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Patient Rooms of a California Based Hospital:
Benefits of Physical Mock-ups vs. Benefits of Virtual Mock-ups

Traditionally, architectural design intent from the architect has been communicated to clients and builders through physical models at various scales, two-dimensional drawings (ie. plan, section, elevation), and three-dimensional drawings and renderings depicting more spatial qualities. Though understanding and construction is possible using these types of representation, more recent technology offers designers the opportunity to utilize a more immersive form of representation to communicate their intent. Virtual Reality, a relatively new form of representation, allows users to enter the design of a space stored on a computer so that they can see how the finished product might turn out months before construction is set to begin. This paper addresses the advantages and disadvantages of virtual reality as it compares with full-scale physical mock-ups of the same space – patient rooms in the design of a California based hospital.

HGA Architects and Engineers and Perkins+Will, in collaboration with the client, designed a hospital whose patient rooms and other critical spaces of the hospital, were/are being mocked-up in physical form so that walkthroughs and testing can be held within the spaces. Full-scale mock-ups of repetitive and functionally complex spaces are important in the healthcare industry so that testing can be done on actual medical scenarios. The mock-ups provide opportunity to the nursing staff of the hospital to become more involved in the design process. Jaynelle Stichler and Sandra Cesario in their article, "Preparing Nurses for a Leadership Role in Designing Healthcare Facilities" acknowledge that 'nursing is the one professional group that spends the most time at the point of service with patients,' therefore their involvement with testing the design is critical in creating the most effective environments for their work, patient safety and patient recovery. (Stichler) Mock-ups can later be used to generate interest in the project, possibly attracting donors. The mock-up process for this particular hospital in California has been taken through several phases, each rendering a different level of completeness and complexity. The purpose for each phase of the mock-up process has also changed based on the level of detail provided as well as the outcome of previous phases. The architectural team and the hospital agreed upon the process of a physical mock-up due to previous experience with users who misunderstood the traditional 2D drawings, which at times resulted in changes to the project following construction. In cases where changes must be made to the actual construction, delays occur in the process that cost the client time as well as large sums of money that rise with increasing lengths of delay. Even a small change to a portion of the construction could start a domino effect that impacts the entire project. Finding out what all of the issues are prior to building will save everyone time and money. This particular process of building physical mock-ups has helped the designers to make decisions based on the testing and feedback given by the hospital's project stakeholders and users.

The Soft Mock-up was done as an initial test to evaluate the overall room size and configuration, nursing staff's visibility to monitors and patients from the corridor, toilet room size and configuration, and the configuration of the head wall. The room for this initial phase was represented through the use of plywood. Some of the equipment furnishing the room was real and provided by the existing hospital –

beds, couches, Computer on Wheels (COW), supply carts and some accessories. All other equipment was represented with plywood – adjustment of regularly moveable instruments was limited. The goal of this mock-up was to communicate the design intent to the client so that the project could move forward with all parties comfortable with basic sizing and configuration.

To evaluate the Soft Mock-up, three walkthroughs of the patient rooms were conducted with volunteer participants from the physician and nursing staff of the existing hospital and the Family Advisory Council. Volunteers were briefed before entering the mock-up so that the objective of their visit was understood. They were given questionnaires to evaluate a number of things within the room. After the walk-through the Hospital Administrator and the Hospital Project Manager, reviewed the comments and questionnaire answers to give feedback to the architects. A few unexpected outcomes occurred through the use of the Soft Mock-up. During simulation of a wheelchair transfer in the ICU and Medical/Surgical bathrooms, the bathrooms were found to be too tight to permit simple transfers. The participants were, however, pleasantly surprised by the spaciousness of the room in general. Other technical and positioning issues were addressed during the review of the walkthroughs. The design had assumed smaller accessories (i.e. sharps containers, dispensers, glove boxes) than what the hospital planned to purchase for the new space, therefore adjustment in space to contain these items was needed. Lastly, through simulation it was found that the original plan for the couch being positioned adjacent to the bed would not allow for access to the patient if a guest were sleeping on the trundle.

