Building a Virtual Reality Viewing Device Using 3D Printing

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The use of Virtual Reality technology in the A/E/C industry is growing quickly. Walkthroughs of these models can be accomplished in 2D quite easily using current technology. However performing a virtual walkthrough in a 3D interactive environment requires some additional costly equipment. The ability to quickly acquire technology inexpensively would enable greater use of collaborative virtual reality tools for design and construction. The growth of 3D printing technology coupled with inexpensive Head Mounted Displays (HDMs) may be a way to expand the use of visualization for field applications. This paper discusses the growth of Virtual Reality in the Construction environment and explores a way to develop inexpensive tools for viewing building models using both HMDs and 3D printing.

Keywords: Virtual Reality, Head Mounted Displays, 3D Printing

Introduction

Construction projects are becoming objects in computer generated worlds. There is a growing demand to interact within these objects in a number of ways. The extraction of data, movement in and around the building, the visualization of building sequencing, and identification of clashes are all evolving interactive requirements of the design/construction team. The use of computers to model and display this information is adequate but has limitations. There is currently little inexpensive and quickly acquired options to experience these objects in a three dimensional visualization.

With the increasing use of 3D Printing and the expanding use of it in the A/E/C world. There are now inexpensive and quick options to develop the equipment needed to interact and experience virtual visualization of buildings.

Virtual Reality Overview

Virtual Reality and Augmented reality for use by constructors is seen as important breakthroughs. Milgram and Kishin (1994) defined their reality-virtuality continuum as a range that spans from real environment to the virtual environment (See Figure 1). Augmented Reality (AR) and Augmented Virtuality (AV) are in between where AR is closer to reality and AV is closer to virtuality.

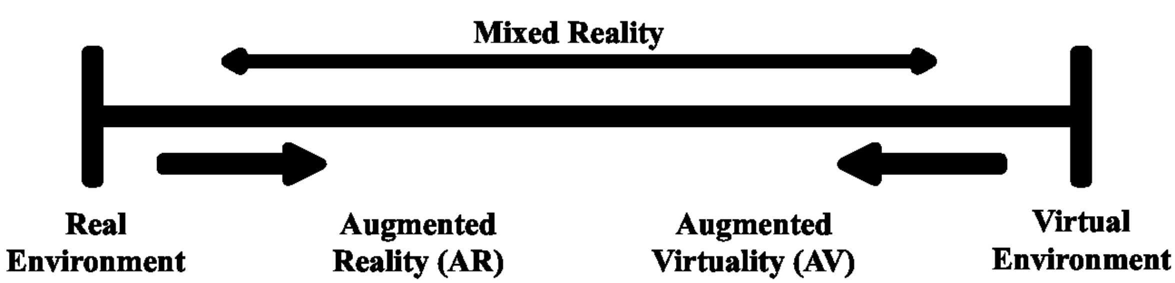

Figure 1: Milgram's reality-virtuality continuum (Milgram et al., 1994)

As illustrated in Figure 2, the whole spectrum of mixed reality spectrum can be utilized through different mobile technology platforms (e.g. handheld devices, tangibles, and wearables).

