Utilizing Discrete Event Simulation to Minimize Scope Creep in Construction Projects: A Case Study

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Scope creep is widely cited as one of the major causes of construction project cost overrun and schedule delay. The loss of a solid understanding between stakeholders' desired outcome and the designer intent often leads to costly changes that have to be made during the construction phase. Design drawings, while expressing static dimensions and spaces of a facility, fall short in characterizing its performance under dynamic real-world conditions—the true representation of stakeholders' desired outcomes. Lack of a deep understanding of how a space will function may hinder stakeholders from making informed decisions in the design phase, which often causes scope creep at a later phase. The objective of this study is to minimize scope creep by providing stakeholders a simulated view of the operating facility during the design phase for optimal design decisions. To accomplish this, Discrete Event Simulation (DES) and 3D visualization are applied to model and visualize a facility, its occupants, and usage so that intended facility outcomes can be verified. This approach is demonstrated through a case study of a health care facility project. The simulation method successfully minimized design changes and scope creep which translated to substantial cost and time savings.

Key Words: Scope creep, Facility design, 3D visualization, Discrete event simulation.

Introduction

The Project Management Institute (PIM, 2008) defines scope creep as adding features and functionality without addressing the effects on time, costs, and resources. In other words, it is an uncontrolled growth or change in the project scope beyond the original intent. Scope creep has been widely cited as one of the major causes of construction project cost overruns and schedule delays, and it occurs quite often in construction projects. In their study, Bresnen and Haslam (1991) reported that 40% of the projects experienced budget overrun due to scope changes or design variations.

Scope creep often occurs when a project scope is not properly defined, communicated, or controlled. In particular, misunderstandings and misinterpretations between designers and stakeholders on facility design have significant impact on construction (Knight and Fayek, 2002). The loss of a solid understanding between stakeholders' desired outcome and the design intent often leads to costly changes that have to be made during the construction phase. Design drawings, while expressing static dimensions and spaces of a facility, fall short in characterizing its performance under dynamic real-world conditions—the true representation of stakeholders' desired outcomes. Lack of a deep understanding about how a space will function hinders stakeholders from making informed decisions in the design phase, which often causes scope creep.

The objective of this study is to minimize scope creep by providing a simulated view of the operating facility during the design phase for optimal design decisions. The paper first reviews industry current practices and related work. A case study of a healthcare facility ~~project~~ is then presented to clarify the proposed approach and confirm the benefits achieved.

Current Practice and Related Work

Poor scope definition at the onset of a project is ranked as the most frequent contributor to cost overruns according to the Construction Industry Institute (CII, 1986). A poorly defined project is subject to changes initiated by stakeholders that will require extra work and effort by the design team to complete (Knight and Fayek, 2002). Effective scope control and change management are suggested by CII (1986) for combating scope creep. Scope control is a preventative process that starts with a detailed project scope and ensures discipline in changing the scope during project execution. Change management involves the processes for managing all changes that occur on a project.

A project has the best chance to influence construction costs during the design phase. The industry has long recognized the importance of maintaining good communication between stakeholders and the design team. Effective visualization of the design ensures the alignment of the design intent and the desired outcome. Traditional communication through design drawings is inefficient due to the complexity involved in designs and possible wrong interpretations. Building Information Modeling (BIM) and 3D visualization of facility design have greatly facilitated communication among project team members. A BIM model is a 3D model of the project components that provides useful information on specifications, schedules, and many other types of project data (Kymmell, 2008). Stakeholders can tour a facility virtually in a computer environment by walking through or flying around the facility freely. However, BIM still falls short in providing clear visualization of the facility performance when its occupants and work processes are introduced. Hence, there is a need to further enhance the current 3D modeling practices to support not only visualization of a facility's geometry but also the measurement of its performance when operational.

