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INTRODUCTION
INTRODUCCIÓN

ESSAYS
ENSAYOS

Architectural Visualization in the Age of Mixed Reality

3,434 WORDS
VIRTUAL REALITY, AUGMENTED REALITY,
MIXED REALITY, VISUALIZATION, COMMUNICATION
REALIDAD VIRTUAL, REALIDAD AUGMENTADA,
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ABSTRACT

Having been a promising visualization tool since the 1950s, ironically, virtual reality (VR) and augmented reality (AR) were not widely used in the architectural design and evaluation process due to the high cost of equipment and complicated programming process required. However, with the recent development of head-mounted displays (HMD) such as Oculus Rift, HTC Vive, Microsoft HoloLens, and easy-to-use game engines, both VR and AR are being reintroduced as Mixed Reality (MR) instruments into the design industry.

This paper explores research related to VR concepts of "essential copy" and "physical transcendence" (Biocca, Levy. 1995), and their use in architectural design studios at the University of Cincinnati. We explored various methods to integrate MR in the architectural design process. This paper discusses two main aspects:

(1) how to integrate MR into the design process as a design instrument, and (2) how to valuate MR methods for communicating architectural data, based on the workflow efficiency, rendering quality and users' feedback.

MIXED REALITY AS A METHOD OF COMMUNICATION

As a visualization and communication medium, computer rendering has been adopted in the architectural design industry for quite a while. However, to represent our perception of architectural space as a spatial-temporal experience, static renderings fail to adequately reflect reviewers' unsteady and ever-changing perceptions over time. Although computer rendering has been well integrated into the design process, it has no significant advantage over conventional representation methods such as hand drawings and mock-up models. It does not provide a pro- gressive viewpoint to experience a space. It is up to the audience to merge several scattered presented images to construct an exhaustive mental image of that space.

Flythrough animation is a partial improvement to the static rendering and provides better communicates spatial-temporal perception. Although the fast-growing rendering technology has allowed for more and more photorealistic animations, they stil are a passive experience. Not being an interactive media, animations do not allow viewers to navigate freely in space. Viewers' viewpoints and navigation patterns are not self-chosen but pre-defined as a linear experience. Therefore, a critical aspect of the spatial experience is missing in animation: the spontaneous interaction between viewer and the environment. A pre-defined camera path does not provide the viewers with the freedom to explore the space and assist them in completing their mental image of the space. According to computational researcher Yuhuda Kalay, it is essential to enable the viewer to "control his or her own actions especially to look around and see the environment at will" (Kalay, 2004, 181–182). To enhance these passive visualization methods, we have investigated the current VR game industry, and several newly developed head mounted displays (HMD), which provide sesor-based head tracking in an immersive environment. The game industry is one of the quickest growing technology-intense industries in the latest development of HMD, and the human-computer interface (HCI) is pushing MR into a new level. Compared to AR-enabled mobile devices such as iPhone, Google Tango devices and mobile apps such as ARki, VR in HMD can provide superior graphics quality using real-time reflection, depth of field, displacement map, normal map, and global illumination The game engines are capable of handling very complicated, high-polygon geometries with a high frame rate. VR games have blurred the line between scientific simulation and interactive game

INDUSTRY

Inspired by VR games, we built an MR system including a desktop, an Oculus Rift, a Microsoft HoloLens, and an Xbox controller. As a generation growing up with video games, most students are already quite familiar with the concept of VR and are comfortable navigating in virtual environments with HMD. We quickly assembled a student research team and started to use game engines—Epic Game's Unreal and Unity—to visualize building models through Building Information Modeling (BIM) software. This system enables us to incorporate voice and gesture control with stereoscopic display and 360-degree videos.

RESEARCH

Frank Biocca and Mark R. Levy discuss "essential copy" and "physical transcendence" as the two main drives behind the formation of all virtual worlds. They go on to describe the searching for "essential copy" as seeking "a means to fool the senses, a display that provides a perfect illusory deception". While they illustrate "physical transcendence" as "an ancient desire for escape from the confines of the physical world, free the mind from the 'prison' of a body" (Biocca, Levy, 1995).