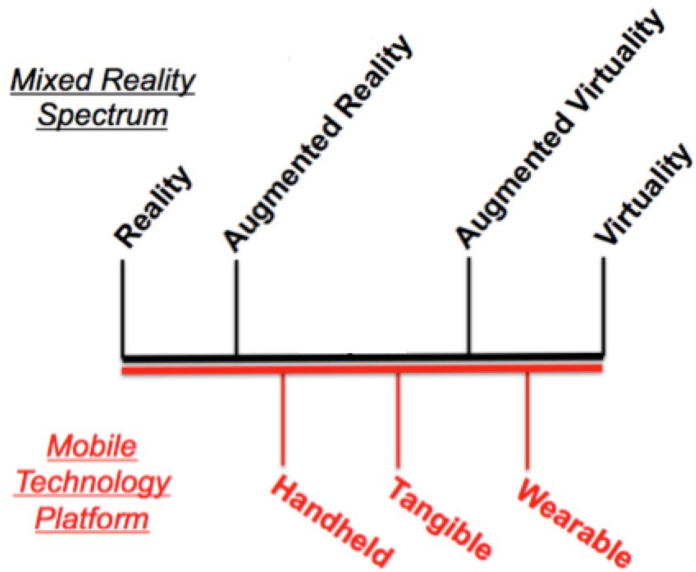

Figure 2: Mixed reality spectrum & mobile technology platform

Howard Rheingold (Rheingold, 1991) defines virtual reality (VR) as an experience in which a person is "surrounded by a three dimensional computer-generated representation, and is able to move around in the virtual world and see it from different angles, to reach into it, grab it, and reshape it." However for this paper a definition more confined to the visual domain: a VR system is one which provides real-time viewer-centered headtracking perspective with a large angle of view, and binocular display will be discussed.

Several common systems satisfy some but not all of the VR definition above. Flight simulators provide vehicle tracking, not head tracking, and do not generally operate in binocular stereo. Omnimax theaters give a large angle of view (Max, 1982), occasionally in stereo, but are not interactive. Head-tracked monitors provide all but a large angle of view (Codella, 1992 & Deering, 1992). Head-mounted displays (HMD) use motion of the actual display screens to achieve VR (Fisher, 1992), this being the subject of this paper.

Previous work in the VR area dates back to Sutherland (Sutherland, 1965), who in wrote about the "Ultimate Display." Later in the decade at the University of Utah, Jim Clark developed a system that allowed wireframe graphics VR to be seen through a headmounted, BOOM-type display for his dissertation. The common VR devices today are the HMD and the BOOM.

To distinguish VR from previous developments in computer graphics, the following are a list of the depth cues one gets in the real world.

1. Occlusion (hidden surface)
2. Perspective projection
3. Binocular disparity (stereo glasses)
4. Motion Parallax (head motion)
5. Convergence (amount eyes rotate toward center of interest, basically your optical range finder)
6. Accommodation (eye focus, like a single-lens reflexas range finder)
7. Atmospheric (fog)
8. Lighting and Shadows

Conventional workstation graphics gives us 1, 2, 7, and 8. VR adds 3, 4, and 5. No graphics system implements accommodation clues; this is a source of confusion until a user learns to ignore the fact that everything is in focus, even things very close to the eyelash cutoff plane that should be blurry.

Issa (Issa, 2000) stated in his paper on Virtual Reality: A Solution to Seamless Technology Integration in the AEC Industry Virtual; "In the long term, VR (fully immersive) will offer the average user the potential to enhance the final presentation by combining 3D images, head-mounted displays, sounds, and self-movements. The ability to support the illusion of the individual's movement through the virtual space will make the implementation of VR much more acceptable to humans. Users will be able to feel/see their movements in space, thus, improving the performance and well-being of the ultimate human user. Users' movements and requests, in virtual space, will be monitored and controlled by an intelligent and integrated knowledge based system and other external construction applications where all communications with external applications' are carried out in virtual space in either a textual or graphical format.

The flexibility offered by virtual environments to visualize and interact with the virtual world, provided that these technologies are available at a reasonable cost, will enable designers, clients, and contractors to use VR to rapidly construct and test their prototypes before constructing the actual project. But this only happens if the strengths of the technology are emphasized and the hype is significantly played down. VR should be treated not as a technology in its own right, but in terms of a suite of technologies which, if carefully implemented, are capable of matching the capabilities of humans to the requirements of the application or task he or she is required to work with.

The potential of VR can only be realized if it is integrated with AEC application packages. An integrated construction environment should be developed where all construction applications are integrated through a central intelligent core. VR can play a major role in the development of a human computer interface for such an environment. Whether immersive or non-immersive techniques are used, users can visualize design and construction information in 3D, photorealistic, and interactive images. Moreover, VR displays and interactive devices should only be selected on the basis of a) human factors issues i.e. what is expected of the performance and well-being of the ultimate human user, and b) customer requirements. One evolving tool for experiencing immersed VR is the use of Head Mounted Devices (HMD)."

Problem Statement

It is accepted that VR will play an important role in the design and construction of buildings. But some of the barriers of implementation are field implementation and use of viewing and interactive three dimensional units for viewing models. Would it be possible to develop and build a simplified method and tool to interact with VR building models in the field? Could these viewing tools be manufactured and implemented on a construction site with little cost in a quick timeframe? This investigation explored these questions and potential solutions.

