GAINING END USER INVOLVEMENT THROUGH VIRTUAL REALITY MOCK-UPS: A MEDICAL FACILITY CASE STUDY

Robert M. Leicht, PhD, Assistant Professor, rmleicht@engr.psu.edu
Department of Architectural Engineering, Penn State, University Park, Pennsylvania, USA
Sonali Kumar, MA, Graduate Research Assistant, suk189@psu.edu
Moawia Abdelkarim, PMP, MoawiaA@dprinc.com
DPR Construction, Phoenix, Arizona, USA
John I. Messner, PhD, Associate Professor, jmessner@engr.psu.edu
Department of Architectural Engineering, Penn State, University Park, Pennsylvania, USA

ABSTRACT

The use of construction mock-ups have become common practice to validate design and work through constructability challenges. The use of physical mock-ups offer significant benefits as a communication tool amongst the project team but must be balanced with a potentially large costs to construct. With the advent of many new virtual prototyping technologies, project teams now have the potential to perform mock-ups in virtual environments. This paper will present a case study of a 14,000 m^2 (150,000 ft^2) medical office construction project which used both physical and virtual mock-ups to allow the facility to meet end-user needs with minimal re-work during the on-site construction. The virtual mock-up was carried out using the Immersive Construction Lab at Penn State to review a rendered model of single occurrence space in the facility. The paper will demonstrate the end-user and construction team feedback about the virtual mock-up processes and the benefits and challenges it presents.

Keywords: virtual mock-ups, BIM, End-user involvement, design review

1. INTRODUCTION

The use of physical mock-ups for the review of finished construction and the means and methods for meeting the design, has become a common practice within the construction industry for review by designers and end-users of facilities (O'Connor and Davis, 1988). The clear value in receiving feedback from viewing an example of the finished product is often offset and must be planned based on the significant cost and scheduling implications on a project (Pulaski et al, 2006). Recent developments in virtual modeling and immersive media allow the creation of virtual mock-ups to enable scale visualization and navigation. Since this application is still new and novel for the average construction project, there is little data to indicate the feasibility and considerations for determining appropriate use of virtual mock-ups, physical mock-ups, or both on a given project. The challenge of identifying the exact costs and providing direct comparisons for a project also make it difficult to quantify the impact and value achievable through virtual mock-ups (Leicht and Messner, 2010). This case study reviews a project where both were utilized with the focus on the considerations for the virtual mock-up use, and the outcomes and value to the project.

2. PROJECT BACKGROUND

The facility used for the case study was a four floor 14,000 m^2 (150,000 ft^2) medical office building, tenant fit-out project. The project was a new construction project, costing approximately \$30 M to construct. The medical facility was constructed in a speculative core and shell office building, with post-tensioned concrete construction, originally intended for office space. The facility hosts 12 departments, included radiology, more than 60 medical exam rooms, four operating suites, and procedure rooms, 72 offices, and its own pharmacy. Owned by a private health care provider, the construction began in February of 2010 with an October 2010 substantial completion deadline.

3. VIRTUAL MOCK-UP

The concept of virtual mock-ups for construction is relatively new. In a virtual mock-up, the detailed 3D geometry of a virtual prototype is viewed in conjunction with an immersive virtual environment (IVE) to perform a detailed review (Yerrapathruni, 2003). The use of virtual prototypes with 3D geometry is a means of rapid creation of the representation of a design, and the ability to analyze a design for (Schaaf, 1997):

- Form and fit
- Logistics
- Human factors integration
- Feasibility analysis

The use of virtual prototypes and creation of realistic computer generated images is often faster, cheaper, and a more effective means to see preliminary design results than physical prototypes, and often allows review of more alternatives (Chua et al, 2003).

The use of physical models and mock-ups has been ongoing in the industry for many years. Wilson et al (1998) identifies models, 3D CAD models, and mock-ups as useful design tools employed by green designers. O'Connor and Davis (1988) showed that the construction of mock-ups helps contractors to fine tune the construction process. Pulaski et al (2006) identified three different contributions from the physical mock-up of a 1,000 m2 fully finished scale space during the renovation of the Pentagon:

- evaluation of innovative sustainable materials for function and end-user acceptance
- durability of new, untested, and unfamiliar sustainable products
- educate the project team, end-users, and visitors

The comparison of the substantiation of the physical mock-up may offer the opportunity for different feedback from the virtual mock-up, however the flexibility of the virtual mock-up due to its nature as a digital model may allow for different review viewpoints or processes than the physical mock-up.

