

ARCHITECTURAL VISUALIZATION AND COMMUNICATION THROUGH MOBILE AUGMENTED REALITY

PEI-HSIEN HSU

*Graduate Institute of Architecture, National Chiao Tung University,
Hsinchu, Taiwan
phsu@arch.nctu.edu.tw*

Abstract. Shifting from head-mounted display to smart devices, there is a new context for augmented reality and its applications. This paper describes a project aiming to re-examine factors of smart-device-based augmented reality and its applications as a tool to support collaborative design and communication, leading to a redefinition of augmented itself and a theoretical framework based on the relationship between virtual content, screen and the body.

Keywords. Design collaboration; augmented reality; visualization.

1. Introduction: Architecture and Mobile Augmented Reality

The technology of augmented reality (AR) (Azuma, 1997) has been mostly locked in laboratories since its invention decades ago for the requirement of special devices. A new context has emerged with the introduction of “smart-device-based augmented reality” (SDAR, AR based on smart devices, e.g. smart phones or tablet PCs), and we see a chance of applying this technology into the field of architecture to support design and communication. However, SDAR is fundamentally different from the conventional augmented reality, normally based on head-mounted displays (HMD). It is, therefore, necessary to re-examine elements of SDAR based on this new context and formulate conceptual models leading to creative applications for architecture.

The key characteristic of HMD-based AR is the disappearance of screen, which may be described as “immediacy” or “transparent mediation” (Manovich, 1995). Although there is a screen, see-through or not, in each HMD unit, it is normally not in the viewer’s attention and is perceptually ignored. With SDAR, by contrast, the viewer holds a portable device, whose screen is

in conscious awareness. Such a fundamental difference is an analogy to the relationship between HMD-based virtual reality and desktop-based virtual reality (3DVE). Screen is addressed as an important design factor as desktop-based virtual reality became prevalent. With the acknowledgement of “screen” and “frame”, 3DVE is distinguished from idealistic virtual reality and is thus linked to conventional screen-based media forms, e.g. animation and cinema, since they share similar screen-viewer relationships and therefore conceptual models of the old media and associated conventions may be borrowed. Such an acknowledgement leads to what Manovich (1995) describes as “cultural interface” and what Bolter et al. (2000) describe as the “digital remediation of media”. Seeing desktop-based VR as another screen-based media form frees it from a technology-oriented thinking. Similarly, it should be argued that SDAR is different from HMDAR not just in terms of hardware, but also the conceptions users may develop. The acknowledgement of screen and frame should lead to different ways of conceptualizing the experience of augmented reality based on portable screens.

A design research project has been conducted to explore the application of SDAR to assist architectural design and communication, and it was divided into two parts, focusing on different scales/scenarios of space. In the first part, a multi-user outdoor SDAR system was prototyped. Unlike conventional HMD-based AR, it allows multiple designers to navigate in an outdoor space and concurrently examine an architectural design from different locations. In the second part, the application of SDAR to support the designing of interior space was explored. Conventional uses of AR in interior design, which are normally limited to the visualization of virtual “objects” (e.g. furniture), was challenged, and it is argued that more flexible AR visualization models can be supported through screen-based AR. Based on a re-thinking of body-screen relationships, three models of SDAR were identified.

2. SDAR Visualization in an Outdoor Scenario

Conventional HMD-based AR lacks mobility, making it difficult to be utilized in an outdoor scenario. There are a few past examples of using AR for architectural/urban design purposes, mostly confined to AR visualization over physical models (Broll et. al, 2004; Ismail, 2009). SDAR, by contrast, offers mobility, and it is one of the major goals of the project to test how it may assist design tasks in an outdoor space.

2.1. DESIGN CONCEPTS

Based on the context of SDAR, a few ideas are developed, with an aim to turn it into a useful tool to support design and communication in an outdoor environment.