Current Head Mounted Displays

There are a number of ways to interact with three dimensional virtual models. For this paper we focused on HDMs since they are the most likely solution as small mobile viewing and interactive device that could be used in the field. There are a few of off-the shelve VR headsets that can be purchased and used, they are typically expensive and require a long lead time to acquire. Some are only available if you commit to being a developer and paying an up-front fee for the use of the hardware. In a study that was conducted in 2013 by the Virtual Reality and Augmented Reality Forum (Lang, 2013), some examples and comparisons of popular Head Mounted Displays were presented (see Table 1).

Table 1: Comparison of Head Mounted Displays (HMD)

	Carl Zeiss Cinemizer	**Oculus Rift Developer Version**	**Silicon Micro Display ST1080**	**Sony HMZ-T1**	**Sony HMZ-T2**
Price	$749	$300	$799	$799	$894
Official Site	Cinemizer Site	Oculus Rift Site	SMD ST1080 Site	Sony HMZ-T1 Site	Sony HMZ-T2 Site
Display Resolution	870x500 (1.74:1)	640x800 (1.25:1)	1920x1080 (16:9)	1280x720 (16:9)	1280x720 (16:9)
Horizontal Field of View (degrees)	H: 30°	H: 90°	H: 39°	H: 45°	H: 45°
Display Technology	OLED	LCD	LCoS	OLED	OLED
Display Size (diagonal)	0.39"	7"	0.74"	0.7"	0.7"
Weight (headset)	120g	379g	180g	420g	330g
Weight (control unit)	60g	unspecified	106g	600g	600g
Pixels Per Inch (PPI)	2572	216	2976	2098	2098
Head Tracking	Optional	Yes	No	No	No
3D capable	Yes	Yes	Yes	Yes	Yes
Audio	Stereo: Earbuds	BYOA	Stereo: Earbuds	Virtual Surround: Headphones	Virtual Surround: Earbuds

From the table it can be seen that there are a variety of types and specifications of these units, all above the $300 price point. Although the cost of one of these units may not be a deterring factor to purchase and use, the question is whether or not it is right for the contractor's use and if the technology has developed sufficiently to justify the expense. With a less expensive and immediately acquired alternative a contractor, regardless of their size or volume, could explore the technology and determine how best to adopt it in their organization.

3D Printing use in Construction

An additional evolving technology that is growing in interest by contractors is that of 3D printing. According to the website 3dprinting.com; 3D printing or additive manufacturing is a process of making three dimensional solid objects from a digital file. The creation of a 3D printed object is achieved using additive processes. In an additive process an object is created by laying down successive layers of material until the entire object is created. Each of these layers can be seen as a thinly sliced horizontal cross-section of the eventual object.

It all starts with making a virtual design of the object you want to create. This virtual design is made in a CAD (Computer Aided Design) file using a 3D modeling program (for the creation of a totally new object) or with the use of a 3D scanner (to copy an existing object).

To prepare the digital file created in a 3D modeling program for printing, the software slices the final model into hundreds or thousands of horizontal layers. When this prepared file is uploaded in the 3D printer, the printer creates the object layer by layer. The 3D printer reads every slice (or 2D image) and proceeds to create the object blending each layer together with no sign of the layering visible, resulting in one three dimensional object.

The use of this type of technology in construction is gaining interest. In the heralded book by Christopher Winnan (Winnan, 2013), he discussed the evolution of 3D printing stating "3D printing is not just an isolated technological breakthrough, but one that will affect an entire spectrum of fields, from design to development distribution." The possibilities are endless when it is considered that materials and building components could be made on-site without the need of shipping or environmental impacts.

Utilization of this technology could be adopted as a way to manufacture an inexpensive and almost instantaneous VR Head Mounted Display unit on a construction site.

Building a 3D VR HMD

In order to develop an inexpensive easily accessible HMD two options were initially considered. The first was a do-it-yourself device made from cardboard and recycled materials. However upon additional research, user reviews and satisfactions were poor. We determined for this investigation to build a device that was of sturdier construction and would also utilize the evolving technology of 3D printing. The device selected was the Durovis Dive - the world's first hands-free VR headset for smartphone, as claimed by the developer on their website.

