Virtual Reality and its Applications in the Mockup Process:
A Case Study

David B. Friend
California Polytechnic State University
San Luis Obispo, CA

Mockups are an important part of the construction process as they provide numerous benefits in both constructability review and aesthetic approval. Virtual Reality is an emerging technology that could prove to be a valuable addition to the mockup process. Many construction firms are attempting to incorporate virtual reality into any process they can --ranging from impressing owners in order to procure jobs to training employees so they can more adeptly adjust to field conditions. This paper will introduce virtual reality and some of its applications in the construction industry, specifically analyzing virtual reality and its applications in the mockup process via a case study. While the projects were met largely with success, they had their share of challenges in implementation. VR mockups proved valuable for aesthetic review purposes. They also improved the design-approval process which, in turn, reduced both cost and time. The technology was still met with challenges in implementation. The primary challenges were: aversion to the new technology, illness/nausea, hesitation about increased investment earlier in the project, and the reliance on available technology.

Key Words: Virtual Reality, Mock-ups, BIM, Cost/Schedule Comparison, Lessons learned

Introduction

Mockups are a tried and true part of the construction industry that have been around in some form for as long as humans have been building. Mockups offer numerous benefits, as a result of which, they have long served the industry. However, like many aspects of the field of construction, mockups have seen very little innovation in recent years. While some might argue, "if it's not broke, don't fix it," others would disagree. Innovation often improves the process for all parties involved. For mockups, Virtual Reality may prove to be just the right innovation. Recently, technology has made its way throughout the industry and has improved processes which, in many cases, will, reduce schedule, improve quality, and cut costs. In theory, introducing virtual reality to the mockup process could provide the same benefits.

Virtual Reality, as a concept, has been around for decades. Yet, it was not until very recent advances in technology that it became a viable option for industries like construction. Many construction firms scramble to figure out how to best utilize this resource; some even spend large sums of money to develop their own tools, while others attempt to adapt tools from other industries. Companies have begun using VR on select projects in a variety of ways as a trial to see what functions are the most beneficial. One company is injecting VR into their mockup process in order to see if there is potential for improvement; the results of this process can be analyzed to discover both the benefits and challenges of VR mockups.

Traditional Mockups

Ask anyone in the construction industry and they will give their own definition of a mockup, since it serves many purposes. Merriam-Webster defines mockup as "a full-sized structural model built to scale chiefly for study, testing, or display" (Merriam Webster, 2018). In construction, mockups serve three main purposes: first, as an aesthetic review; second, as a constructability review; and last, for assembly testing. Aesthetic is the most obvious of the three aspects and, arguably, one of the most important. Aesthetic review allows the architects and owners to view a sample of what the product will look like and approve it for use in the final product. This can be used for two

purposes: either for approving specific materials or entire decors. Constructability review is another important purpose for mockups. Constructability review serves to test plans in order to ensure they are constructible or to determine if they need to be changed/RFI'd. Beyond verifying the constructability of the plans, this review also comprises checking to make sure there are no scope gaps and that each subcontractor is capable of performing the work required. The last main purpose of a mockup in the construction industry is for testing how assemblies perform either alone or as a system. Assembly testing can save costs when it is determined before installation that a system doesn't achieve its purpose.
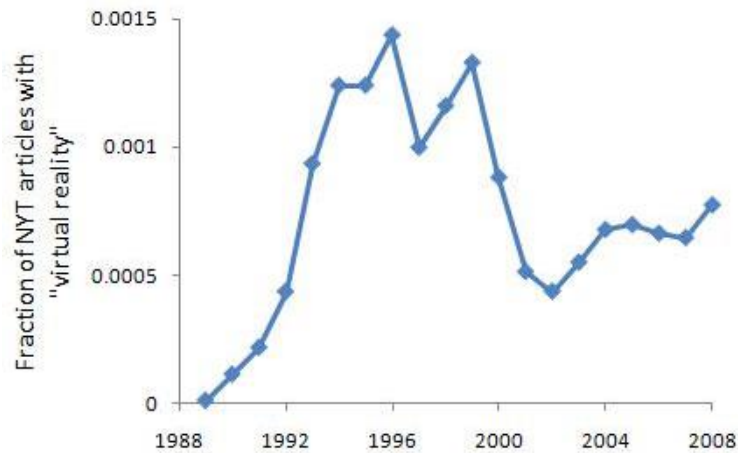
Virtual Reality