Methodology

This study proposes to use of Discrete Event Simulation (DES) and 3D visualization to model and visualize a facility, its occupants, and usage so that the intended facility outcomes can be verified. The simulated view of an operating facility during the design phase can promote an unparalleled level of communication between stakeholders and designers. It encourages a deeper discussion and early identification of missing items, unspecified client preferences, design issues, and improvement opportunities. Once the parties agreed, the design solution can be refined in the design office, avoiding costly late change in the construction field.

A simulation model is a chronological and logical model representing a real-world system. In particular, DES can model the operation of a facility as a discrete sequence of events in time, such as a patient arriving at a clinic, receiving service, and departing. Simulation techniques have been widely used in analyzing future system performance, identifying bottlenecks, evaluating alternative plans, and improvement strategies. A BIM model augmented with DES provide many benefits. As mentioned above, BIM and 3D walk-through are limited to convey a sense of shape and space, but fail to characterize the performance of a facility. DES fills in the gap by allowing performance measurement and capture of design flaws, such as congestion. Furthermore, DES allows users to conduct what-if analysis and virtual experiment of a facility design for optimal decisions. In summary, utilizing DES can potentially help stakeholders to identify missing items and catch potential work flow issues thus reducing scope creep during the construction phase.

The proposed approach is demonstrated through a case study of an Intensive Care Unit (ICU) renovation project. The facility design and associated 3D models provide a background to overlay the behavior of occupants (i.e. staff, patients, and visitors) and work flows (e.g. medical services and family visiting) represented by DES models. A simulation tool, Simio (2014), is used in this study due to its flexible modeling and animation capabilities. With the developed DES models, stakeholders can spot work flow problems and understand how the space will be utilized by seeing how different entities move around the space. The following sections describe the detail implementation of the case study, modeling and analysis, design improvement, and confirmation of benefits achieved after the ICU was built and operated.

Simulation Case Study

The case study involves converting an existing acute care wing of a hospital to an ICU. The original acute care wing consisted of 24 patient rooms, one children play area, one family lounge, and one nurse station. Due to regulatory codes, the project had to isolate this wing from other services and provide all ICU services within the wing. The work scope involves the addition of a respiratory room, a nurse station, a family lounge for visitors, medical gasses (three oxygen, three vacuum, and one medical air), power and data for required ICU equipment. The unit is also expected to provide nurse-to-patient visibility from outside the patient room and adequate equipment storage for emergency equipment in the unit.

The goal of simulation is to help properly locate these new required facilities and refine their design, via simulation of workflow, during the design phase to help minimize scope creep in construction. To capture the initial design, the existing 2D floor plan was exported from AutoCAD into Simio. Once the floor plan is exported, building elements such as walls in Simio can be extruded, and other 3D elements such as furniture and people can be added. Model parameters such as visitors arrival time and service duration were collected from an existing ICU features similar conditions and patient population as well as expert estimates. Simulation experiments were progressively done to help fine-tuning the unit layout and workflow until the stakeholders are content with the final layout. To verify savings, the original design was served as the cost baseline. Estimated quotes of cost and duration were provided by the contractor to quantify savings due to favorable changes made after the simulation study. This case study investigated three key work flows in the ICU with a goal to refine the original design, including the work flow of patient-to-room, visitor-to-welcome desk, and visitor-to-patient/family lounge, which is elaborated below.

Patient-to-Room Simulation

Safe and efficient movement of patients in and out of patient rooms is the focus of the ICU facility. Thus, a simulation of the patient-room work process can help determine best locations for the service rooms.

The initial simulation model assumes all 24 planned rooms in the facility as patient rooms. This is to weigh the pros and cons of each room's location, thus helping stakeholders and architects to decide which patient rooms to eliminate for the new service rooms. To realistically model the unit, the simulation requires input parameters in the form of probability distributions to represent random variables (McLaughlin 2008). In this model, patients are brought in and the length of stay is set at a random exponential distribution with a mean of 14 days. The server, which represents the patient bed, is set at a capacity of 1 as only one patient can be accommodated in a room at a time. As shown in Figure 1, a node list is also created, which directs the patient randomly into the next available room. The patient bed is set to have zero output buffer as the model is to repeat the process of a patient going into the room that is unoccupied. Admission of patients will continue until all rooms are occupied.