During the process of construction of the Soft Mock-up, changes that were made to the mock-up drawings were submitted to the owner for approval, if necessary, then given to the contractor to make additions or adjustments (i.e. couch move, planters added, toiletry shelf added) Some changes were simple and therefore made directly on site. The construction cost of this phase of the mock-up was $100,000, the design cost $50,000 and equipment costs $676,000 (equipment cost spread to later phases of mock-up). Through the use of the Soft Mock-up to test sizing, configuration, and placement strategies many things were learned about the design and function of the space that were reviewed between owner and architect in order to move forward with necessary changes to a more developed version of patient room mock-up which HGA refers to as the Hard Mock-up, Phase 1.

The Hard Mock-up Phase 1 looked at goals of testing the room and equipment configuration in greater detail as well as verifying whether or not the ICU patient room required a boom. The architects hoped to achieve a fairly realistic venue within which to perform simulations and to test the design of each space. This mock-up was located in a rental facility and required the issuing of permits due to its size and because the space would have functioning elements that needed to be code compliant. Construction documents were drawn using a Revit model separate from the full building model. In this phase of the model the pieces of equipment were mostly real and could be moved and operated so that more rigorous testing could be achieved. The owners and a medical planning consultant procured the equipment, from various vendors, if not already provided by the existing hospital. Casework in the rooms was constructed of MDF and/or plywood.

A more robust testing period was done to the ICU and Medical/Surgical patient rooms for the Hard Mock-up Phase I. The same evaluations given during the Soft Mock-up were given over a period of several weeks with an increased number of participants during this phase. Participants included members of the nursing staff and physicians, Family Advisory Council members, individuals from Human Resources, foundation members, administration, respiratory therapy, and various technical support staff. During testing, only minor accessory and equipment revisions were made, though throughout the overall process of bringing the model to the level of walk-through ready, revisions requiring back and forth between various parties were required. In order to determine if the space functioned properly for medical scenarios, simulations of various medical procedures were held and recorded. The number

of participating staff in these scenarios ranged from 1-16 people in the room at a time looking at code situations and configurations under various levels of acuity.

Through the testing and evaluation of the spaces during Phase I of the Hard Mock-up it was determined that the medical/surgical unit layout was generally good, but the bed crowded the family zone and the toilet room was felt to be too small even after reconfiguration resulting from the Soft Mock-up walk-through and testing. It was also found that the tub in the toilet room was too small and hard to use. The ICU patient room was determined to be too tight with the boom and needed significant reconfiguration to accommodate for the boom and to facilitate code scenarios.

This phase of the mock-up required much more time and energy from each party in weekly meetings to discuss mock-up progress, attendance of architects during simulation testing, and generally more detail required in drawings for permitting reasons. The construction cost of this phase of the mock-up was $820,000, the design cost was approximately $200,000, and the equipment cost $676,000 (carrying over from the initial mock-up). Like the Soft Mock-up, Phase I was useful in determining the best ways to move forward in the process of design for the overall project.

Phase II of the Hard Mock-up is in progress right now. This phase is being done in order to test the 'final' room configuration and design, including details and finishes. The designers/architects are interested in determining what works in the finishes for functional and practical relationships between materials as well as aesthetic purposes. The mock-up will also be used to encourage donor involvement and provide opportunities for tours. The documentation for this mock-up comes from a portion of the actual construction set that was issued to the contractor as a stand-alone set. The space for this mock-up is that of the Hard Mock-up Phase I – the same rooms are being built upon with actual finishes, mill work, plumbing fixtures, ceiling, and lighting. Any piece of equipment or accessory that was not already procured for the first phases will be procured and installed by the contractor.

The point at which this mock-up stands is very near to completion and testing, however it has been a struggle for over the past year to develop the needed documentation when many interiors decisions were outstanding. Additionally, many details have not been completely worked out because final construction documents have not yet been issued. The mock-up documentation requires a level of detail beyond the point at which the actual project has been developed. Now, after six addendums have been submitted for the Hard Mock-up Phase II, the original deadline for construction completion and testing of the space is very near. Due to these complications, however, the project deadline has been delayed further.