Virtual DAAP was a project launched in 2016 to explore the concept of "essential copy" by reconstructing an existing space in VR. Beyond merely modeling the physical characteristic of the space, we are particularly interested in studying human behavior and wayfinding in the "copied" virtual environment. Using a Leica Scanstation laser scanner, we scanned the grand stairs of Peter Eisenman's Aronoff Center for Design and Art. After the point cloud data was cleaned in Autodesk Recap360, a mesh model was constructed, transferred to the Unity engine, and compiled into Oculus Rift. Computer-generated crowds with AI controlled wayfinding behaviors were developed in the Unity game engine. In a multi-agent system, the autonomous 'action' of each agent lies within modifying its movement based on the repulsion or attraction to neighboring agents in addition to the environment itself. The researchers analyzed participants' wayfinding behaviors in this immersive VR environment and their interactions

Figure 1. VR for “essential copy”, point cloud data from the laser scan.

with virtual agents.

Oculus Rift demonstrated a high power to render animated crowds, complex 3D forms, and photorealistic lighting effects. Having a high frame rate, the HMD maintained a promising graphics.

Meanwhile, we tested Microsoft HoloLens as a platform to experiment the concept of ‘physical transcendence’ by blending imaginary forms and physical, abstract sculptures that created hallucinated effects. Even though the holographic light field generated from HoloLens was not as photorealistic as VR, it enabled designers to program virtual objects to react to the physical context using HoloLens’ infrared scanning and spatial mapping technology. HoloLens also supports multi-user interaction, meaning that multiple users will be able to communicate within a shared virtual environment.

In 2016, our MR installation, “Misbehaved Tectonic”, was displayed at the SOFA Expo Chicago. The project included a holographic animated sculpture that was superimposed on top of a real sculpture, to create a dialogue between the digital and the physical realm. The real-time spatial mapping constantly tessellated the physical environment and projected to the viewers an illusion of floating with jellyfish. The exhibition’s site, sculptures, and people were constantly digitized and overlapped with their digital form to achieve a ‘physical transcendence.’ Through HoloLens, a real-time blending between physical form and its virtual counterpart was made and shared with the audiences. After the research projects, we started to apply MR methods in the architectural design studios and focused applying these technologies to facilitate the design process.

STUDIO I: FUTURE CITY PROJECT WITH VR

Future City Studio emphasizes on the simulation of urban systems and site information as input para meters. The research is defined as a hybrid method which seeks logical architecture/urban forms and analyzes their sustainability and performance. The studio project expands future urban system research by exploring, collecting, analyzing, and visualizing urban information, as well as using VR technology for representing this information through various immersive environments.

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Through intense training, students quickly grasped the technique of alternating the virtual site in a game engine. Landscape, including trees and grass, was carefully added to match the characteristics of the real site. Through the VR system, students explored various design concepts by “walking” with HMD. Additionally, a daylight system allowed students to simulate sunlight in different times of the day, and adjust their building envelope to achieve the best result. We also customized the user interface and provided visual cues to assist with communication, and a bird’s-eye map was added on top of the 3D scene to illustrate player’s current location and orientation.

To compress the design timeline and maximize the efficiency of workflow, we used various 3D modeling tools, which allowed students to quickly generate parametric models and load them into a game engine, to then export them into VR. Materials were procedurally generated in the game engine with node-based networks. Reflection probe and light probe were used to simulate reflective materials and dynamic lighting, sunlight, and skylight were set up to generate global illumination and dynamic daylight system, and point lights and spotlights were added to simulate interior artificial light. In the end, students were also required to review each other’s works in the VR environment by “walking through” their building. Several design issues were addressed during this VR walkthrough, including the interior circulation of the building, the visual connection between the designed building and existing urban context, as well as the changing view the proposed past.

During the critiques, reviewers either actively controlled their navigation using HMD or observed others walking through a building. In the second scenario, reviewers gave commands such as “turn around”, “go to the second floor”, and “look out of the window” to the players. Usually, a passive observer would switch his/her role to an active player by wearing HMD. With the game controller, players selected their path and navigated through the building while asking questions and giving comments simultaneously. The VR aided-critic is very similar to the natural way of critiquing a building when two people are physically walking together. However, this critique is more comprehensive than a traditional review because the large screen makes it possible for the audience to directly observe the player’s gaze in real time and understand their verbal comments, the audience would realize what design features attracted the player’s attention, how long it took the player to find a specific path, and where the player got confused (Fig. 2).