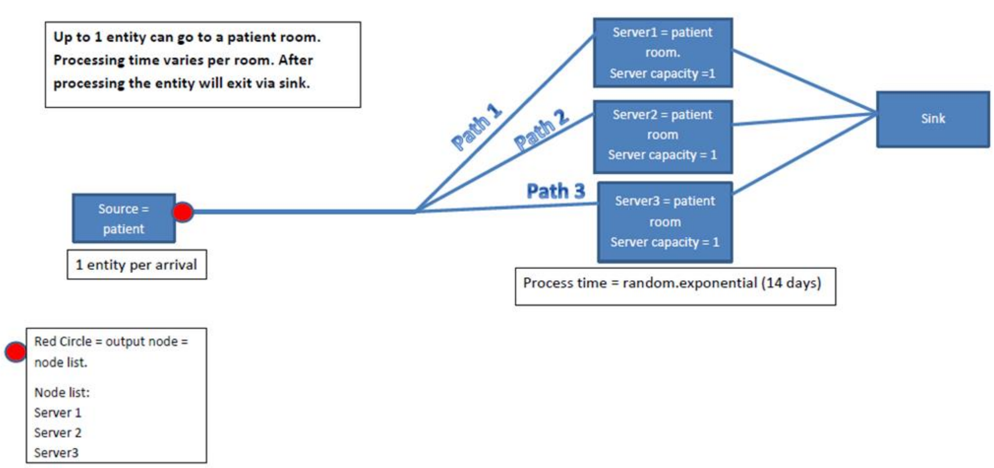
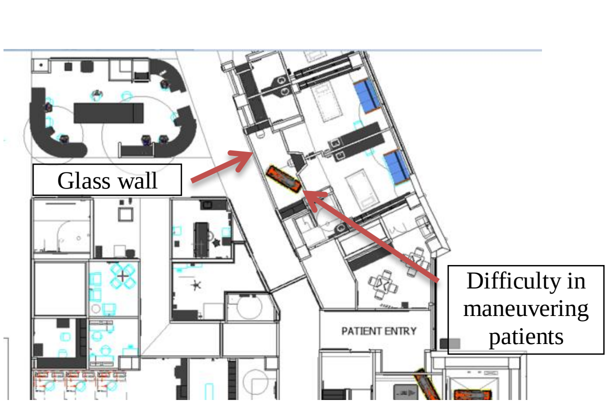


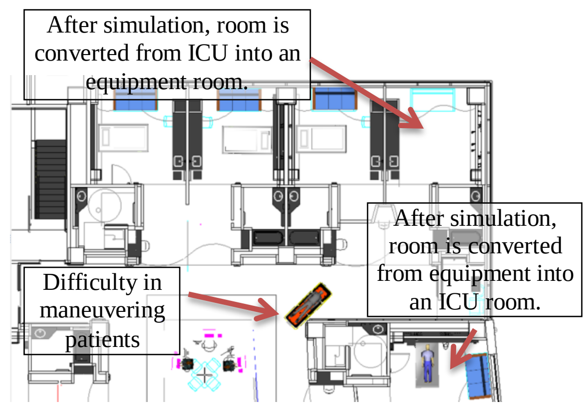
Figure 1: Patient-to-room flow diagram.

After running the simulation and viewing the 3D animation, various issues were noted. The first issue came from the isolation rooms. The existing isolation rooms are enclosed in glass, and the simulation and visualization showed the difficulty of maneuvering the beds in and out of the space (Figure 2a). As an acute care wing previously, this was never perceived as an issue as there is more time to prep for an acute care patient. However, the prep time for an ICU patient is minimal due to the severity of a patient's illness. Also, ICU patients require more equipment and having to maneuver all the equipment along with the bed would not be practical and would pose a safety concern for the patient. Since the hospital's number one priority is patient safety, the client decided to keep the existing isolation rooms as acute care rooms and not convert them into ICU rooms. Catching this decision in design saved the project an estimated $110,000 and 16 weeks of additional construction time, by eliminating the need to add medical gasses, recertify the gas lines, purchasing and installing a patient visibility window, purchasing and installing physiological monitors, and additional power and data to run all the ICU equipment. Additional time saved in re-work was eight weeks, as that is the amount of additional time that would have been needed to complete the work if this issue had not been recognized.