Throughout the entire process of making and testing physical mock-ups, the design team, client and contractor follow a long cyclical path of design, build, test, review, and revision before the work can finally be signed off as complete and ready for full building construction. (See Figure 1) Without this type of mock-up feedback loop in place, a project might encounter problems in building construction that could cost the client somewhere from 5% - 15% of the construction budget to fix, whereas the cost of a physical mock-up of the space, to catch issues before they are real, is a mere .5% of the construction budget*. To a client the physical mock-up may look like quite an additional cost, therefore there is great benefit to finding ways of bringing down the cost of mock-ups, in order to effectively test and make important design decisions.

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* .5% figure is specific to the this California based hospital

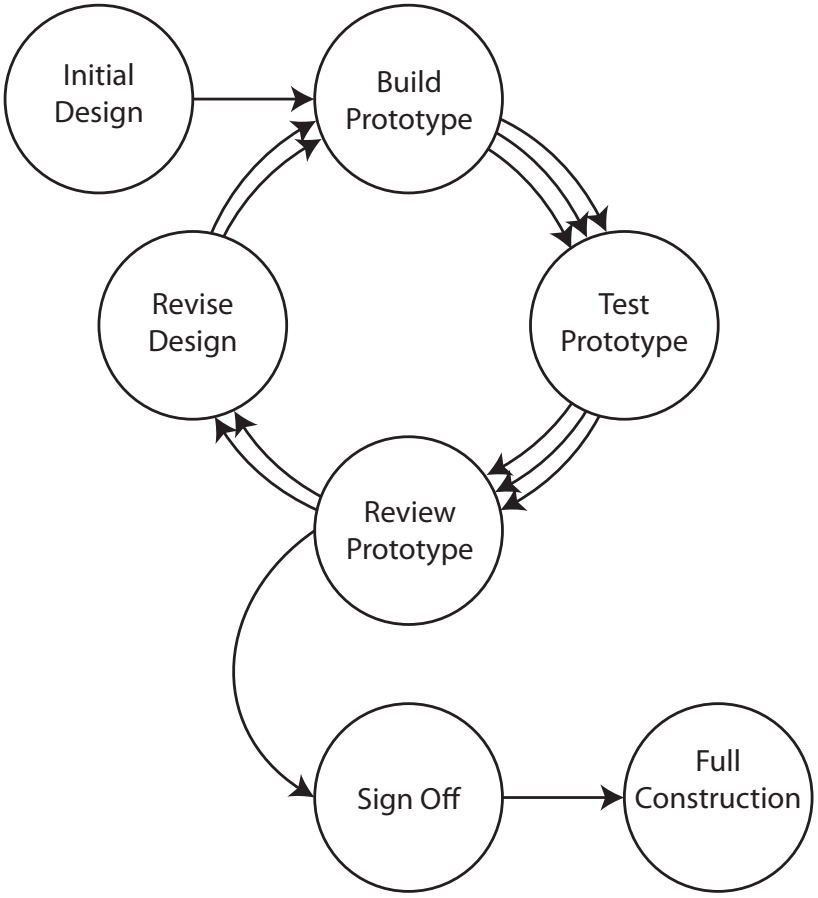


Figure 1 - Process using physical mock-up - over a span of 2+ years the physical mock-up has gone through three phases of documentation, construction, testing, and review.

It is reasonable to consider virtual reality as a tool that can help to offset the costs of mock-ups if the technology renders and represents to a level that equals, or even surpasses the representation that is achievable through the use of physical mock-ups. It is exciting to imagine a point where virtual reality becomes the tool that will replace the building of physical mock-ups thus saving time, energy, money and materials that would be put toward mock-up construction and testing. The following outlines the University of Minnesota – College of Design's Virtual Reality system and it's capabilities.

The University of Minnesota – College of Design's Virtual Reality Design Lab is located in the courtyard of Rapson Hall. Twelve cameras are suspended on a square truss attached to the four columns of the courtyard. The cameras face the center of the court in order to pick up the location, movement, and head positioning of the VR user with an accuracy of about half a millimeter. The head requires six degrees of freedom for visualization in virtual reality. LED lights are attached on the head mounted display and are tracked by the cameras that follow the position of the head and match it in the model. The system communicates with itself through two computers, one of which tracks the person using the head mounted display while the other projects the view in the model. (See Figure 2)

Steve Aukstakalnis and David Blatner describe three stages of Virtual Reality: passive, exploratory, and interactive. "Each of these offers slightly different features. And each progressive step is that much more difficult to create." Passive VR allows the viewer to stay stationary as the virtual world moves around them. Exploratory VR allows the viewer move throughout the stationary space. Interactive VR allows

