AN IMMERSIVE VIRTUAL REALITY MOCK-UP FOR DESIGN REVIEW OF HOSPITAL PATIENT ROOMS

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ABSTRACT: Having identified a scarcity of evidence-based design principles and practices for patient-centered healthcare environments, researchers at the Purdue University Regenstrief Center for Healthcare Engineering have developed a Virtual reality (VR) mock-up of a hospital patient room to explore its efficacy for identifying how physical environment and design elements impact behaviour, processes and safety. The VR patient room mock-up is designed to have a high degree of interactivity to facilitate evaluation of the designed space as a "healing environment." Positive feedback from healthcare practitioners regarding the modckup has motivated the Investigators to leverage their experience to create VR mock-ups for other hospital units and venues.

KEYWORDS: CAVE, mock-up, design review, patient room, patient-centered design

1. INTRODUCTION

Although a growing body of evidence links patient satisfaction, health and safety, and quality of care to the way in which a care facility is designed, today's care environments are negatively impacting patient and associate safety, the patient/family experience and operational efficiency. Employing high impact design concepts could significantly improve care delivery and contribute to better health outcomes. However, in a library search of the literature for evidence of high impact design to improve healthcare delivery showed that of the 360,000 citations listing "evidence based design in healthcare facilities" only 57 had quality criteria providing guidance for improving the design of healthcare facilities. Because of the lack of guidance designers and users of healthcare facilities often work from traditional models for designing and building healthcare facilities—often with poor results as attested by healthcare practitioners.

Traditional design ranges from blueprints to 3D models, to costly mock-ups for client evaluation. In fact, standard practice in the process of design is to build full-scale mock-ups to develop and confirm details for the build-out of critical hospital units such as operating rooms (ORs), patient rooms, and nurse stations. This practice affords healthcare professionals and staff the opportunity to provide focused feedback regarding design based on their opportunity to experience a realistic representation of the design concept.

These mock-ups can be completed to a stage anywhere from framing and bare drywall to complete finish and furnishings. They are therefore costly in terms of initial construction expense, costs associated with making modifications for re-reviews, and the final demolition and disposal costs. It is not unusual for the cost associated with mock-up rooms to range from hundreds of thousands of dollars for a single room or unit to over $1M for multiple units in a large facility. FIG. 1 shows examples of these mock-ups erected in a dedicated warehouse space, the cost for which is included in the project expense.

FIG 1. Mock-ups of selected hospital rooms (http://www.arnett.com/camc.html).

The use of virtual reality offers an opportunity for various stakeholders representing the client healthcare organization to have an interactive experience with hospital units ranging from a patient's room to an operating room to an entire hospital at a fraction of the cost of mock-ups. Recent work on patient-centered design through the Purdue Discovery Park Regenstrief Center for Healthcare Engineering (RCHE) and the Envision Center for Data Perceptualization at Purdue University has produced a Virtual Reality (VR) model of a modern patient room that can be inspected in a Cave Automatic Virtual Environment (CAVE). The full-scale, stereoscopic, real-time, 3D visual simulation in the CAVE facilitates a compelling experience of the actual spatial relationships that would result from the room design.

Literature documents notable examples of this technology being utilized in similar fashion to support design review for federal courtrooms (Majumdar et al., 2006; Moldovan et al., 2006). The motivation for these examples was also to replace or supplement the practice of using full-scale mock-ups, constructed typically or plywood in this case. While the critical aspect of courtroom design reviews is proper sightlines from the various vantage points of courtroom occupants, the patient room review involves such things as evaluation of mobility of equipment and furnishings; dimensions and placement of doors, windows, and cabinetry; accommodation of flow into, out of, and within the room; accessibility and safety of the bathroom facilities; assessment of noise levels filtering in from outside the patient room; identification of architectural features for infection control; and intensity of various light sources. Hospitals constitute an even more suitable application domain for this technology due to the greater number of varied units to be constructed, the operational dynamics of many patient care processes, and the high concern for patient safety and comfort. For example, FIG. 2 depicts an OR design concept in which it is apparent that the motions of flexible and mobile equipment must be fully understood and considered. Not only can such equipment be visually simulated using VR, but the dynamics of human activity in the OR can also be modeled. Real-time interactivity with the 3D design model is a value-adding capability that separates this immersive visualization over other 3D model visualizations.