Maneuverability also became a concern when transporting patients to the room located in the upper right hand corner (Figure 2b). Again, after identifying potential unsafe conditions that may contribute to adverse events (Chisholm 2008), the client decided to eliminate the corner room from becoming an ICU room to avoid having to maneuver more than one patient to that corner, and opted to convert the room into an equipment room. This change subsequently caused the client to change the equipment room's original location to become an ICU room. Catching these issues in the design phase saved the project an estimated total of $85,500 and 10 weeks of re-work (8 weeks for the ICU room, and 2 weeks for the equipment room).



a) Isolation rooms



b) Corner rooms

Figure 2: Maneuverability issues

Visitor-to-Welcome Desk Simulation

The original design of the welcome desk was to convert the existing one-person desk to become a two-person desk in order to accommodate more visitors. A simulation model was developed to model the visitor-to-welcome desk process and analyze queue length and waiting time in order to evaluate the design adequacy. As shown in Figure 3, visitors are represented as the source and a path is set from the source to the server, which is the welcome desk. Once visitors are administered, they will be either directed into the family lounge or be given access to the patient room. An inter-arrival time of a visitor/visor group at 3.75/minute is assumed based on statistics obtained from a similar ICU facility. The number of visitors in a group was estimated by an experienced ICU manager and a triangular distribution with a minimum of one visitor every 60 minutes , a mean of four visitors every 15 minutes, and a maximum of eight visitors every 7.5 minutes. The processing time of the receptionist is assumed to be between 1.5 to 2 minutes per visitor group.

After comparing the simulation results of one-person and two-person design, excessive wait time never became an issue as there was never more than 4 visitors waiting to be served, which satisfies the client requirement. Therefore, it was decided that only one person would be needed to staff the welcome desk. This decision kept the project from having to accommodate an extra desk to support an additional person (Figure 3). Eliminating the unnecessary work saved the project an estimated $21,300. Six weeks were saved as many activities were eliminated: demolishing existing walls, installing flooring, counter top, millwork, and electrical system for a new computer and a phone.