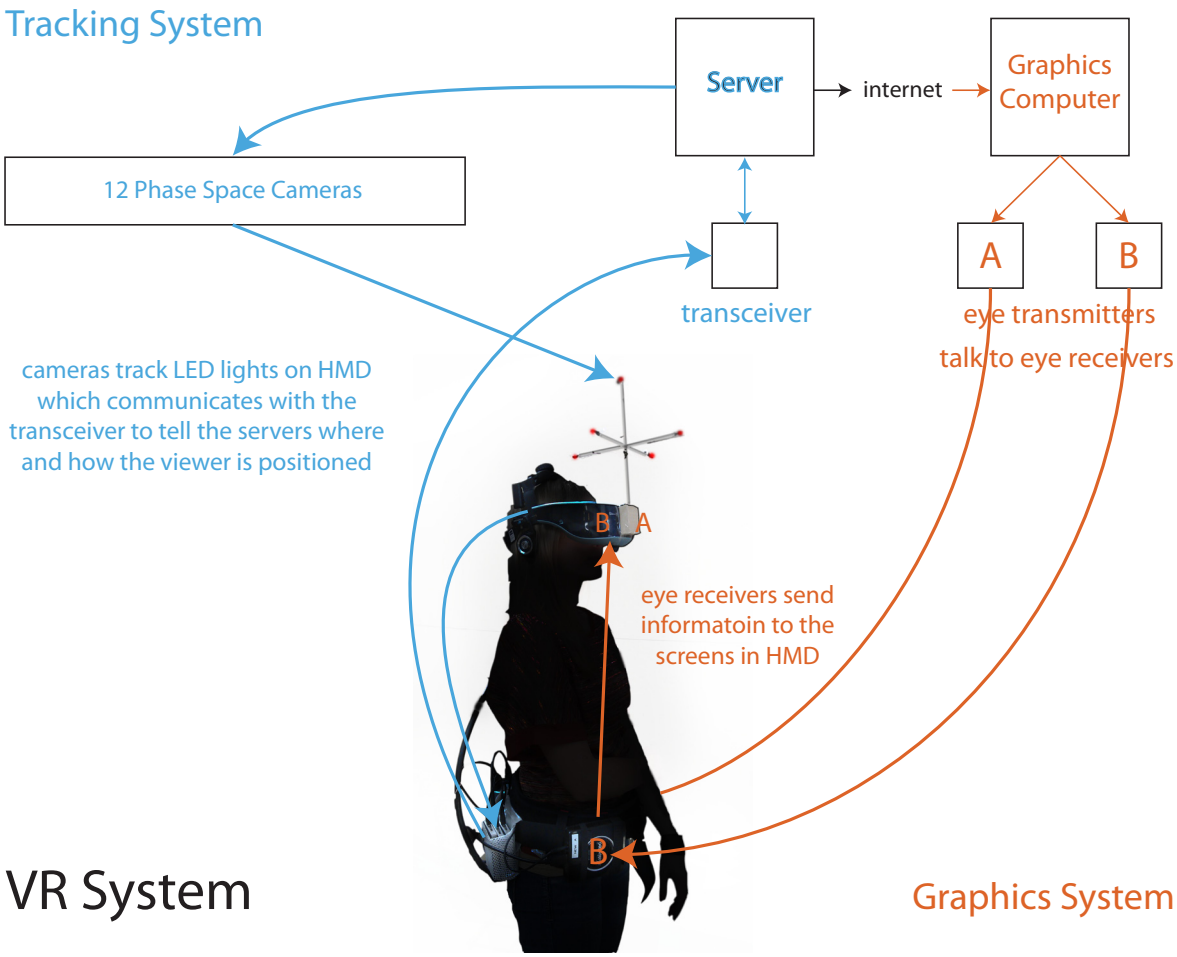


Figure 2

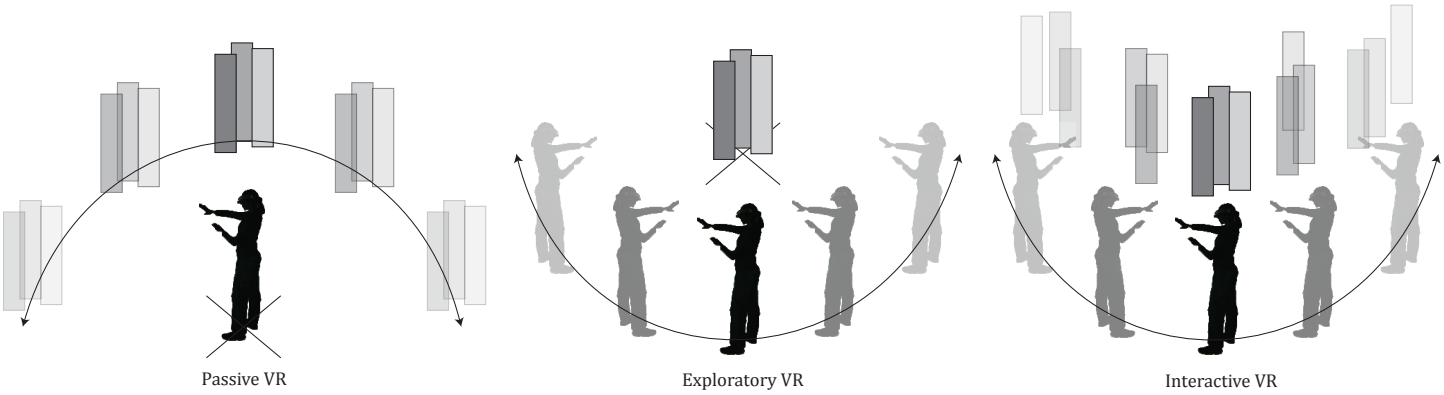


Figure 3

the viewer to move throughout the space while also having the ability to manipulation the virtual world. (Aukstakalnis ,22-23) (See Figure 3) The ultimate goal for a successful walk-through of a patient room would be to achieve a level of interactive virtual reality so that equipment could be manipulated and moved by the person walking through in real time. Our time and system capabilities, at this point, will allow us a level of exploratory virtual reality. In order to test things in various positions or locations we can create a series of models to explore that have variable conditions to test. In the event that the virtual mock-up is used to determine room size, equipment position, and mobility, the control of the exploration stage may actually benefit the testing of each space.

In order to compare the physical mock-up benefits and testing capabilities with the virtual reality mock-up benefits and testing capabilities, the same spaces needed to be created within the computer for testing in the VR system. The process followed to create the ICU and Medical/Surgical patient rooms of the California based hospital design is as follows:

Journal of Process
Bringing Current Project Model into Virtual Reality

HGA has a current project on the boards for a California based hospital in which the use of a series of physical mock-ups were used to test the size, configuration, function, among other things, of patient rooms and nursing staff areas. For the purpose of the directed study and virtual reality research, we focused attention to the medical/surgical and intensive care units to test in virtual reality and compare with physical mock-ups.

The hospital had been modeled using the Autodesk Revit software, which has the capability for 3D rendering, however the current VR set-up in Rapson Hall uses VR software that communicates with Google SketchUp. Before the models of these patient rooms are viewable they require transfer of the information from Revit to SketchUp.

Due to the size of the Revit file from which the patient rooms would be exported, locating, cropping and exporting the areas took about an hour and a half. In order to bring in all pertinent data to have the VR model as close to accurate as possible, all options and layers remained checked on for export. It was also decided that the export should include the entire wing of the medical/surgery section so as to see more context in the VR model. The export produced nine separate .dwg files of various pieces of the model and any equipment in the rooms. Having all of the .dwg files prepared, they could then be imported into SketchUp. The time that it took for each import varied dependent on the size of the file or what was contained in each file. The equipment tended to come in on one file, this one being the largest – suggestions for keeping this piece separate while working on the rest of the model have been made, due to their inherently large number of faces attributed to each piece of equipment.