4. RESEARCH PROCESS

A virtual mock-up of the facility's pharmacy was performed, with the researchers creating the virtual mock-up from a building information model (BIM) developed by the architect. The virtual mock-up was held at the Immersive Construction (ICon) Lab at Penn State University. The project team and end users used the same basic procedure as the general contractor employed for the on-site physical mock-up, except the mock-up was visualized on a large scale display rather than on the project site. After the mock-up, the outcomes were documented and the attendees were surveyed for their impressions of the value of the virtual mock-up process and use of the ICon Lab for hosting the review.

For the project, the architect of record developed most of the design content using a building information model (BIM) authoring program, Autodesk Revit®. The model was then exported to a CAD package to detail and finalize the contract drawings. The architect shared the BIM and it was utilized as the starting point for the virtual mock-up development. For the virtual mock-up, the intent was to perform a detailed review for the end-users, similar in nature to the physical mock-ups performed on site. Thus, the level of detail needed is quite high to purvey the sense of presence and realism comparable to the true constructed space (Nikolic, 2006; Zikic, 2007). First, the detail in the design BIM was reviewed and areas where additional detail was needed were identified. The two focus areas for the pharmacy were the cabinetry or casework, and the electrical and data outlets. The BIM for the pharmacy did contain some geometry for the casework. The subcontractor shop drawings and field discussions with the electrical foreman were held to clarify any discrepancies between design documents and create the model in accordance with what the construction team was planning to construct per the project model and drawings.

To develop the virtual mockup, additional design content from a Google Sketchup model and shop drawings of the facility focusing on detailing and custom geometry which were more time consuming to model, which were then incorporated in Autodesk Revit model. After the geometry for the pharmacy was added, the pharmacy model was exported to Autodesk 3ds Max as an .FBX file format. Although the texture and lighting information transferred from Autodesk Revit to 3ds max, it did not transfer over to VR4MAX, the plug-in for real-time viewing in virtual reality systems. Standard textures and lighting were reapplied within 3ds Max but texturing of the model was not a focus of the modeling labor; the intent was to utilize already existing materials in the 3ds Max library that were reasonably close to the specified finishes. Once all the model content, textures and lighting were in place for the pharmacy, the model was exported using the VR4MAX plug-in from 3ds Max as a .VMX file. The model was finally viewed and navigated using VR4MAX from Tree C in the ICon Lab stereoscopic display system.

Figure 1: Image capture of virtual pharmacy mock-up.

After the model was textured, the textures could then be rendered and carried over to the VR4Max plug-in, and an executable file was created to view the content in stereo. This stereo executable file was then used as the model during the mock-up design review.

5. MOCK-UP REVIEW

On the day of the virtual mock-up review, the review was attended by two pharmacists, the facility manager, and the owner's project manager, the general contractor's project team, the project architect, and the casework subcontractor. To begin the meeting, a brief overview of the ICon lab research and activities were presented to introduce the team to the facility.

Figure 2: Project team reviewing the virtual mock-up in the ICon Lab.

At the start of the pharmacy review, the team was given a brief walk-through of the entire pharmacy to provide an overview of the space and layout. Then the detailed review began, starting at the customer desk and proceeding clockwise around the room reviewing each wall and arrangement of casework in succession, the changes identified are summarized, along with brief reasons for the changes and likely cost implications in Table 1.

Table 1: Summary of design changes or clarifications identified during the virtual mock-up.

	Change, question, or confirmation	Description of area of concern	Cost Impact
1	Millwork partition dividing two sales stations at column line FF will shift 1' to the north in order to create a divide between customers at the adjacent stations	End-User identified issue with privacy for clients at adjacent sales stations	**No-cost change** (shift in wall location before walls were framed)
2	Note 7 on E3.00A requires coordinate of data outlet height with millwork. Data outlets will be installed directly adja-cent to duplex outlets. Please confirm the elevation.	Discrepancy between drawing note and model outlet location	**No-cost change** (shift in final outlet location before rough-in)
3	All indicated locations are printers and orientation is iden-tified by the arrows. All printers need to be mounted on casters to allow for service access to the rear of the printer.	End-user comments about preference of equipment layout at workstations	**Savings** (reduction in amount of shelving to meet printer layout)
4	Narcotics unit located at the east end of the millwork will switch to the west end and millwork will be shifted east to fill where the narcotics unit was.	End-user comments about location and access of specific, locked, casework unit	**No-cost change** (re-arrangement of casework layout before fabrication)
5	Indicated millwork units will have adjustable and identi-cally sized shelves to allow for moving of shelves between units. 10 shelves and matching support hardware will be provided.	End-user flexibility requested regarding adjustable shelving heights and number of shelves provided	**Added cost** (small add to project for shelving attic stock to be provided)
6	Millwork end unit will be added facing west. Vertical areas at either side between the upper cabinet and counter top will be enclosed. Upper cabinets will extend 14" and counter top will be 24" wide.	End-user comment about layout/access and potential for more casework to be provided	**Added cost** (addition of a small cabinet to adjust the layout slightly)