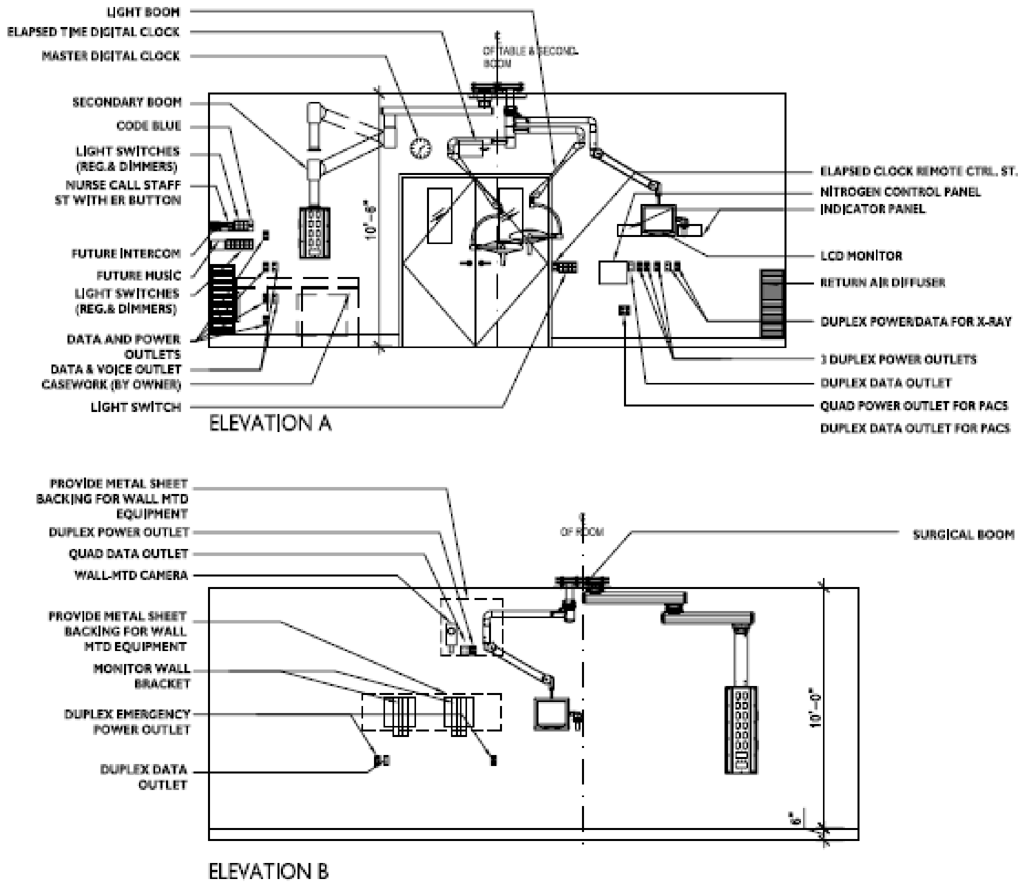

FIG. 2: Example of modern operating room design

The remainder of this paper describes the VR patient room mock-up, gives an account of its evaluation, and makes recommendations regarding possible enhancements and how the experience gained by the Investigators can be leveraged to create VR mock-ups for other hospital units.

2. DESCRIPTION OF PATIENT ROOM VIRTUAL MOCK-UP

The patient room mock-up is modelled after actual rooms in the Bariatrics and Obstetrics department at St. Vincent Indianapolis Hospital. The patent room mock-up is explained in the following sections with respect to hardware, the development software used, and the key features of the application. Examples of functionality are also highlighted to underscore the usefulness of the VR visualization.

2.1 Hardware

The virtual patient room was created to run in Envision's CAVE-like setup (FIG. 3), a Fakespace FLEX™ system featuring three ten-foot by eight-foot panels for active stereo rear projection. These movable screens can be easily and rapidly rearranged to form a traditional CAVE (Cruz-Neira, 1995) with three walls plus a fourth panel as the floor, or as a large 30' wall capable of display for up to 50 viewers. This VR Theater is also equipped with an Intersense IS-900 ultrasound/inertial tracking system that allows correct perspective rendering and direct interaction with the virtual environment. A 5 channel speaker system in the corners of this facility further contributes to the effect by adding surround sound cues to the virtual reality environment. The displays are driven by a 4 node, 64-bit dual Opteron Linux PC cluster with nVidia Quadro FX4500G graphics cards.