The quality of the model required clean-up on the side of SketchUp. Unknown is whether the quality of modeling in Revit could be improved to better transition into SketchUp or if SketchUp's need for triangulation caused the transition issues or a combination of both. The following describes the quality of the model as it was imported from Revit to SketchUp:

- non-orthogonal elements, mostly, come in with severe triangulation – breaking up planes into multiple surfaces
- triangulating elements are missing chunks, (ie. walls have holes in them)
- there are many layers to the import that do not always follow a pattern or logic
- details are missing (i.e. lighting cove in corridor)
- file sizes are quite large - model runs slowly
- equipment is not always positioned on a wall/table/surface, rather it floats

In addition to fixing all of the above issues by redrawing, moving, or adjusting elements, it was decided at HGA to do a number of things to try and make the transition in VR as seamless as possible. The following things were done in conjunction with a series of red line reviews to the medical/surgical patient room and the ICU patient room as additional fixes to the models:

- deleted all excess equipment to reduce geometric complexity
- deleted many walls that would not be glimpsed during a walk through
- assigned colors or materials to surfaces
- any inaccurate line-work that appeared was hidden

During the process of reviewing and red-lining the SketchUp models, it was detected that there were discrepancy between the Revit drawings and what would actually be built in the mock-up. Additionally, the 3D import from Revit had differences from the elevations of the interior spaces. All discrepancies were noted, clarified and if changes were needed in the SketchUp model, they were made.

The second phase of the physical "hard mock-up" has been in progress during the time we have been working toward getting the virtual model prepared for walk-through. Updates have been made to the design/outcome of the physical model that we wished to reflect in the virtual mock-up so that they would be as close to each other in representation as conditions would allow.

After passing the SketchUp model on to the Virtual Reality Team at the college, the model went through another round of clean-up in order to be able to run in the Virtual Reality software. The things that remained to be done included: material application, group exploding, and layer flattening. In the end the patient room models could not be run in the virtual reality system the way that they had been revised to that point. Katy Dale, VR research fellow, decided to start the process over to see what types of manipulations would work best to be able to achieve a working VR model.

The benefits to having a detailed, best practice process for getting a Revit model, or any model to work in the VR system would save both the firm involved and the UMN VR team a lot of time and effort in assuring a correctly detailed and running model. If Virtual Reality is chosen by the firm as a representation tool early on in the design process this would avoid altogether the trouble of translating from other programs to SketchUp. Because HGA's project has been in the process of development using Revit, the translation was used as a test to see where problems occurred in the case that other projects using Revit could have a system for translating the model. Key things to remember about the required qualities of a Sketch-up model for use in VR:

- models with greater than 300,000 faces will run very slowly, if at all
- models with nested components lag in the system – explode entirety of the model
- "z-fighting" will occur in VR when two faces are one on top of the other
- save views from under feet – VR system determines height of view
- Revit files import with large amounts of extra detail that are unnecessary for VR viewing – this detail needs to be removed

When the model of the Medical/Surgical patient rooms was brought up to a point that it was able to run in the Virtual Reality System, architects from HGA and I were invited to visit the space. My experience of the virtual patient room is described below.

While in the virtual model using the College of Design's VR system, visual perception is at a 60-degree field of view. Seeing/perceiving only 60 degrees of a space at a time gives a very different feeling of a space than what humans are generally used to perceiving in reality. "When you're looking straight ahead, each eye is capable of providing visual information as much as 90 degrees off its central axis… because you can pivot your eyes to the left and right about 45 degrees, you can actually perceive an additional 90 degrees making for a total lateral field of view of approximately 270 degrees." (Aukstakalnis, 70-71) Our current head mounted display projects the 3D model through two lenses - similar to binoculars. Looking through this type of display, along with the 60-degree field of view, was similar to walking around with blinders. All peripheral capabilities are unused, making it exceptionally difficult to perceive spatial quantity of the room. Cues such as furniture and equipment placement and window views made the room open up more, suggesting that the room is spacious. When in the bathroom, however it seems extremely cramped because one does not get the sense that movement can happen without running into something. Other sensing cues such as sound and touch that would help to locate and place a person within the model are not available to make up for the loss of vision at this time. Another difficulty was in determining proximity to objects. It was clear when approaching an object such as the bed or desk that things were within a certain distance and they should be walked around – I was even startled by "running into" the IV stand – however without being able to reference one's body in the model it was not easy to guess the relative distance to an object.