The Durovis Dive (Durovis, 2014) is the world's first hands-free smartphone holder that allows you to get immersed into virtual reality. It can be made from high quality flexible nylon plastic, it is lightweight and comfortable. It is less expensive than the HMD's discussed previously because it is powered by a mobile smartphone, which most people already have available. Using a smartphone makes the Dive easy to use and allows you to wirelessly experience 3D stream movies and interactive virtual environments. According to the developer, the unique Durovis Dive Tracking Technology offers brilliant low-latency quality and a fully immersive experience.

The Dive works by inserting a smartphone, starting the application which can be downloaded from their website, and adjusting the lenses to your eyes. The Dive has an opening at the bottom of the unit that allows you to perceive your surroundings in your peripheral field of vision to keep your orientation grounded and to avoid nausea.

Although this unit can be purchased and shipped completely assembled for a cost of approximately $140 US, the researchers for this paper also wanted to explore how it could be built onsite using 3D printing technology. The Dive is a completely open system for development. It also provides OpenDive files for use in 3D printers utilizing STL formatting. The items that must be purchased are the lenses and headstrap which can be ordered through the Dive website for approximately $10 US.

The OpenDive 3D STL printer file was used in a CubeX ABS and PLA printer. Approximate cost of both was $1,200. Our model was printed using PLA a biodegradable form of 3D printer filament. (Doesn't actually degrade unless recycled). A free piece of software called KissSlicer was used to process the model prior to printing.

Although the initial cost was higher than the purchase of a completed off-the-shelf HMD, many units can be manufactured with this initial investment of equipment and material. Multiple manufacturing for low cost could enable wide distributed at construction meetings with subcontractors, suppliers, and design professionals enabling them all to review the same model in real time collaboration.

Figure 3 shows the whole steps required to build and use the AR HMD using 3D Printing. CAD model of the HMD was in STL format. The model was then used to build the HDM using PLA filament. This process took approximately 8 hours to complete. Printed pieces of the model were completed and then separated and readied for assembly. Assembly of the unit was quite easy and total time to print and assemble was approximately 10 hrs. With repetition, this time could be reduced. It should also be noted that 3D printers are evolving and newer models have a higher rate of production than the one that was used for this investigation. The final steps in the assembly of the Dive is to insert a smartphone and download the viewing applications. The device can then be fitted to the head and optical lenses adjusted to accommodate any user. Viewing and interaction are very easy and control is done by head movement.