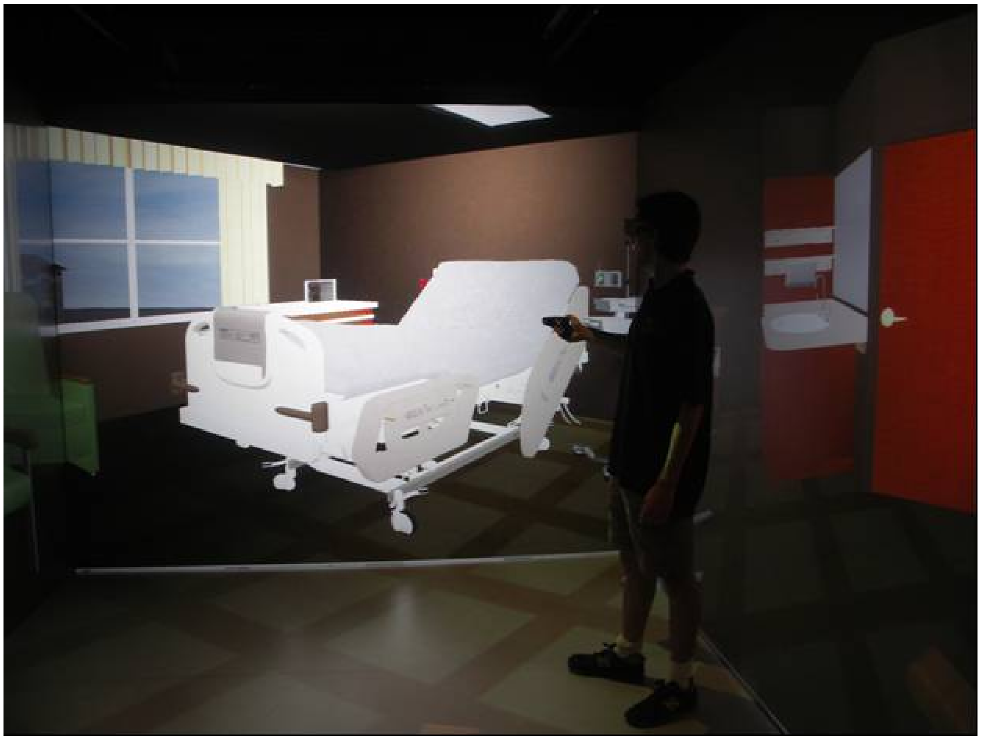

FIG. 3: Patient room display in VR Theater CAVE setup.

2.2 Development Software

The patient room application was developed primarily using the VRJuggler toolkit (Bierbaum et al., 2001). Coding was done in C++ and utilized the OpenSceneGraph (OSG) rendering API (www.openscenegraph.org). Models for the room and furnishings were created in 3DS Max, and then exported to OSG using the OSGExp plugin. Items were named so that they could later be located in the scenegraph. This allows the developers to search for specific items, such as “bathroom_door” and then program interactions for that piece of geometry. Use of these Open Source toolkits allows for a great deal of flexibility and portability. For example, it may not always be possible to transport nurses, doctors, hospital health and safety professionals, and architects to Envision for a design review. Instead, a portable VR system can be taken to remote sites for reviews of the patient room. More details on this system can be found in (Arangarasan, et al., 2003), and a picture is shown below in FIG. 4. The VRJuggler toolkit allows the patient room application to run on the portable system with no changes to the code. It would also allow the application to run on other operating systems, with different hardware such as a head-mounted display.