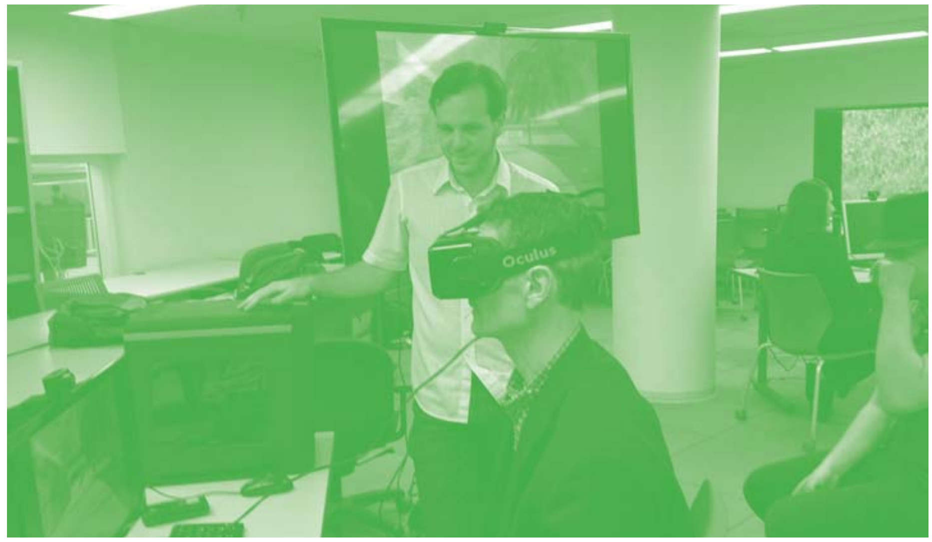

Figure 2. Architecture studio review with an Oculus Rift and a large screen at the University of Cincinnati.

Reviewers were able to use VR as a new communication instrument to discuss the spatial quality in an immersive environment. VR “allows the critic to become engaged and immersed in the project...point out moments of strength/weakness in the design and areas to improve on” (Survey). Spatial memory and cognitive features of design were discussed while at the moment of walking inside of the virtual space. There are also lessons learned in this studio. Because we limit the player’s walking speed to match human’s actual walking speed in the physical world, it took a long time for players to walk through a large site. Therefore, a flythrough or teleport mode was suggested. Since there were no other animated figures on the site, players felt strange when they “walk along” in the empty building.

STUDIO II: URBAN MOBILITY AND PUBLIC SPACE

After the first studio, we started the second MR studio to address some of the questions and problems we discovered in the former one. The new studio presents a study investigating urban mobility and public space integration by visualizing urban information through MR technologies.

In this studio, Microsoft HoloLens was also deployed to explore AR applications. Being different from computer renderings in VR, hologram technology provides a photographic record of a light field. Students visualized their designs within a HoloLens 3D environment using gesture and voice recognition. By applying Unity’s AR support to develop MR applications, various interactivities such as gaze, gesture, voice, spatial sound, and spatial mapping were tested through Holo-Lens’ emulator. In the end, design projects were developed and compiled as apps in HoloLens. Students also applied 3D modeling tools to build conceptual models, imported them into a game engine, and compiled them to HoloLens. Various gesture-based interactions, such as rotation, scale, and move allowed users to manipulate the models virtually.