- **Manipulation.** Rather than simply displaying the “virtual content” over physical backdrops, SDAR may serve as an interface, letting users manipulate information artefacts, and this can take advantage of touch screens, along with graphical user interface.
- **Multi-user collaboration.** Multiple users can use a system to view a proposed architectural design from different locations and thus get different points of view while sharing the same information contents, including 2D and 3D. The statuses of 3D virtual elements, as a result of joint manipulations, are updated and shared in real time, and the latest statuses are kept for later uses.
- **Swap-view.** Face-to face communication is not supported between people distributed in large-scale outdoor space, and this makes design collaboration difficult. It is possible to exchange AR views between two users over the network to support mutual understanding, leading to better communication.
- **Comments/notes.** With SDAR visualization and designed interface, users can leave comments/notes to particular 3D elements, and such comments/notes are saved and become information artefacts “attached” to associated 3D elements. Such information can be retrieved later and support asynchronous communication among users.

2.2. IMPLEMENTATION AND EVALUATION

The implementation of the prototype involves three major parts:

- **Image registration:** positioning and tracking of the mobile device to enable the coupling between virtual content and physical environment
- **Virtual contents:** 3D models for the content of AR visualization
- **Interface and interaction:** user interface and programming for operations and manipulations of virtual contents in AR

Positioning and tracking in an outdoor setting is difficult, and for positioning, GPS is perhaps the most feasible and available technology, although somewhat unreliable. For prototyping purpose, the project uses a tablet PC and integrate it with an external hardware module (Figure 1), which contains a micro controller (Arduino Nano) linked with a GPS module and an IMU sensor (for 3-axis orientation data), fitted into an attachment holder. Combining position and orientation data, “virtual camera” can be programmed and act accordingly in the augmented reality application (produced with Virtools DEV). A middleware (Processing application) is used in this system to process sensor data from the micro controller and translate the data into a particular protocol (OSC) before sending to the AR application (Figure 2). GPS data, however, has a common “drifting” problem, which makes positioning unstable. A solution to this is developed in the project: GPS data is “normalized” with a designed algorithm and it is read only as the smart device/user is in an idle status. Orientation data is more stable than the position data. One issue discovered during prototyping is that an IMU sensor is high

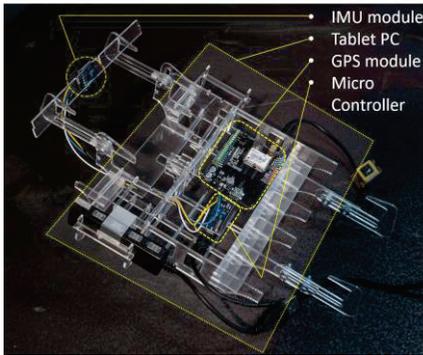


Figure 1. The micro controller module

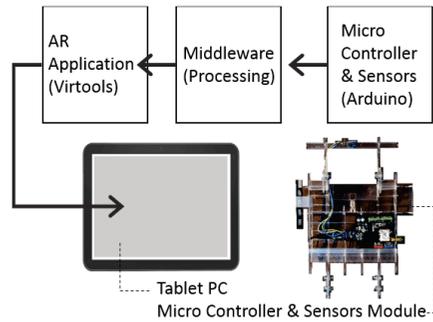


Figure 2. Information processing in the SDAR system

ly sensitive to magnetic forces, and thus it must be kept apart from electronic devices which generate a magnetic field, including table PC used in the project. As a result, it is installed on an element protruding from the micro controller module fit on the back of the tablet PC.

Multi-user connection is achieved with typical server-client network structure, and a database is setup on the server computer, providing data storage and retrieve from/to the client computer. With this mechanism, a user can create new information object, which can later be retrieved by other users. As a user open the AR application, it immediately connects the database and updates information available. Each comment/note information is geographically attached to (a portion of) a 3D element as part of an architectural design. An icon is used as a representation of information available, which is display in full on the interaction of the corresponding icon. An interface is designed to allow a user to mark a particular portion of a 3D mass, which is linked with a comment/note information object (Figure 3). A saved comment/note information is read through this process:

[interaction with an information icon] → [display of the associated area, if there is] → [confirmation of icon selection] → [display of the associated comment information in full].

Two user modes are developed: general mode and designer mode, and an interface is designed for the selection of user modes. In addition, for demo purpose, simple manipulations of 3D geometries are made available (only in the designer mode), and this include scaling/rotation/movement of 3D elements and changes of surface materials. Updates of 3D elements are made automatically as they are changed by any user and the latest statuses are saved and shared among users in real time. The idea of “swap view” (Figure 4), however, is not implemented due to limitation of data bandwidth over the network and related programming issues.