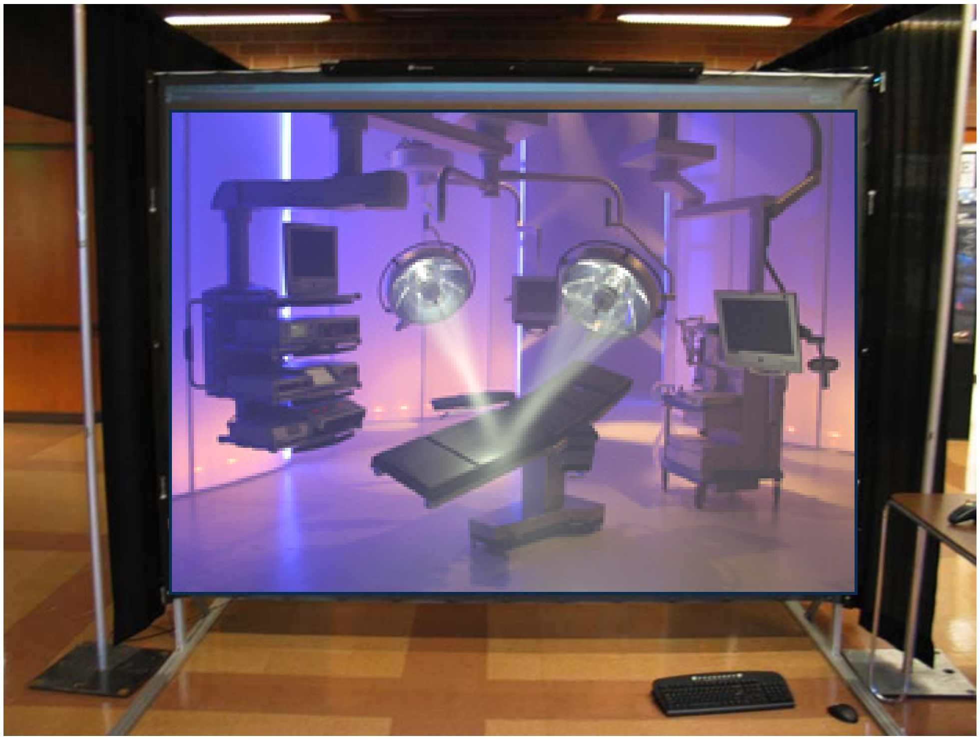

FIG. 4: Portable VR display system.

2.3 Application

The application begins with the user standing in the hallway of the hospital, outside the patient room. At this point, the audio is relatively loud, as is common in public areas of a hospital. The audio used is an actual recording taken at the hospital used for the virtual model. The user can then open the door to the patient room and enter. As the user closes the hallway door, the audio level is scaled down, but still audible, for a realistic impression of sound levels within the room. Within the room itself, localized sounds are available, so that as the user gets closer to an object like the clock, the audio produced by that object gets louder.

Once inside the room, the user can perform a variety of actions. He can wander throughout the room to check clearances, sound levels, sightlines, functionality, and general appearance. Nearly all the furnishings in the room are mobile, so the user can grab pieces of equipment and furniture and rearrange them within the room. He can also carry items with him while walking to check whether there is adequate space to move equipment to the positions needed. FIG. 5 shows a user moving the table to be closer to the bed, while avoiding colliding with the IV pump. Doors and drawers on the furniture can be operated to further check clearances. FIG. 6 shows the user opening one of the dresser drawers near the bed.

FIG. 5: User demonstrating furniture mobility by rolling table closer to patient bed.

FIG. 6: User opening drawer to check clearance.

By moving and changing objects in the room, users can determine possible problems with the room layout. For example, FIG. 7 shows the user opening both the door to the hallway and the door to the bathroom at the same time. He can clearly see that the doors work correctly and do not hit each other even when both are open. However, he can also see that the space between the doors is fairly small, so that plans to place any objects (such as a coat rack) behind the door would be inconvenient. In FIG 8, the user has discovered a potential problem. When working on the far side of the bed, by opening a cabinet door to get an object out, the user has become trapped between the wall, the bed, a table, and the cabinet. Clearly there is too much furniture in such a small area.