7	All units indicated (facing south) will have full height, locking doors. Shelves will be able to pull out from resting millwork position.	End-user desired a different amount of locked casework than shown/currently provided	**No-cost change** (addition of doors balanced with deletion of shelves)
8	All upper cabinets indicated (west of column line EE) will not have doors.	Clarification regarding a change which occurred but was not yet issued to the contractor	**Savings** (deletion of doors for indicated cabinets)
9	Lower shelves indicated (facing north) will be adjustable and 5 shelves will be provided with evenly spaced clear-ance elevations.	Clarification on number of shelves to be provided based on discussion with end-users about required height between shelves	**No-cost change** (confirmation that number of shelves shown is to be the final number provided)

6. OBSERVATIONS & RESULTS

Some of the challenges faced during the virtual mockup review were that reviewers sometimes found it hard to orient themselves and identify their exact location within the facility. It also took the reviewers some time to get used to the navigation within the facility, especially when they would switch between the design documents and the screens with stereo projection of the facility. One of the suggestions made was to display the design documents for markup on a smart board next to the virtual mockup.

The questionnaire distributed to the attendees included nine statements allowing for Likert scale feedback with a five point range (1-5) and with three questions with written responses, and an additional area for comments and feedback. For the Likert scale statements, the values ranged from (5) standing for strong agreement; (1) for strong disagreement; and (3) identifying neutrality. Table 2 lists the statements and the averages from the eleven participants.

Table 2: Average and Median values from questionnaire statements, scale of 1-5; 1 - strongly disagree, 5-strongly agree.

Statement	Average Response (scale of 1-5)	Median Response (scale of 1-5)
The Lab would be a good environment for future design review meetings	4.64	5
I have more confidence in the design after seeing the model.	4.36	5
The model was adequately realistic for reviewing the pharmacy design	4.09	4
The model was useful for reviewing specific criteria related to the pharmacy design.	4.36	4
I have a better understanding of the design after viewing the model in this lab	4.27	4
The design review process in this lab was beneficial as a whole	4.64	5
The large scale display was valuable for a true scale of building views	4.18	4
The layout of the room was effective for design review purposes	4.18	4
The process used to review the model worked well	4.27	4

In reviewing these outcomes from the questionnaire, there were a few overall indicators, though the sample size was not large enough to draw any statistically significant conclusions. First, all of the responses ranged between 3 to 5, showing no disagreement with any of the statements. Three of the statements stand out having a median score of 5 on a five point scale. This demonstrates that more than half of the attendees strongly agreed with those statements. The statements demonstrate benefit from the ICon Lab environment, the process as a whole, and an outcome of greater confidence in the design. These imply that the overall process and concept behind using virtual mock-ups to improve the design review process offer benefit and that virtual environments or spaces, such as the ICon Lab, are suggestible if not necessary for such.

When comparing the median scores with the average scores, several items are noteworthy as having very close mean and median outcomes at the level of agreement, suggesting that something about the model, process, or lab could have been improved to make the overall value of the virtual mock-up greater. The three which indicate the most potential for improvement are that the model was adequately realistic, the large scale display was valuable, and the layout of the space was effective. By cross referencing the observed activity and the written response question feedback, some insight into these areas has been identified.

In regard to the adequate level of realism within the reviewed model, five of the eleven questionnaires contained feedback suggesting greater realism or detail would be of benefit. Three of these suggested that more realistic lighting and more realistic rendering of the lighting would improve the model. Two items suggested that more realistic textures to show the finishes would have been beneficial as well. One of the challenges in converting the model identified previously was the conversion and proper rendering of the textures and lighting, this was a known issue by the researchers and one which was considered acceptable for the purposes of the study. In addition, due to some limitation of the modeling tools to produce a perfectly rendered, realistic, and accurate model to match the final materials and lighting, it was determined to be a concern that the end-users may receive an incorrect impression about the design based on the model texture that could cause unforeseen outcomes when the space was constructed and did not reflect the exact finishes per the visualization of the model.