Figure 3. Interface for information display in the outdoor scenario

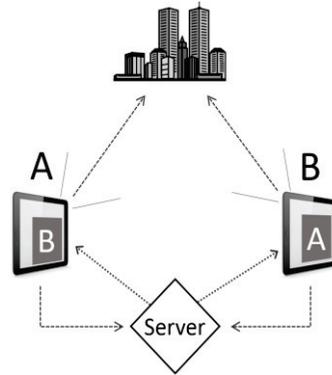


Figure 4. The concept of “swap view”

3. SDAR Visualization in an Indoor Scenario

Combining AR with the designing of interior space is not new, and there are many examples of AR visualization for interior design, however, mostly restricted to the visualization of “objects” (e.g. furniture). To avoid such a restriction, a re-examination of AR is performed, leading to a redefinition of AR based on mobile devices.

3.1. THREE MODELS OF SDAR

The term “augmented reality” essentially refers to a relationship in which virtual elements are, conceptually, merged into the physical world, and this does not necessarily mean the coexistence of virtual elements and physical spaces *inside* the same screen, in the context of SDAR. By rethinking the relationships between person, portable screen and virtual images, three models of SDAR are identified: *Filtered Reality*, *Parallel Reality* and *Projective Reality*.

Filtered Reality (Figure 5(a).) refers to the most common setting where the viewer holds a portable device with its screen relatively close to the eyes, roughly covering the field of view. AR vision is perceived in a way similar to a HMD-based setting, although the screen frame is somewhat visible but generally ignored. By adopting a metaphor — a filter held in hands —, we may turn this setting into a more comprehensible scenario. The screen is conceived as a piece of see-through filter overlaid with a layer of information, 2D or 3D, through which vision is manipulated.

Parallel Reality (Figure 5(b).) is similar to *Filtered Reality* in terms of the eyes-screen relationship. A relatively longer eyes-screen distance leads

to a major difference to the former model — the display screen only occupies a portion of the field of view, and this consequently allows a special coexistence of two types of vision inside the viewing spectrum: vision that comes directly from the physical environment and vision from the screen. There is a “registration” between the virtual and the physical, like in the former model. The virtual content, however, occupies the whole screen, which is normally regarded as virtual reality. It is, nevertheless, argued that the coexistence of the virtual and the physical, which occurs outside the screen itself, leads to a redefined augmented reality. The word “parallel” denotes a scenario in which a viewer looks through a magical “window” into a parallel world which generally shares common statuses with “this world” in various aspects while, on the other hand, may have its own properties (e.g. texture, lighting, time, form, etc.).

Projective Reality (Figure 5(c).) combines projection with smart devices and the idea of “mobile augmented reality” is again questioned. In this model, the coexistence of virtuality and physicality is achieved by merging virtual content with a physical space through projection, and the coexistence of the two is in on the surfaces of the physical space, rather than inside the screen. With proper positioning-tracking mechanism, virtual content is registered with spatial locations even if the holding of the device is unstable. This can lead to a “projection mapping” in which imagery is mapped onto particular parts of a physical setting and create dynamic illusions to otherwise static object

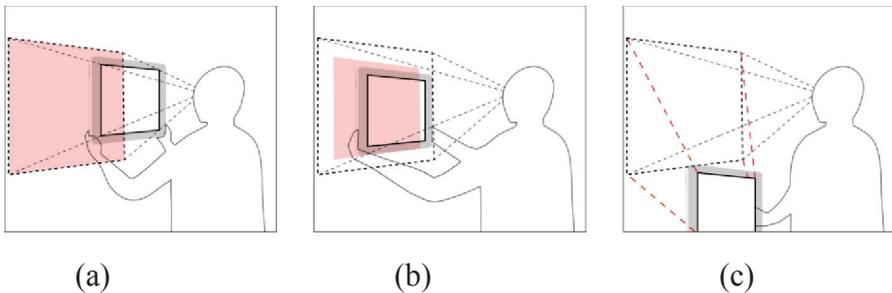


Figure 5. Three models of smart-device-based augmented reality (SDAR): (a) Filtered Reality model; (b) Parallel Reality model; (c) Projective Reality model