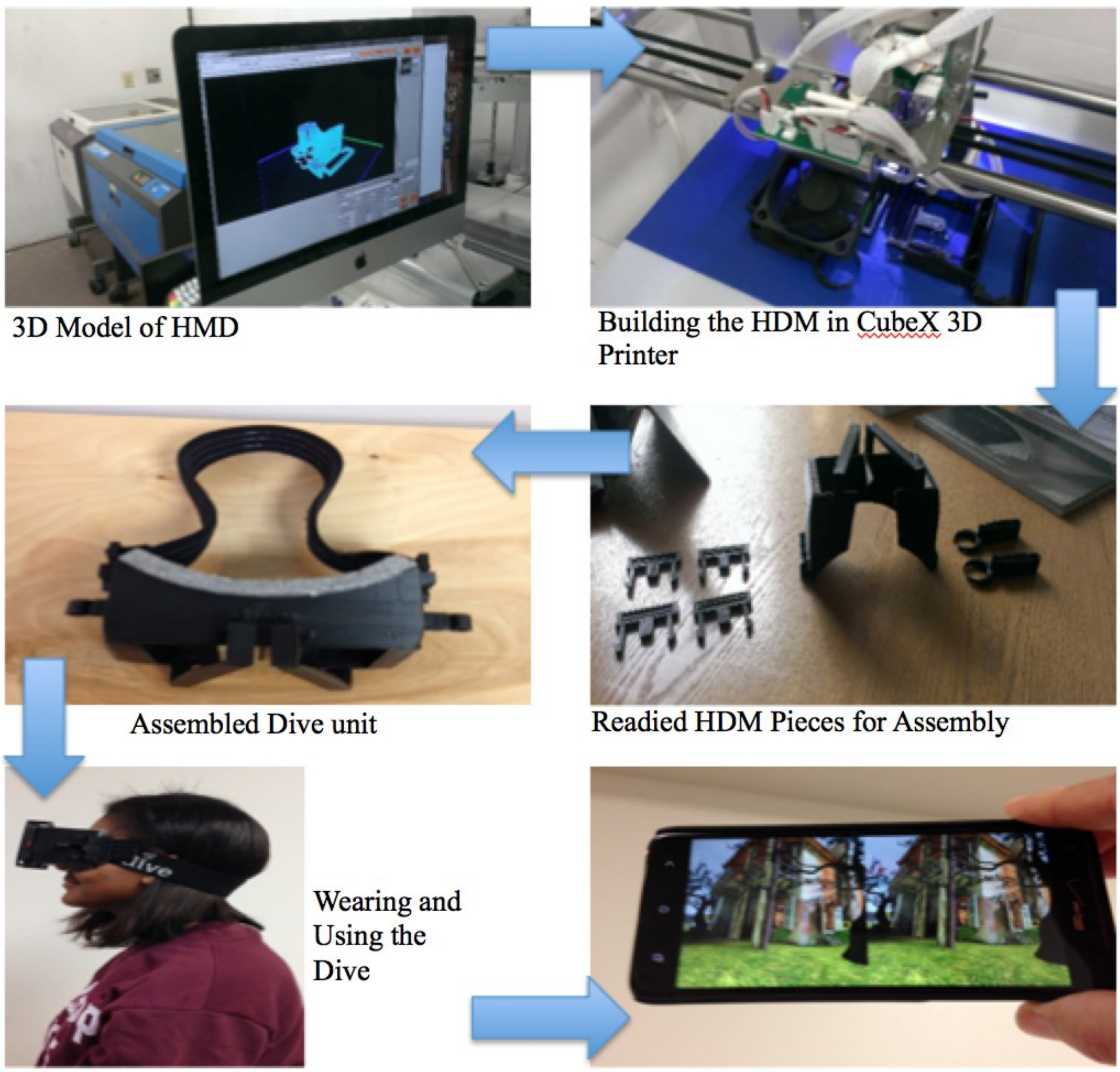

Figure 3: Steps required to build and use the AR HMD using 3D Printing

Viewing Virtual Models Using the 3D Printed HMD

There are a number of pre-developed applications that can currently be download to a smartphone for use with the Dive HMD. Most of these are geared toward gaming, VR experiences, and optometry. However the company has developed two free downloads that allow the user to experience a virtual tour through structures and buildings. For this paper we used both The Height and Tuscany Dive to explore the technology. The Height is a 3D walkthrough of a virtual structure in which you can maneuver through as you view various parts of a modified concrete and steel structure. The Tuscany Dive is a 3D walkthrough of a fairly detailed villa in Tuscany Italy in which you can walk around the grounds and through the building. Both experiences are fairly realistic and allow the user to start and stop motion at will. An example of the view can be seen in Figure 3. The normal image on the smartphone is stereoscopic, but when viewed with the Dive becomes a 3 Dimensional picture of virtual space.

Conclusions

The use of Virtual Reality and interaction with building and construction models prior to and during construction is a growing area of study and field application investigation. The ability to easily view walkthroughs and building operations is an important development as we look to improve the design and building process. Building Information Models (BIM) and Virtual Design and Construction (VDC) are quickly becoming the norm in design and preconstruction planning by architects and contractors. The current technologies for viewing and interacting with these models have some limitations, especially for use on a construction site.

This investigation examined two new technologies, that when coupled, may provide a solution to VR viewing and interaction in the field. The growth in popularity of evolving HDMs and the ability to rapidly manufacture components using 3D printing may pave the way to increased use and implementation of interactive VR models. There is more work that must be done. A true BIM model was not used in this investigation and the software was limited to that which the Dive developer has freely provided. However there is future opportunities to investigate development of translation tools to push BIM files into VDC in 3D that can be viewed by HMDs. There is also a need to evolve the use of 3D printing as a tool regularly used on a construction site. With these advancements an easy and inexpensive tool will be available for all involved on the project and give them the ability to experience the design and construction in a virtual environment.

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