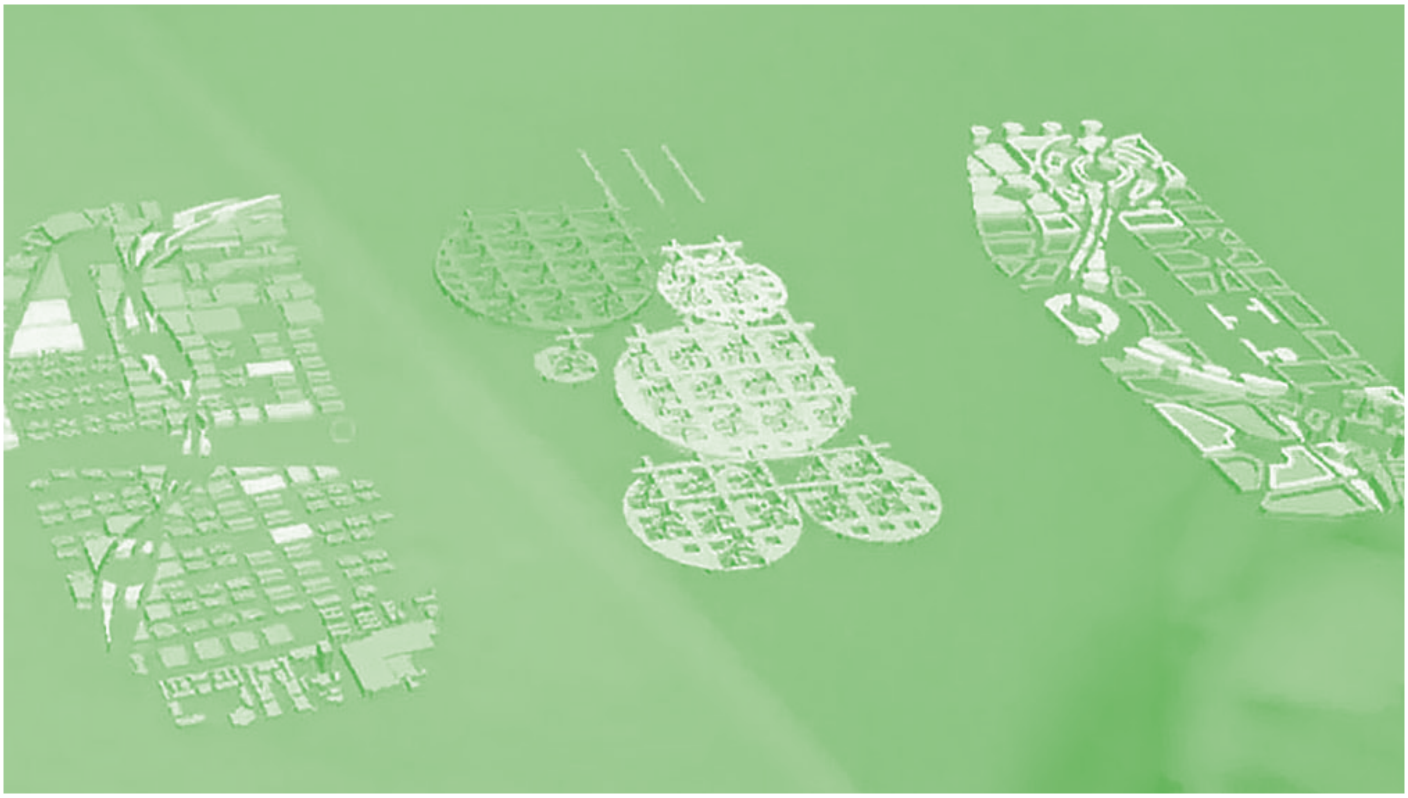

Figure 3. The studio project is presented as hologram models with Microsoft HoloLens. A user can interact with the model with gesture and voice.

Compared with Oculus Rift, HoloLens HMD is itself a power ful computer which provides users with a freedom to explore the digital content. With its spatial mapping technology, AR gives users an unlimited space to navigate through. More critically, AR does not exclude the virtual world from the physical one. Users can still observe the physical environment and interact with other people while exploring the overlaid digital content, while also allowing virtual collaboration by connecting multiple HoloLens HMDs (Fig. 3). In the studio, we also improved VR methods by introducing fly-through navigation, as well as mass animated crowd systems. We connected agent-based simulation and streamed the animated crowd into the VR system, finding an effective fit between urban mobility research and pedestrian movement in public space. The first-person experience was also captured on a 360-degree spherical video, and shared through Google cardboard.

At the end of the second studio, we surveyed both methods (VR and AR) with students and reviewers. VR received a higher satisfaction rate primarily due to its higher rendering quality. Indeed, these two methods provide entirely different rendering styles. VR rendering with Unity or Unreal can be described as 'hyper-reality' due to its photorealistic rendering. AR Rendering running with HoloLens is more an abstract reality due to its limited rendering power. We can anticipate that AR will continue to be developed and reach a higher rendering capacity in the near future. Overall, players feel more 'immersed' in the VR 'hyper-real' world. Another reason for VR's higher satisfaction rate is its natural interaction. VR + a game controller allows viewers to interact with 3D objects. Users can open or close doors and windows, turn the lights on and off, or take an elevator by using buttons on an Xbox controller or Oculus Touch. These well-understood interactions psychologically increased players' presence level and made the scene more believable. However, the gaze, voice, and gesture control in AR are not rooted in the real world and disconnects with our mindset in a virtual environment. We also found that VR-based 360-degree video has a high potential to allow the viewers to partially enjoy the freedom of VR, while it has fixed the camera path in a predefined curve. This video-based method is proficient in maintaining the high-quality rendering with the right frame rate, without the need for an expensive high-end computer. By using a simple mobile phone and Google cardboard, viewers can experience VR easily.