Though the perception of the space in virtual reality was hindered by the small field of view and the proximity estimation troubles, the overall experience of using the virtual model was very interesting. It

was exciting to walk around a space that only exists on a computer and it would likely be helpful to more quickly and effectively understand one's own design as well as to communicate the design to colleagues and clients. Wearing the head mounted display and related equipment though unusual in viewing a model, was personally not a hindrance for exploration in Virtual Reality. There are limitations to the equipment that do not work for all viewers, however, for example; glasses cannot be worn while wearing the headset. Other 'side effects' of virtual touring affect people physically, for example nausea. How the physical experience of the participant affects their impressions of the space they are viewing is something to consider when bringing outside participants to walk through the virtual spaces.

Comparison of Mock-ups

Physical mock-ups, used frequently by healthcare designers to test aspect of a project, have many immediately obvious disadvantages when compared to building a mock-up virtually:

- physical mock-ups require new spaces to house them – in the case of the project describe in this report a rental facility was acquired for the span of the Hard Mock-up phases which are yet to be completed
- a physically running mock-up space may require the need for permits from city officials, costing time and money to acquire
- building an actual space requires additional costs for materials, contractor fees, change costs, and time commitment costs
- physical mock-ups are difficult to adjust; several weeks of documentation and construction time could occur between participant visits to the mock-up – this is very inefficient

Thinking more broadly about the capabilities and benefits to the physical mock-up, however, begins to suggest that there are also strong advantages. Without having actually tested each type of space to compare one-to-one the responses from practitioners of medicine, there are assumptions based on the results of the physical mock-ups and experiences of the virtual mock-ups that pinpoint some advantages of the physical mock-up process as compared with the current capabilities of the VR mock-up:

- mobility of real equipment is good for testing many different variations real-time
- a real space and real equipment allow for full scale simulation with many participants in the space at one time – limitations in the design can be easily discovered in simulating 'worst case' scenarios
- spatial qualities can be perceived in a physical space, and also readily tested
- space can be 'turned on' – a working mock-up allows for running equipment
- a physical space is more readily available for touring potential donors and other people who might be interested in the project

With the use of the University of Minnesota – College of Design's Virtual Reality Design Lab and help from the VR team, HGA can look at the possibilities for using VR as a tool for mocking-up designs in place of, or in addition to using physical mock-ups. The experiences had to date in this system have brought to light some disadvantages when compared to the testing that has been done on the California based hospital's physical mock-up:

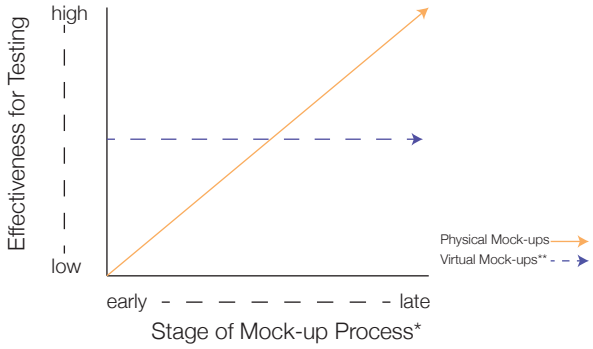
- mobility of equipment in VR is more difficult to represent and interaction with the moving equipment is even further from reach
- simulation with multiple people is not a possibility at this point
- perception of quantifiable space is difficult because peripheral vision is not in use
- perception of quantifiable space is difficult because running into an object is 'allowed' – without the physical cue that a wall has been hit, assurance that a space is an acceptable size is hard to make

The virtual experience provides architects and clients with some advantages over physical construction as well:

- elimination of physical construction cuts down in the time and money spent in making the mock-up space
- using the Virtual Reality space currently residing in the UMN – College of Design Rapson Hall courtyard, necessity for space and permits is removed
- especially in the case of the hospital project, had it been available earlier on, the VR mock-up could have cleared up detailing issues that were never solidified thus preventing the physical mock-up construction delay
- virtual reality permits mock-up of exterior spaces and large interior space not permitted or practical through physically constructed mock-ups

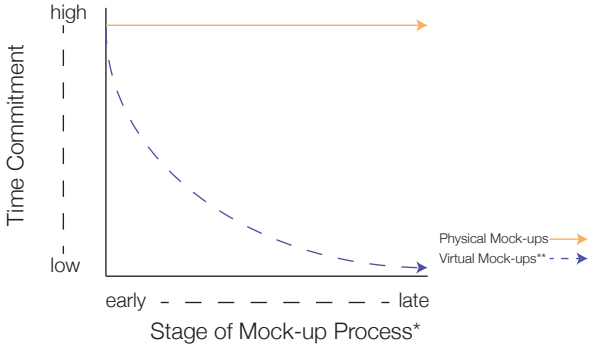
Figure 4 addresses some of the advantages and disadvantages of each method of mocking-up a space. Note that the graphs illustrate relative outcomes based on the experience of this study.