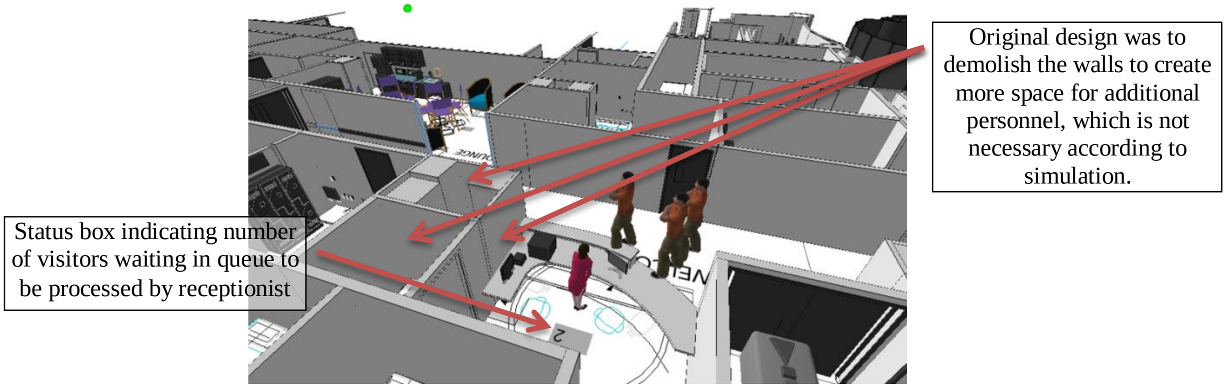


Figure 3: Welcome desk simulation in Simio

Visitor-to-Patient/Visitor-to-Family Lounge Simulation

This simulation model is twofold as it simulates a visitor's movement to either a patient room or the family lounge depending on room availability. Each patient room has a capacity of 2 visitors. If the patient room has no visitor or only one visitor, the incoming visitor at the welcome desk will be directed to the patient room. If the patient room is full, the simulation model will then redirect the incoming visitor to the family lounge. This logic is shown in Figure 4.

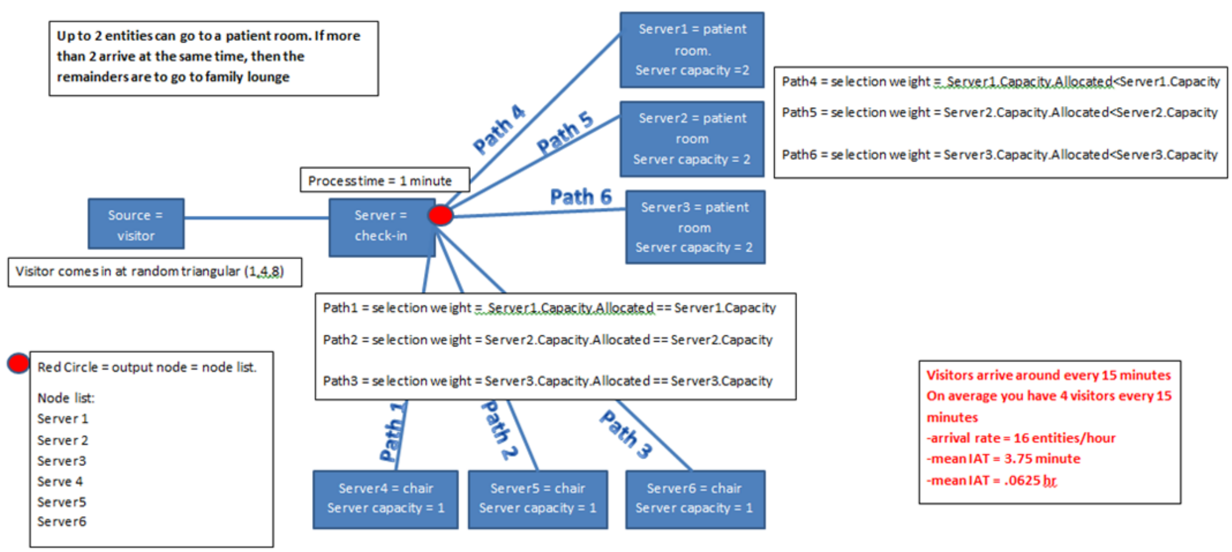
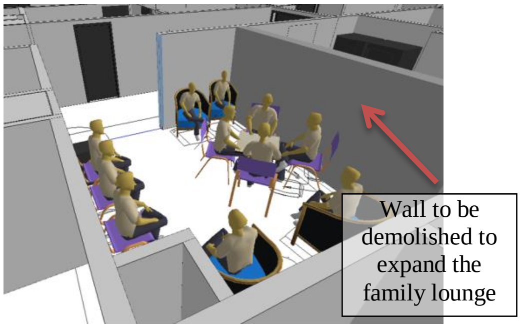
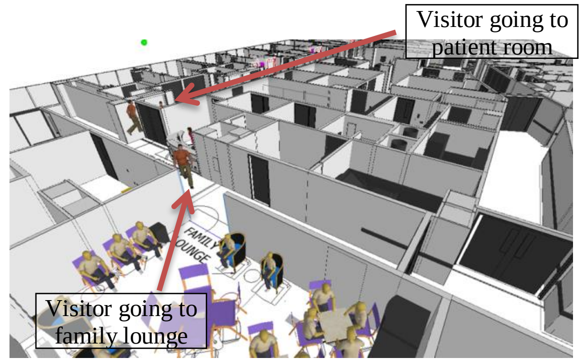