CONCLUSION

During the past two years, our research and teaching have focused on applying MR in the architectural design process, where sensory-intensive "immersive displays" facilitate many design decisions. VR and AR integrate site survey, design evaluation, and construction within a new communication system, which allows a proposed space to be generated, visualized, and shared quickly. Both methods have achieved this primary goal. With a steep learning curve, students can master these advanced technologies and use them to assist their design. By implementing these methods to the studio projects, we find some benefits as well as some constraints.

BENEFIT OF MR AS A MEDIUM OF COMMUNICATION

Architect Ana Regina Mizrahy Cuperschmid described the benefit of applying MR using a smartphone and smart glasses in the assembly of a precast wood-frame wall, based on the BIM model of the wall execution sequence (Cuperschmid, Grachet, Fabrício, 2016). MR served as a visualization tool for training and construction quality control. In our approach, MR, as a design instrument, is applied in the early stages of the design process. In our project, building models were imported into the game engine and visualized through HMD. This pipeline enabled students to design, exam, and modify their design while interacting with it. It became a fast cycle of refining and evaluation. There was a significant amount of positive feedback from faculty and students when they "interactively walked inside" of a proposed design.

After exploring the VR environment, students had the opportunity to understand the meaning of movement patterns. They experienced how color, lighting, and materials could affect people's perception of space. A student mentioned in the survey that "the primary benefit, currently, is in spatial (including scale, adjacency, and circulatory flow) perception and 'buy-in' for stakeholders, while also having high marketing value for new practices." A reviewer mentioned: "It can more accurately represent the experience one would have in reality hence (virtual reality), as opposed to other types of representation, such as 2D drawings and renderings. The ability to understand the psychology of a piece of architecture is made easier with VR."

In the VR environment, design issues such as scale, proportion, rhythm, and circulation were discussed in a "natural" way when both the reviewer and the designer "walked" through space simultaneously. VR has stimulated more thoughts on spatial recognition, spatial memory, and other unforeseeable design topics, but these were too complicated to be addressed in the studio.

CONSTRAINTS OF MR AS A MEDIUM OF COMMUNICATION

Besides the well-known motion sickness of HMD, we also found other limitations of MR as an emerging architectural communication system. In various studio presentation, students are encouraged to use MR without 2D sections and plans displayed on boards. However, we quickly found out about the problems associated with abandoning these traditional representation methods. According to a participant in our survey, VR has difficulty in illustrating "overall understanding of the concept as it relates to a program of the building or space (typically displayed with site plans, sections, and building plans)" (anonymous, survey, 2016). "Similar limitation exists within this design communication process/ methodology as when well-executed renderings take center stage (often the case in our profession). The 'wow factor' of product and technology overshadows discussion, fine-tuned development, and evidence-based disclosure of social, legal, and building science design programming." Some students mentioned: "It (VR) gives the first-person interaction with space, but not with the overall mood of the space (i.e., more materiality, lighting conditions, and tactile relationships with the building)." "(It is) hard to comprehend the big idea through the process and organizational strategies of the design concept."

After observing the limits of MR as an interface during the communication, some reviewers argued that "it cannot be the only form of presentation but rather another tool for students and critics to understand the student's vision and idea", and suggested to "have students construct a 'pre-programmed path' with highlights to streamline the interaction and incorporate means to receive and document feedback." Some reviewers pointed toward the need for data beyond just the sensory experience. "Hybridize VR much in the way BIM has hybridized embedded information within the model. Dashboards and other visual, 'on call' feedbacks (visual, audio, and haptic) can be further developed within real-time VR models to bring higher meaning, interactivity, and holistic integrity to future stakeholder presentations."

We also observed that the performance and frame rate of MR would drop dramatically if a scene had a large number of polygonal faces. The level of detail (LOD) required the building to be modeled efficiently to minimize the polygon number, which has never been a priority in the standard BIM software. The skills to optimize a complex model for real-time rendering is essential. However, as a side effect, the low polygon model will lose details and look worse when the camera gets closer to the object in HMD. Students mentioned that "being able to detail a digital model to the level that a user would perceive in reality, can strain the limitation of our current computing power and is not very easy to use for someone with no experience in operating the software and other components necessary to have the experience… The digital model needs to be at a level of detail not needed in other representations."

Overall, we gained an understanding of MR as a new means of communication which should not only be used for generating sensory experience, nor to create a copy of physical reality. The MR technology is becoming an 'ultimate display' which will allow us to explore, discover, evaluate, and improve our design. In other words, it should become a part of an iterative process of our continuously evolving architectural practice.

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