Figure 1: Popularity of VR in Press vs. Time (Unknown-1, 2009)

The first known reference to Virtual Reality, as we would describe it today, came in 1965 by Ivan Sutherland who stated, "make that (virtual) world in the window look real, sound real, feel real, and respond realistically to the viewer's actions" (Mazuryk, 1996). This description is still accurate to the goal of modern Virtual Reality despite the huge shift in technology since that era. There were a few major uses of VR in the 1960s when it first came into existence. NASA used VR for unmanned surveys of the lunar surface (Wexelblat, 1993). The technology peaked interest in the 1990s. However, the technology at that point was lacking, and interest waned. It was not until recent advancements in both hardware and software that there has been a resurgence in its popularity (see figure 1). Virtual reality (VR) is a term used to describe an experience of a simulated "reality" (Huang, 2018). The technology works by using two focused lenses to trick one's eyes into perceiving that one is actually in the simulated location. "Vision is the strongest sensory input that humans have; replacing it with a virtual world can make one feel as if one is in another world" (Huang, 2018).
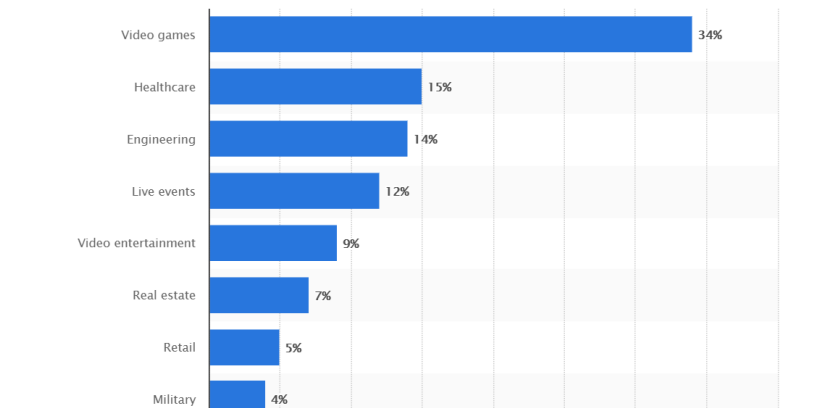

Figure 2: Virtual Reality Market Share by Industry (Sharma, 2018)

Many industries utilize Virtual Reality technology. Figure 2 shows the market share of various industries on VR. This Figure shows one of the biggest uses of VR to be video games. Since there are so many interested customers, the video game industry is the primary entity pushing the technology forwards. Other industries, including construction, simply adapt this technology for their own use. Another industry, education, seeks to "use VR technology… in professional education and training. VR technology has also been used in K-12 and higher education" (Zhang, 2018). One of the main uses is to attract at-risk and challenged students back into education. Other industries that utilize VR include healthcare, military, space, and many more (Sharma, 2018) (Wexelblat, 1993).

The big question: How can Virtual Reality be implemented within the construction industry? Virtual reality is a very visual technology, so any aspects of the industry that are predominantly visual are good candidates for VR. One obvious candidate is for training. For example: operators can sit in front of a control panel with a VR headset on and learn how to use the controls for that piece of equipment without actually using it. This can make training cost less, take less machine time, and be overall safer since it is a simulation rather than a real machine. Another area in which VR can assist is with coordination. BIM models are already used in this capacity, VR can be set up to run clash detections so one can walk through a project and visualize each issue. VR models can also aid in the QA/QC process. Engineers can digitally visualize what something is intended to look like and then walk out to the field to see if it was actually installed as specified. Lastly, and probably most importantly, is marketing --VR can help owners visualize a project better than they can with plans. This can be used for owner relations on an existing project or to help procure a job before it is bid (Unknown-2, 2018).

Virtual Reality has a lot of potential uses, some of which make the technology sound very similar to BIM in general, and that's not wrong. BIM, of course, focuses on the information stored in a model. VR, on the other hand, focuses more on the aesthetics and gives more of a "feel" of the project than one can get from a computer screen.

Virtual Reality Mockups

"The successful transformation of design intents into physical reality has always been a challenge for the parties involved in a construction project" (Pietroforte, 2010). This leads into another way that Virtual Reality can be utilized in the construction industry: as a Virtual Reality Mockup. VR mockups can serve as the middle ground that aids in the transition between design intents and what actually gets built.