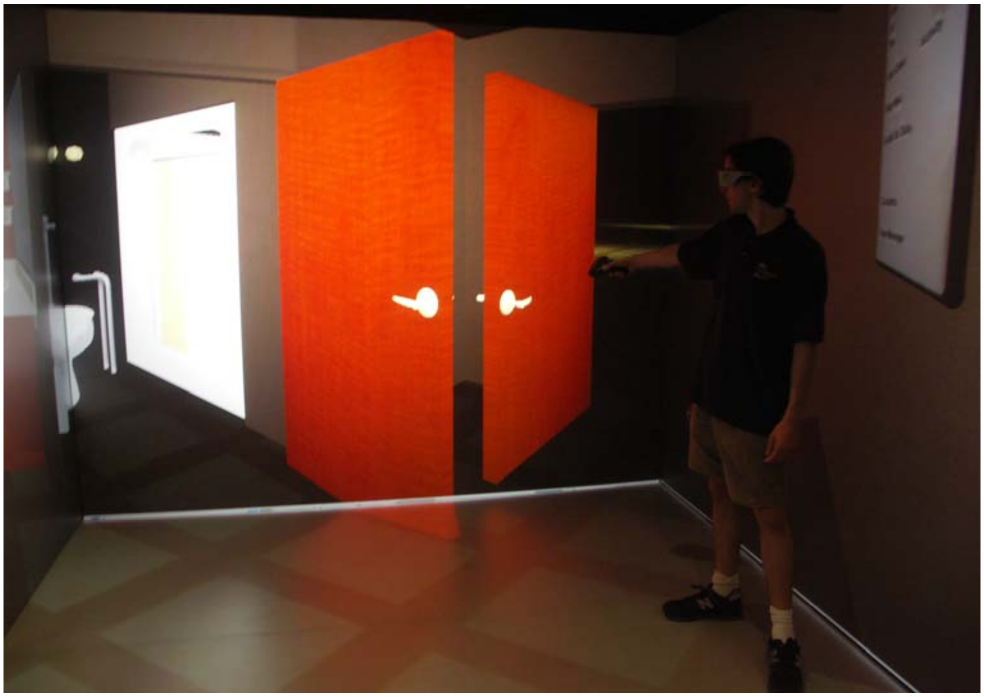

FIG 7: User demonstrating adequate clearance between entry and restroom doors.

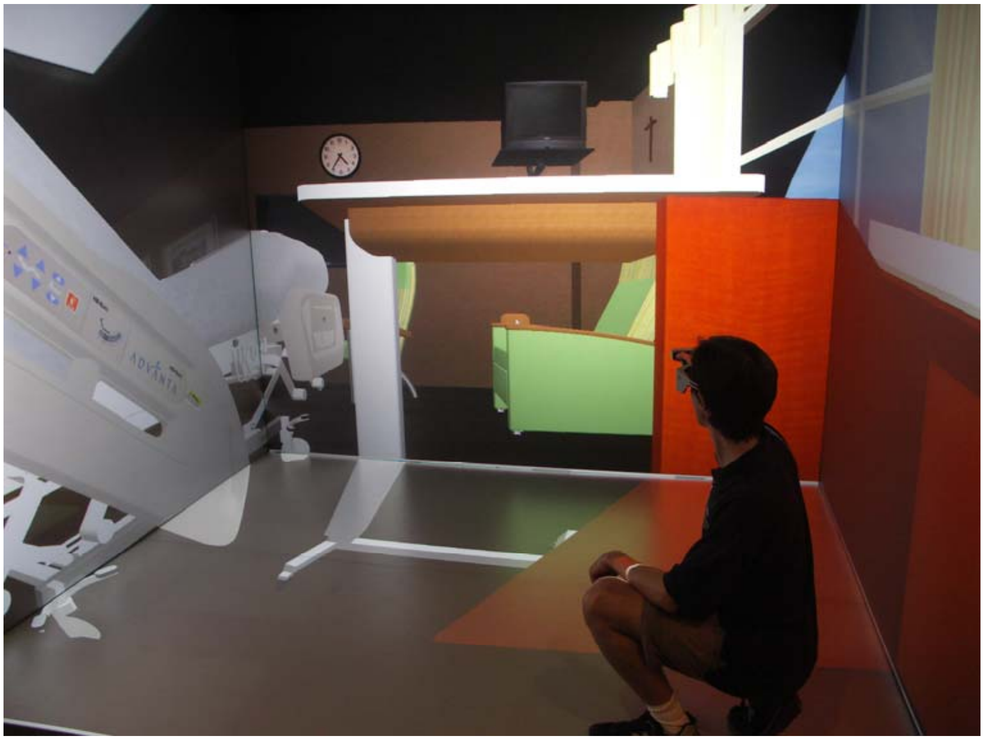

FIG. 8: User finding himself trapped between furnishings when cabinet is opened.

In addition to changing specific items in the room, the user can also change the overall environment. The lighting levels can be adjusted to a variety of settings. The image outside the window can also be changed to simulate the view from ground level, higher levels, urban environments or more natural environments. Given a specific location for the hospital, the unique views from each room could be simulated. Finally, the user can change the size of the room. Currently there are only two presets—a standard size room and a large size room. Future additions could make it possible to actually move the walls continuously until the user felt the room was the ideal size and shape.