3.2. SDAR AND INTERIOR DESIGN

Interior design deals with the designing of indoor environments, covering formal design of spatial enclosures (walls, floors and ceilings), arrangement of objects (furniture, fixtures and appliances), lighting, use of materials and textures, underlying wiring and other technical managements. SDAR visual-

ization can be used to support such tasks, and a particular model out of the three models, explained above, may be more suitable than the others for a particular aspect of interior design. In Table 1, a cross-comparison of the three models over aspects of interior design is made to analyze their capabilities.

Table 1. Three SDAR models and their capabilities to display information. Symbols to distinguish between capabilities of each model (strengths of linkages between a model and a specific aspect):

(○: strong Δ: medium ×: weak)

Model	Object	Spatial Enclosure	Lighting	Wiring
Filtered Reality	○	Δ	×	Δ
Parallel Reality	Δ	○	○	Δ
Projective Reality	Δ	Δ	×	○

Firstly, visualization based on the Filtered Reality model is conventionally used to visualize *objects*, and it indeed is most suitable for this purpose, since visualization based on the other two models do not provide a clear presentation of *objects* against *spatial enclosures*, virtual or physical. It is, nevertheless, a misconception that augmented reality can only visualize *objects*, and it is unnecessary to limit “augmentation” inside the display screen.

Secondly, Parallel Reality, in contrast, is most capable of visualizing *spatial enclosures*, since in this model, by definition, virtual representations of spatial settings, which include *spatial enclosures*, are displayed in full inside a portable screen, and this is otherwise not supported in the Filtered Reality model (full virtual content in the Filtered Reality model reflexively breaks augmented reality). *Lighting*, as an accompanied element of spatial enclosures, therefore, can also be best visualized based on the Parallel Reality model.

Thirdly, in the Projective Reality model, imageries are projected onto surfaces of a space, and it is difficult to achieve an illusion that a 3D virtual object exists *in* the space. On the contrary, it is a major advantage of this model that virtual objects are placed on physical surfaces, which makes it particularly useful for the visualization of *wiring*. Locations of wiring can be marked down in a physical space with the assistance of such a visualization, and it can be naturally shared by multiple viewers due to the disappearance of screens.

3.3. PROTOTYPE IMPLEMENTATION

Similar to the outdoor scenario, the implementation of the prototype for the indoor scenario also includes three major parts: *image registration*, *virtual contents* and *interface/interaction*. Two approaches are tested for the mecha-

nisms of image registration. The first one is a computer-image-based mechanism. A smart device is captured through “omni-cameras” (cameras that capture 360° image) installed on the ceiling, and the captured images are processed in a server computer, with designed algorithms, to provide positioning data (coordinates and z-axis rotation angle) which is transmitted to the smart device through Wi-Fi. Combined with data of the other rotation angles (along x and y axis), this positioning data determines the parameters of the “virtual camera”, which generates perspectives accordingly. The second mechanism is a marker-based approach. The position of a smart device in a room is calculated with programs in itself based on the relative distances between the device and the markers, whose locations in the room are pre-defined. There are a few markers in the room, providing better exposure of the markers to the camera of a smart device. While no marker is captured (e.g. as the camera is facing the floor or the ceiling, which is likely to happen in the Projective Reality model), positioning is determined temporarily based on data from the built-in sensor of the smart device.

A major challenge of the system implementation lies in the processing of associated cameras, including physical and virtual ones. Built-in cameras of smart devices are used for two purposes: recording real-time video as the “backdrop” of AR and capturing markers to enable image registration. In addition, based on the differences among the body-screen relationships in the three SDAR models, it is theoretically feasible to make the system automatically switch among three users modes accordingly on the change of body-screen relationship, and this requires another built-in camera to capture the viewer’s body/face, detecting its status against the smart device. Due to a hardware limitation, however, two cameras on a dual-camera smart device cannot be activated at the same time, making it impossible to use the front camera to detect the body-screen relationship while it is necessary to use the back camera to enable AR. Alternatively, graphical interface is designed for users to manually make choice among the three SDAR modes.