Methodology

The main methodology of data collection I have chosen to work with is a case study of two projects that utilized both VR mockups and traditional mockups. Some of the data is quantitative cost and schedule data provided from the projects as well as best practices of the company. The rest of the data for the case studies is qualitative data that I received by discussing the projects with those involved, as well as by working on the projects myself. The collected data mostly falls into two distinct groups: benefits of VR mockups and challenges of VR mockups. Benefits being reasons to use VR mockups and challenges being hurdles the industry will have to overcome in order to best utilize the technology.

The objectives for these case studies are to:

- Analyze Virtual Reality mockups and assess their benefits.
- Identify challenges that must be overcome to make VR mockups successful.
- Quantify the cost and schedule impacts of Virtual Reality mockups.
- Assess the software utilized to better the industry's understanding and selection process.
- Provide data to the industry that helps companies understand when and how to implement VR.

Case Study

For the purpose of this report, I mainly worked with two projects that utilized both virtual reality and physical mockups. For their modeling, both of these projects utilized a software called Unreal Engine, which was developed as a free-to-use video game software. This made it ideal for testing mock-ups without having to commit large sums of money. Unreal Engine's primary benefits are its high level of detail for finishes and its low cost of entry. That said, the program does have some downsides. The biggest downside is that the program requires a custom model be made specifically for Unreal. This model takes employees significant time to produce and is therefore somewhat expensive. Other downsides for Unreal are that the program is hard to use/learn and that it requires a high-end PC to run. Despite utilizing the same software, the projects themselves serve drastically different purposes. Beyond the two projects analyzed, the company had some other VR mockup work in progress that had some educational value. These other endeavors utilized a different software entirely that had its own pros and cons. This new program, Fuzor, was easy to use and was able to import models directly from Revit. Beyond that, one could attach cost and schedule data to the model. Fuzor, too, had downsides. First, the software requires an expensive annual subscription fee. Second there is a very low level of detail in the model since it will only be as high a quality as that of the Revit file from which it came.

SFO Hotel Rooms

Figure 3: SFO VR Mockup

Figure 4: SFO Physical Mockup

The SFO hotel project was in an interesting position during pre-con. The estimates for the building kept rising, and since it was a P3 project, expanding the budget was not a simple task. There were rumors that, since the budget was blown, the project was close to being cancelled. This led the project team to either value engineering or to remove significant aspects of the project. At this point, the mockup hotel rooms were among the removed aspects. The plans were acceptable, but the architect's model was lacking in visual representation. The GC took it upon itself to use this as an opportunity to test out some of their new technology: their first VR mockup. Over time, the project's budget improved, and it was decided that they still needed to do an offsite mockup for these hotel rooms. This allowed comparisons between the two to be made.

The VR mockup (see figure 3) was produced in Unreal Engine which meant the model had a very high level of detail in its finishes, even when compared to its real-life counterpart (see figure 4). This VR mockup focused mostly on an Aesthetic Review, allowing the GC, architect, and owner to visualize the rooms and finishes without raising a single hammer.

New Century Plaza Balconies
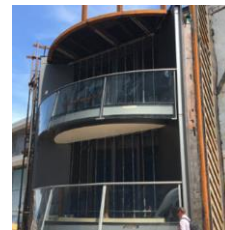

Figure 5: VR Mockup

Figure 6: NCP Physical Mockup

New Century Plaza was a real estate development by a large Chinese conglomerate. Unlike the SFO hotel, money was not an issue. Obviously, they would like to keep costs down, but the project was never at risk of being canceled. So why did this project opt to utilize a VR mockup? This project aimed to be unique and to catch people's eyes. As such, this led to some complicated designs and assemblies that some individuals were not even sure were feasible. The biggest example of this was the balcony structure. For this project, the team decided to double up on mockups. they began with the VR mockup (see figure 5), then later revisited the design with a physical mockup in China (see figure 6) for further testing and review.

While aesthetics were certainly a consideration for this mockup, this model goes beyond appearances in that it also implements a form of constructability review. This VR mockup, beyond having visuals, is actually interactive -- things like doors can open. More importantly, the entire balcony assembly can be "blown up" and effectively disassembled. By doing this, one can spread each part out in order to understand how the assembly is constructed.

Results and Discussion

Both of these projects' endeavors into Virtual Reality mockups were met with mixed results and there were some successes as well as some shortcomings. Ultimately, the key for Virtual Reality is to learn from its failures what might be its challenges. This will allow the user to find a way to work around them while still capitalizing on the technology's strengths.