Relative Relation of Effectiveness for Testing



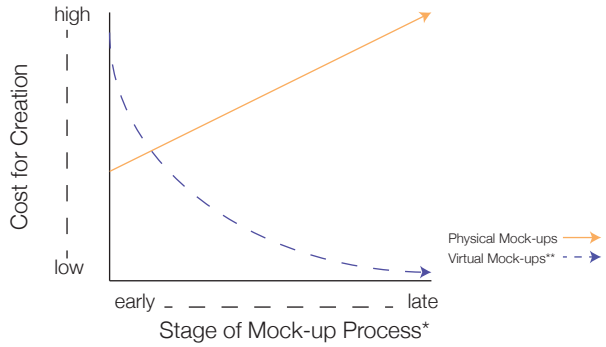
* Comparisons made to CA Hospital mock-up stages of Soft, Hard PI, and Hard PII
** Assuming that VR mock-up is fully detailed throughout whole process and that line represents hypothesis due to lack of hard data

Relative Relation of Time Commitment



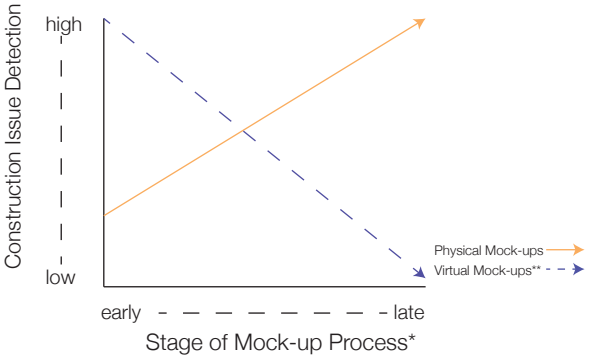
* Comparisons made to CA Hospital mock-up stages of Soft, Hard PI, and Hard PII
** Assuming that VR mock-up is fully detailed throughout whole process and that line represents hypothesis due to lack of hard data - subject to shift

Relative Relation of Cost to Create



* Comparisons made to CA Hospital mock-up stages of Soft, Hard PI, and Hard PII
** Assuming that VR mock-up is fully detailed throughout whole process and that line represents hypothesis due to lack of hard data

Relative Relation of Construction Issue Detection



* Comparisons made to CA Hospital mock-up stages of Soft, Hard PI, and Hard PII
** Assuming that VR mock-up is fully detailed throughout whole process and that line represents hypothesis due to lack of hard data - subject to shift

Figure 4

It is difficult to judge the value of presenting the mocked-up space virtually rather than physically not having responses from people outside of the design profession who have experienced the patient rooms in Virtual Reality. The excitement for the technology is high coming from HGA professionals. I question what types of tests or experimentations would actually be valid in the virtual setting. Only the sense of vision is being utilized in the virtual mock-up, which makes it extremely difficult to accurately judge accessibility to equipment and patients, configuration of equipment, mobility of equipment and people within the space. These are all things, however that can be achieved through building a physical mock-up. Classmates who have had non-design visitors in their virtual models have reported that the tool proves to be useful in helping to communicate the design and its intent to someone who may not understand the traditional 2D imagery they are presented. For this reason, the value of the virtual reality mock-up might be more in line with design and process understanding and experience rather than testing of space.

It will be interesting to find out how the walk-through of the completed virtual space is received by individuals outside of the design team at HGA. The plan to give the same survey as was given to the participants of the physical mock-ups, with additional experience related questions, should actually show what the capabilities are for people viewing the virtual space. At that point one might be able to make a clearer picture of the role that virtual reality can successfully take in the realm of healthcare design.

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