Due to differences between parameters associated with users’ vision, including eyes-screen distance, height and the eyes’ field of view (FOV), another interface is developed to allow the inputs of such parameters to match between a user’s natural perspective and the perspective generated according to the parameters of the virtual camera. The virtual camera in Parallel Reality is different from it is in Filtered Reality not only in terms of eyes-screen distance, but also the “coverage of vision”. Real-time rendering of 3D space in Parallel Reality needs to be cropped to simulate the perspective of “looking through a window”, in which the window only occupies a portion of FOV (Figure 6). In addition, for the way the micro projector is linked with the tablet PC, a user needs to rotate the integrated device (with the screen

facing upwards), and this requires the virtual camera to rotate automatically on the change of user modes.

It should be noted that a precise representation of visualization in Parallel Reality is nearly impossible due to the fact that visualization, along with associated parameters, in this mode is designed to produce perspective with proper visual alignment of the virtual and the physical *through a viewer's eyes*, rather than through a camera used to capture the screen and the backdrop it is facing — a “third-person” viewpoint is never the same as the first-person one unless we can somehow record what is visually perceived in the body.

4. Conclusion and Future Research

We see that, with popular smart devices, SDAR has the potential of becoming useful tools to support the designing of architecture and interior spaces. Linking database with SDAR under a multi-user network extends SDAR to a platform which assists collaborative design and communication, synchronously or asynchronously. Positioning and tracking appears unstable and lacking accuracy, although usable, at the time of research. This paper does



(a)



(b)



(c)

Figure 6. The concept of visualizations based on the three SDAR models and their applications on interior design:

(a) Filtered Reality model and virtual objects; (b) Parallel Reality model and spatial enclosures; (c) Projective Reality model and projected images on the wall

not focus on technologies related to this issue. For future research, however, evaluations of mechanisms for image registration, which is essential to any AR application, is important. Emerging technologies, such as iBeacon (Martin, P et. al, 2014) which may serve as alternative positioning-tracking mechanisms, should be investigated. In addition, a few novel ideas developed through the project which have not been implemented, such as the idea of “swap-view” and the idea of automatic SDAR mode switching, can be continued as future research.

Augmented Reality is not just a technology, but a specific way for us to look at our world, a complex amalgamation of both physical and virtual entities. Rethinking augmented reality based on the differences between conventional HMD display and portable screen display leads to more flexible applications of such a technology, and, reflexively, augmented reality itself is redefined. Metaphors and conceptions described in the three models do not lead to ultimate answers to the designing of applications based on SDAR. Instead, they point out the importance and possible benefits of re-examining factors of augmented reality based on the new context. They also show that, with such a re-examination, design possibilities can be explored.

References

- Manovich, L.: 1995, *The Language of New Media*. The MIT Press, London
- Bolter, D., Grusin, R.: 2000, *Remediation: Understanding New Media*. The MIT Press, London
- Azuma, R. T.: 1997, *A Survey of Augmented Reality*. In: Presence: Teleoperators and Virtual Environments 6, 4, 355-385
- Ismail, A. W. S., M.S. 2009. *Multi-user Interaction in Collaborative Augmented Reality for Urban Simulation*. Machine Vision, 2009. ICMV '09, 2009. 309-314.
- Ismail, A. W. S., M.S. 2009. *Collaborative Augmented Reality Approach for Multi-user Interaction in Urban Simulation*. Information and Multimedia Technology, 2009. ICIMT '09, 2009. 19-23.
- Broll, W., L. I., Ohlenburg, J., Wittk, M. Yuanc., Novotny, T, Fatah, Schiecky, Mottramy C., Strothmann A.: 2004, *ARTHUR: A Collaborative Augmented Environment for Architectural Design and Urban Planning*. Journal of Virtual Reality and Broadcasting, 1.
- Martin, P., Ho, B.J., Grupen, N., Muñoz, S., Srivastava, M.: 2014, *An iBeacon primer for indoor localization: demo abstract*. BuildSys '14: Proceedings of the 1st ACM Conference on Embedded Systems for Energy-Efficient Buildings, ACM, New York, USA, 190-191