Lessons Learned: SFO Hotel

Initially, the VR mockup for the SFO hotel rooms was going to be the only mockup of these rooms. Therefore, the success of this mockup was critical to the success of the project. Lessons learned specifically from this project relate mostly to VR standing on its own. When not paired with a physical mockup, VR mockups missed out on two out of the three required aspects. The issue for VR is that one misses out on the constructability review and testing that one could only perform on physical materials. Another loss is that one doesn't have the opportunity to find scope gaps. Further, one cannot actually feel anything. This intangibility impedes the technology's effectiveness. Lastly, the finishes, despite being high quality, are not perfect replicas of the real-life product.

Nevertheless, not all VR results were bad. This project helped identify some strengths and reasons to use VR mockups even if used in conjunction with physical mockups. One positive this project helped to identify was the ability to have a human perspective in a digital model. This allows one to see sizes and sightlines that wouldn't be possible without VR. An example of this was in one of the hotel rooms. The table was very close to the end of the bed, which was fine, except that there was a chair between the two that stuck out far enough that it made for a very tight squeeze to get to the other side of the room. Noticing this allowed the project team to resolve the issue early, by altering the room layout.

Lessons Learned: NCP Balconies

New Century Plaza always planned on creating a physical mockup, so the VR mockup was more of an experiment than something on which to rely. As was established by the SFO Hotel lessons learned, VR should be a supplement, rather than a replacement, to mockups. Overall, the VR mockup was considered successful. It helped with owner understanding and identifying discrepancies when the physical mockup was constructed.

The main issue this project faced was capitalizing on the benefits of Virtual Reality. After viewing the VR mockup and watching its success, the owner of this project was very impressed. Initially, the owner wanted to utilize more VR mockups on the project. However, there was no follow up. After several months, the owner lost interest in utilizing VR mockups and the GC lost out on potential work. The lesson learned here is how to properly deal with interest in trendy technology like Virtual Reality. One must follow through on any interest as soon as it arises.

Benefits

There are additional benefits to VR mockups beyond those identified in the lessons learned from the two projects. The largest benefit of virtual reality mockups is the potential for long-term cost and schedule savings. This benefit is not immediately apparent nor is it guaranteed. During pre-con, the architect will specify assemblies and materials. It is common practice for the architect and owner to need to be approve these. Often, this approval process can be for something as small as a material sample, but it can be for something as large as a full-sized mockup. If this sample is not initially approved, then the process of procurement begins again. This means that all the time and money spent was wasted. Considering some materials have high price tags and long lead times, this can be quite devastating. This is where VR mockups are helpful. Instead of building the mockup and having to redo or change it later, one can instead create a VR mockup at a fraction of the price and schedule, then get that approved by the architect and owner. After the VR mockup is signed off, one can create one final physical mockup to verify anything that the VR mockup cannot. Essentially, the VR mockup is a mockup of the physical mockup.

Another benefit of Virtual Reality mockups is that they can help identify deficiencies in the plans so one can remedy them early in the project. VR mockups are typically done earlier in the project in order to capitalize on their benefits. One such benefit might be finding holes in the plans. Issues with the plans can be RFI'd to the architect, so a solution can be found before it becomes an issue. For example, in a project in which a VR mockup was not utilized, there was a significant issue with the plans that was not identified until construction of the physical mockup. This issue could effectively halt construction on the mockup and thereby cause huge delays.

There are plenty of other benefits to Virtual Reality mockups besides those that affect the cost and schedule. VR can be used from the safety of an office space. This is great when compared to the dangerous conditions of a construction site. Also, VR can help with owner understanding of the plans. Owners are notoriously bad at reading plans. That said, it is not really their job. It is part of our job in the industry to help them understand the plans so they can give input into the design and ultimately be happier with the product. This could result in improved relations between parties. In a similar vein, VR mockups can be used to receive end-user input. This input is especially important in projects like medical facilities where everything has very specific location and size requirements.

Challenges

Along with the benefits come some challenges. VR faces its fair share of hindrances to success. One such challenge is the added costs with the potential for little to no payout. VR may present some cost savings, but it is not a free technology. One needs to hire employees to specialize in VR or one must outsource it. Either way, that's a new cost that current projects don't consider. Beyond that, companies will have to pay for new software and hardware, this further increases the barrier of entry into VR and VR mockups.