The layout of the space was raised in different regards indicating room for adjustment and improvement. First, two responses indicated the need for a plan table directly in front of the large display for simpler viewing of some 2D project documents while concurrently viewing the model, as seen in Figure 3. In addition, three other responses had separate indicators about other ways to display the 2D drawings for assisting in the shared visualization by the whole team. One other response indicated the suggestion of a different seating arrangement to provide a better array of views. These strongly point to the fact that the layout of the space needs to support the review process – in a physical mock-up the users would be able to roam the space whereas with the virtual mock-up the space needs to comfortably provide the needed perspective and information. Somewhat related to these responses were the indication that the large scale display was necessary. One response was explicit to this point, but in consideration of the references to the documents it may be that there could be better ways to utilize the display to support the review process, from displaying the 2D documents on a separate screen, or better arranging the displays for this particular type of model review.

Figure 3: Team gathered around a table with 2D project drawings in front of the display.

In addition to these pointed items of feedback about the process, model, and display system, there were a few additional comments made upon which none of the statements reflected. First, one of the participants pointed out the value of having the full array of team members present for the review. The designer, contractor, select specialty subcontractor, end-users, owner, and facility manager were all represented and this allowed for the quorum needed on any issue raised to be able to quickly move to the heart of an issue, identify potential solutions, and identify the likely solution to move forward. Related to this topic, another response pointed out that this review process would have been beneficial even earlier in the process to incorporate the comments that created changes to the design.

The second area where additional comments seemed to point was the incorporation of additional information or data as a visual in the model. The first area for this was the owner furnished equipment for the space which had not been explicitly selected, so modeling of the items would have been generic – but placeholders may have been informative for the intended layout. Also, one response suggested incorporating some key dimensions into the model as visual call-outs. In the process used, these dimensions had to be taken from the 2D documents with referencing between the two media for verification that the correct dimension was being identified. Another option would be to find a different software tool, or incorporate into the used tool, a feature for taking real-time measurements. The third item suggested to visualize additional information in the model was the display of indicator arrows for such information as the flow of customers, walking routes for specific tasks, or other items to demonstrate the function and the intent of the design to reflect the space's use. Often the team's discussion was focused on the challenges created for carrying out the end-users tasks, privacy concerns created for calling out information through the space, and optimum walking routes or access points. There was much discussion, most of the time explanation by the end-users to the team about how the space should function, that could have been more efficient and more quickly understood if there were a means for visualizing and evaluating the tasks to be performed.

7. CONCLUSIONS AND FUTURE WORK

The virtual mock up provided an opportunity for all the project stakeholders including the project architect, general contractor, subcontractor, owner and end users to be in the same room for an extended review. The reviewers were fully immersed in the space and were able to interact with the model components by coming in close proximity with the screen, while some tried to touch the objects. They sought to view the virtual mockup from differing perspectives and were able to evaluate various features and detailed components such as the electrical outlets.

The integration of all the project stakeholders made it easier to focus the attention of all reviewers on the issues at hand and resolve them systematically. The reviewers found the virtual mockup to be helpful as it enabled them to identify some of the issues instantly. Case in point was when they first entered the pharmacy in the virtual mockup and they realized that the millwork partition wall needed to move out to provide more privacy to their customers. Overall, the end users and the general contractor's project team were able to get a good impression of what the final pharmacy product.

The ability to get everyone to view the model from a select viewpoint was helpful in keeping the team on a focused task and discussion, but the navigability of the model made it challenging to find the optimal viewing angle in certain scenarios. In addition, there were challenges noted in finding the best layout for reviewing the model on the display and finding the necessary information in the drawings, this could be resolved by either finding a better way to display the 2D documents for the team, or to incorporate more information, in some visual manner, into the model.

Future work should further delve into the planning of the mock-up review process to identify the focus of the review tasks purpose and identifying the necessary level of detail for meeting that purpose. Also, finding better means for evaluating tasks within the model and ways to provide designers the ability for automating or simulating tasks to evaluate alternative design options would greatly assist in decision making process. Alternatively, conveying the intent for decisions made to the end-users reviewing the design would also offer opportunity for improved communication.

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