Figure 4: Visitor-to-welcome desk/visitor-to-patient room flow diagram

After running this simulation, the result indicates crowding in the family lounge as there would be up to 5 visitors waiting in the queue to be seated. Initially, the existing conference room was to be converted into the family lounge, but after seeing the number of visitors outnumbered the amount of comfortable seating capability in the family lounge, the client decided to demolish the existing office that was adjacent to the conference room in order to make a larger family lounge (Figure 5a). Making this decision was an important one because the stakeholders recognized that families who are experiencing some of the most traumatic moments of their lives need an environment that is comforting and de-stressing (Pande, 2010). Once the family lounge was made larger in the model, more servers (represented by chairs) were added and overflow is no longer an issue (Figure 5b).



a) Original lounge design



b) Visitor to patient room/family lounge simulation

Figure 5: Family lounge design and simulation

This simulation also caught another issue when visitors would enter and exit the ICU. A minor bottleneck issue occurred when visitors entered and exited the unit as the door next to the welcome desk is the primary entrance and exit for visitors. This bottleneck creates an issue of privacy and noise for the two proposed patient rooms located adjacent to the door (Figure 6). After viewing this issue, the client decided to eliminate those rooms as patient rooms and have them utilized as the respiratory work room and equipment room. Catching this during design saves an estimated total of $51,800 in cost of re-work and four weeks of additional construction time.

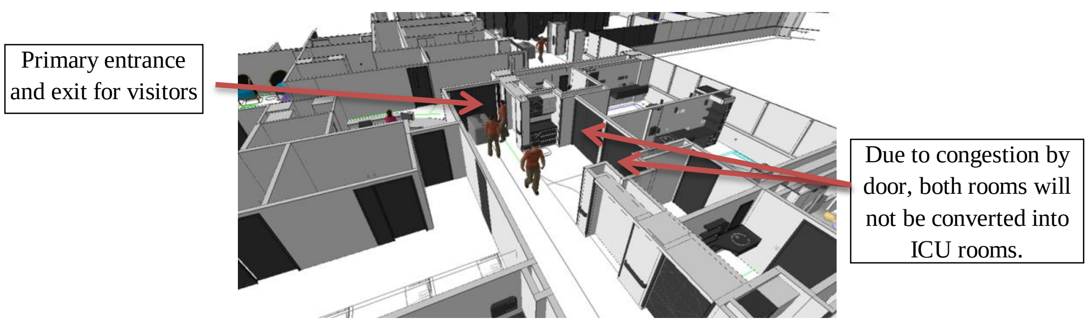


Figure 6: Entry/exit to the ICU

Results from the Completed ICU

After the above design issues were addressed, the client felt confident in proceeding with the updated design produced based on the simulation study (Figure 7). The design team then produced construction documents. After the construction permit was attainted, weekly construction meetings were held in which the stakeholders walked the space to view progress. During this process, the update design was thought to be satisfactory, and as a result, no construction changes were made. The project was completed ahead of schedule and under budget. Due to the early design changes suggested by the simulation study a total estimated cost saving of $236,100 and time saving of 34 weeks of possible wasted time was realized by eliminating possible rework.