Another issue is the dependence on the available technology. Recent years have seen significant advancement in hardware, thanks to the video game industry. However, software is still trailing behind. There are some clear uses for VR, in general, that we can theorize. However, the software is not ready to perform. This leaves companies with two options: either develop their own technology or wait for something better if they aren't satisfied. Neither option is great.

Other issues include an aversion to technology and nausea caused by the technology. Solving the aversion to the new technology will be a challenge, many grizzled construction vets don't care to learn something new even if they can see its benefits. Solving the nausea caused by wearing the goggles is more on the technology. As it advances, this issue should improve. However, for some it may never go away. That is something that the industry will have to work around.

On a smaller scale, implementing VR mockups requires some changes to how a project is run. VR mockups would likely need to be approved by the architect and owner. This means there would need to be a new submittal-like process for VR approvals. Another rather large challenge is getting owner and architect buy-in. In some cases, like the NCP balconies, owners will hop on board. In others, like the SFO Hotel, architects will heckle and claim that VR is a waste of time and resources. There are two ends of the spectrum. The mockups are also best utilized earlier in

the schedule of a project. This means coordination would have to begin earlier in order to have everything ready for the VR mockup. Lastly, there would have to be a shift in the dynamic of relations between parties to better allow input into the design from both the owner and the end users.

Comparison

While we have established that, in the long run, VR mockups have the potential to save both time and money, this doesn't come free. In the early stages, projects utilizing VR mockups will have an increased investment of time and money. Data from the two case studies shows that a VR mockup of two rooms and a hallway takes a team of two specialists two to three weeks to create. If one factors in all the coordination required, it could reach up to two months. This can be compared to physical mockups to help justify the investment. For a physical mockup of the same size one can expect one to two months or more for the actual construction. But if one includes buyout, procurement, coordination, and any other requirements, one might spend around 12 months. In some extreme examples, the time requirement to build physical mockups can extend up to two years or more.

The same analysis can be done for the cost of VR mockups. A VR model takes two specialists two to three weeks to produce. The model costs between $3,000 and $5,000. When compared to physical mockup costs, this price is almost nothing. For example, the SFO hotel mockup from the case study cost $600,000. This absolutely dwarfed the VR expenses. VR does have expenses outside the model that must be factored into the overall project costs. First, there are some fixed nonrecurring costs for hardware. One may spend roughly $5,000 on this one-time fee. Given enough use, it will pay off. The other extra expense is a fixed recurring cost for any software licenses. Fuzor, for example, charges a $10,000 annual fee for a single license. This can be hard to justify.

Conclusion and Further Research

In conclusion, Virtual Reality mockups have the potential to ultimately become common practice on every construction project. If the technology advances further, VR mockups could entirely replace physical mockups. Today, however, the technology is not ready to run independently since there are challenges that must be averted in order to successfully utilize VR mockups. Nonetheless, in the right environment, if one can work around its challenges and convince project teams that it is worth the extra up-front costs, VR mockups can be a tremendous asset that improves relations within project teams, saves costs and schedules, and is completely safe.

References

Huang, P., & Gagnero, P. (2016). Seamlessly Displaying Models in Virtual Reality.

Mazuryk, T., & Gervautz, M. (1996). Virtual reality-history, applications, technology and future.

Mockup. 2018. In *Merriam-Webster.com*. Retrieved December 7, 2018.

Pietroforte, R., & Tombesi, P. (2010). Physical Mockups as Interface between Design and Construction: A North-American Example.

Sharma, S. (2018). *Augmented Reality Becomes Integral Technology of Fourth Industrial Revolution*. *Credencys Solutions Inc.*. Retrieved December 7, 2018.

Unknown-1 (2009). *Gene Expression: Is virtual reality making a comeback?*. *Gnxp.com*. Retrieved December 7, 2018.

Unknown-2. (2018). *Construction Applications in Reality Technology (MR, AR, VR)*. *Reality Technologies*. Retrieved December 7, 2018.

Wexelblat, A. (Ed.). (1993). *Virtual reality: applications and explorations*. Academic Press.

Zhang, M., Zhang, Z., Chang, Y., Aziz, E. S., Esche, S., & Chassapis, C. (2018). Recent Developments in Game-Based Virtual Reality Educational Laboratories Using the Microsoft Kinect. *International Journal of Emerging Technologies in Learning (iJET)*, *13*(1), 138-159.