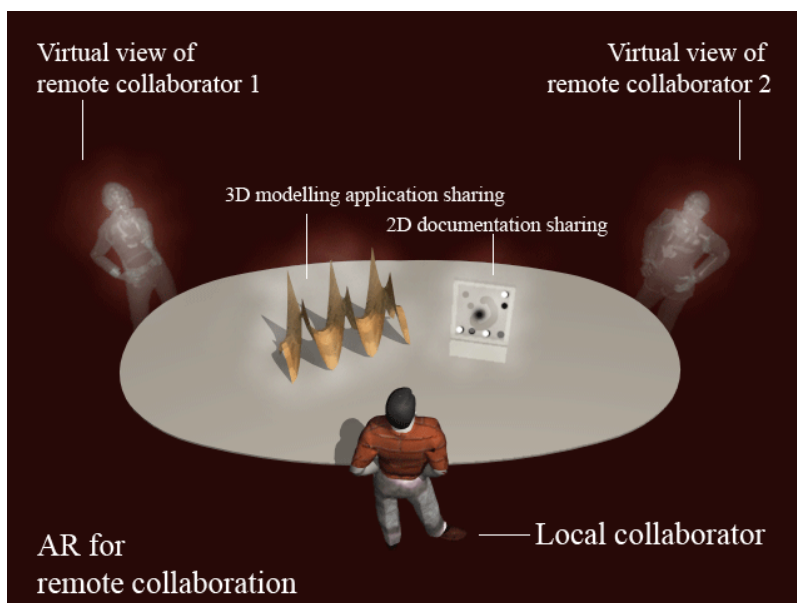

FIG 3: Depiction of the proposed AR system

6.1.3 Avatar visualization of collaborative design team

For supporting virtual presence and to provide the impression of "being there", graphical/video representations of the participants are inherently needed. In most collaborative virtual reality-based systems the users are either represented as abstract geometry or as avatars (animated 3D characters). Abstract geometry (like a cone) seldom supports the presence of another person that is acting on the remote site; avatars are often not convincing unless they have a very high level of detail and properly behave kinematically, which is computationally very expensive. In augmented reality-based videoconferencing applications, the participants are displayed as videos images. This provides realistic representations of the participants but does not well represent the spatial relationship within the meeting. In our proposed setup, we intend to present the virtual appearance of remote participants in a way to give sufficient spatially realistic details during distant meetings (e.g., eye contact and eye gaze). For instance, if a remote user turns his/her head, the connected video appearance will move accordingly in the real space. This provides each participant with information about what his or her collaborators are looking at. Even when the user moves freely within the room, the system can follow and trace the movements.

6.2 Future technological developments

After the implementation of the above system for remote team collaboration, the system could be used as a base platform to further test the following ideas proposed as a wish list by the industry partner:

- Graphic and rendering qualities of the design representations in AR.

- Use of AR with large Building Information Modelling (BIM) models

- Use of AR for on-site and outdoor design.

- Exploring the potentials of AR beyond urban design.

- Modelling capacity especially free-form modelling in AR.

7. CONCLUSIONS AND FUTURE WORK

This paper presented an analytical framework to measuring designers' perceptions on adopting Augmented Reality concept and technology into the design sector. The presented analytical framework provides a first step towards more differentiated understanding of AR use within the design sector. The pilot study presented in this paper was a starting point for exploring patterns of use of AR within the design sector by applying part of the presented analytical framework. The findings from an empirical pilot study into the perceptions of using Augmented Reality technology in design activity are discussed. Ten design practitioners were invited to give their insights about how two Augmented Reality systems might change the way they design currently.

Their perceptions on how Augmented Reality can be integrated into the design sector from the perspective of process and product design were focused. In the design process related questions, 80% of the participants agreed that AR technologies would better facilitate design communication and design information sharing and therefore help them to express their ideas to the team. AR can make contributions to supporting multi-user group activity, acting as a platform to enable effective team working where interchange between participants and conveying of information can be improved. A majority of 70% agreed indicated a simultaneous increase in the number of different disciplines represented in the teams with which they had been associated. The result reveals that the existence of pressures to achieve close integration between team members, to achieve greater efficiency, and to improve the quality of the output of the team motivates them to consider AR as a potential effective tool. 80% of the participants agreed that AR technologies would better facilitate spatial cognition compared to traditional tools. There were 70% positive responses believed that AR can potentially support and improve design creativity and problem solving. A majority of 70% of the respondents agreed on the positive impacts of AR technologies in facilitating design modifications and refinements. In the design product related questions, a majority of 70% agreed that AR technologies could potentially increase the quantity of design production. The result shows that AR seems to increase the quantity of the work that the respondents get through, and the rating is predominant. An absolute majority of 90% agreed with the positive impacts of AR technologies on design presentations. This is an important finding from this study that they saw that Augmented Reality opens up new markets for their services. They were specifically interested in using AR at the customer interface as a

communication vehicle to convey design intentions to non-professional parties. 70% of the participants agreed that AR technologies would reduce lead-time, costs and environmental impact during operation. In the open discussion and interview session, most of the designers invited believed the followings: that the quality of the virtual AR image and the ability to manipulate designs are critical in conveying design concepts; that the demonstrated AR systems better serve a collaborative and smaller scale work/project; that the AR tools are quite suitable as a presentation tool to clients and consultants as a key value-add to designer-client communication; that the ability to change their viewpoint of the virtual design in a natural and quick way is the most impressive feature in which they preferred to the traditional desktop-based constraining design space. No negative response was obtained on the possibility that AR technologies might hinder project development in any ways (e.g., in terms of design creativity, information overload, organizational and/or technical operation). The 3D effects provided by AR can help clients to better understand the designers' intentions. AR technologies can also better engage these non-professional parties into the designed 3D space.

An important finding from this study is that the participants saw augmented reality opening up new markets for their architectural design skills, as dynamic and spatial media are incorporated into the built environment, and as spaces are designed and represented virtually in interactive, spatial, real-time media. They were also specifically interested in using AR at the customer interface as a communication vehicle to convey design intentions to non-professional parties.

The scope of this study is limited only to one architecture company with a limited number of invited participants. Future study will take this analytical framework to interview more design firms on their visualization practices such as their leading digital visualization and simulation practices in architecture, design, urban and landscape planning, engineering, and construction. Design firms can be identified through their participations in industry forums on visualization such as virtual reality and simulation, or through visualization software suppliers' recommendations. They will predominantly be design and architecture firms in Australia, the USA and Europe. The major measurement instrument in the next stage is the use of multiple case studies. Multiple case studies will be used to systematically investigate the mechanisms through which specific AR technological changes happen for the current visual practices. This would be based on the completion of usable AR packages that can be readily used in design sector for certain realistic projects. There are several other issues that need to be considered as well, among which one is the national differences between the design sectors in Australia, the USA and Europe. For instance, the early adoption of Augmented Reality in the Silicon Valley region may be strongly influenced by local high-tech industries. Future studies should also include disciplines other than architecture, such as real estate owners, housing developers, and construction contractors or consultant engineers. Then a better perspective of how AR can supplement their current visualization and simulation modules/practices can be formulated.

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