These interactive features are critical to the value derived from the VR mock-up because they allow users from among the healthcare provider team to evaluate more than just a static layout but the actual active environment in which care will be provided to the patient. Practitioners exploring the VR mock-up noted that the very same shortcomings known to be in the actual patient room are readily identified in the visual simulation, thus confirming the value of a VR mock-up for design review.

3. ASSESSMENT OF CURRENT MOCK-UP

Purdue researchers conducted pilot testing of this VR patient-centered room among selected healthcare personnel, including nurses. Some of the nurses who have experienced the simulation also work in the actual facility from which the VR room is modelled, so their impressions were particularly insightful. The evaluation was not structured, but essentially demonstrations to obtain informal responses to the simulation. An additional objective was to help in the thought process for a questionnaire and biometric feedback (i.e., heart rate, respiratory rate, blood pressure, galvanic skin response) to quantify emotional responses to the VR simulation and to compare this with constructed mock-ups and with the actual finished product.

Nurses and healthcare personnel who have interacted with the VR liked the “immersed” and interactive sense of the simulated hospital environment. This effect is something they could not obtain from a "window-on-the-world" (desktop) 3D environment. They were especially impressed with the relative perspective of the patient room when they changed position. For example, when stooping down to reach a lever to raise the bed, the VR room changed convincingly with their viewing perspective as though they were in the actual room.

4. PLANS AND CHALLENGES FOR FUTURE MOCK-UPS

Success with the patient room mock-up encourages the Investigators to leverage knowledge gained to develop simulations of other hospital units. The operating room (OR) is considered to be an option of high priority to hospital officials. Such a model would be distinguished from the patient room by two particular elements:

- Population by manipulatable equipment—fixed, mobile, and flexible mounted devices (see FIG. 2) and
- Human avatars (i.e., articulating virtual manikins), programmed to follow typical travel paths of medical professionals and staff entering, exiting, and performing basic functions.

These additional elements will enable the uniquely dynamic nature of the OR where the important issue for practitioners is process and flow of activities associated with various medical operating procedures.

The Investigators contend that the potential for cost savings from using VR mock-ups in lieu of full-scale physical mock-ups is compelling, but direct cost is not the only factor to be considered. While the authors roughly estimate that a VR mock-up from scratch (new computer code) might cost on the order of one-fifth the cost of the average mock-up—which might vary on average between $150K to $500K depending on the design and number of modelled rooms—it also could take from 6 months to a year to produce in the typical academic research environment utilizing students programmers. The research team has learned from conversations with healthcare practitioners from various hospitals that this time requirement for creating such highly interactive simulated environments is the prime limiting factor preventing project teams for new hospitals from investing in VR mock-ups. The typical hospital design and construction schedules are so rapid that many decisions must be made faster than a mock-up can be created from scratch. While the creation of the rooms is relatively simple and can be done quickly, documenting and then modeling the many specialized types of equipment and fixtures with interactive features is considerably time-consuming.

Therefore, a future objective of the Investigators is to develop a library of generic objects for quickly populating VR mock-ups of particular hospital units, the end goal being to develop the capacity to quickly create compelling, interactive VR mock-ups that can be reviewed in a timely enough fashion to contribute to the design process for new hospital projects. In addition, the authors have found that more university research institutions are developing "template" code where the programmer does not have to start from scratch but can use existing code to reduce time and costs. Another movement that is occurring to speed up the VR mock ups is for like-minded research institutions to share code with each other. This can be done by having a central repository where the data can be stored, used, and enhanced.

5. CONCLUSIONS

The use of VR as a means of creating a database of qualitative and quantitative elements for patient-centered design for current and future state appears to be a reasonable and cost-effective means to advance the state-of-the-science in form and function for hospital design, construction, and operation. Success with this technology application has prompted the consideration of VR as a less expensive yet similarly effective means to reach consensus decisions among healthcare personnel, designers, and construction contractors regarding design for various hospital units and venues. Critical next steps must accomplish the development of a software library of hospital units and venues and the capacity for rapid turnaround (within 1 to 3 months) in creating VR mock-ups to keep pace with hospital design and construction decision-making time horizons. University institution partnerships may play a key role in developing repositories to enable this level of responsiveness to industry needs.

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