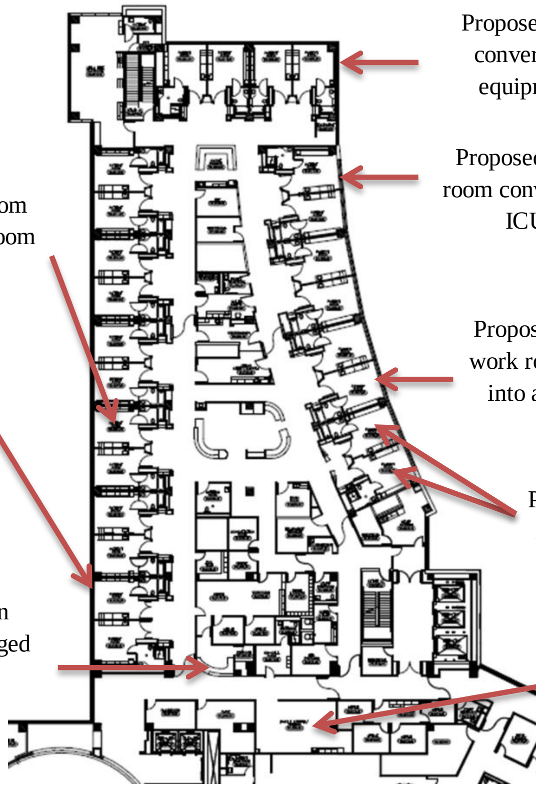
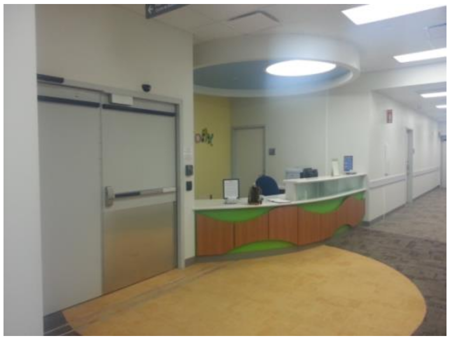


Figure 7: Final approved ICU floor plan

Figure 8a through 8e shows photos of the as-built ICU. Based on the simulation study, the family lounge was expanded from 355 square feet to 560 square feet in order to accommodate more visitors in waiting. The ICU wing has been open for about eight months and the family lounge has not experienced overflow issue (Figure 8a). After the simulation queuing analysis, the design kept the one-person welcome desk. To date, the welcome desk has not experienced any back-up in administering visitors (Figure 8b). The simulation also helped the client to visualize and determine the best locations for ICU rooms and service rooms. It avoided unnecessary changes of converting two acute care rooms to ICU rooms, thus saved time and money that could have been committed to unnecessary demolishing the millwork, and adding medical gasses along with power and data (Figure 8c). Also, by not converting some rooms into ICU rooms, the footwall was able to remain the same (Figure 8d). If the room were converted into an ICU, a patient visibility window would have been installed (Figure 8e). Not installing the patient visibility window saved money in rework necessary for relocating some electrical lines to install the window.

a) Family lounge (560 sq. ft.)



b) Existing welcome desk

c) Existing acute care headwall

d) Existing acute care footwall

e) ICU footwall

Figure 8: Photos of the completed ICU

To date, no workflow issues have been noted or expressed regarding the location of the ICU rooms, equipment rooms, or the respiratory work room. Properly locating these rooms early on saved money in construction costs, time for rework, and created a better functional space for the patients, visitors, and staff.

Conclusion

This study applied simulation and 3D visualization techniques to provide stakeholders a simulated view of an operating facility, during the design phase. This approach is demonstrated through a case study of renovating a healthcare facility. Simulation allows stakeholders to understand how a space will be used and function. Virtual simulation experiments can be conducted to verify the performance of a facility and evaluate what-if scenarios. Verifying design solutions in a simulated environment is more cost effective, faster, and practical (McLaughlin, 2008).

From the industry perspective, simulation improves communication between stakeholders and the design team and allows them to jointly identify and address design issues for design optimization. Recognizing these issues early on and making informed decision prevent catching them later in construction, thus reducing scope creep and avoiding costly change orders and rework. Ultimately, minimizing scope creep will translate into more projects being completed on time and within budget.

BIM is revolutionizing the building industry. It is replacing the 2D hand drafting tools that have long been the industry standards (Epstein, 2012). However, even though BIM and 3D visualization provide many useful functions, they can be augmented with simulation for a higher level holistic analysis of a facility design—both the space and its performance. This integration should be addressed in future research endeavor.

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