Applied Ergonomics 70 (2018) 288–299

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

# Using an integrative mock-up simulation approach for evidence-based evaluation of operating room design prototypes

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ARTICLE INFO

*Keywords:*
Operating room
Mock-up
Mock-up evaluation
Multidisciplinary design evaluation
Design communication
Simulation

ABSTRACT

This paper describes the process and tools developed as part of a multidisciplinary collaborative simulation-based approach for iterative design and evaluation of operating room (OR) prototypes. Full-scale physical mock-ups of healthcare spaces offer an opportunity to actively communicate with and to engage multidisciplinary stakeholders in the design process. While mock-ups are increasingly being used in healthcare facility design projects, they are rarely evaluated in a manner to support active user feedback and engagement. Researchers and architecture students worked closely with clinicians and architects to develop OR design prototypes and engaged clinical end-users in simulated scenarios. An evaluation toolkit was developed to compare design prototypes. The mock-up evaluation helped the team make key decisions about room size, location of OR table, intra-room zoning, and doors location. Structured simulation based mock-up evaluations conducted in the design process can help stakeholders visualize their future workspace and provide active feedback.

## 1. Introduction

Operating rooms (ORs) present high-risk to physicians and other clinicians. Thus, their design requires a deep understanding of the roles of clinical stakeholders, critical care processes, technology, and equipment utilized during care as well as the myriad technical aspects of the healthcare building process itself. A recently published literature review highlights a range of built environment problems in ORs including contaminated surfaces, inadequate workspaces, poor adjacencies, trip and bump hazards, poor furniture and equipment ergonomics, loud noises and uncomfortable work environments (Joseph et al., 2017). These environmental factors contribute to a range of adverse outcomes during surgery including injury to staff, flow and task disruptions during surgery and surgical site infections.

Many of these problems can be avoided or mitigated through a careful and shared understanding of the work systems that includes the organization, people in the space, required tasks, technology and equipment, and the built environment. The built environment is a critical component of the healthcare system and has the potential to impact patient and staff safety and quality of care. Decisions made during the healthcare facility design process have the potential to create latent conditions that may adversely impact work practices of clinicians and contribute to adverse outcomes (Joseph and Rashid, 2007; Reason, 2000). The 2014 Guidelines for Design and Construction of Hospital and Outpatient facilities recommends a safety risk assessment (SRA) as part of any healthcare project (Facility Guidelines Institute, 2014). The SRA is intended to be a multi-disciplinary process that engages team members (including architects, clinicians, patient advocates, and risk managers) in a discussion about key design decisions that may have an adverse impact on outcomes such as patient falls, healthcare acquired infections, and medical errors (Taylor et al., 2014).

It is absolutely critical for healthcare facility design teams to proactively evaluate the impact of key design decisions before facilities are built to avoid unsafe and unhealthy spaces that are harmful for patients and staff (Reno et al., 2014). However, it is hard for clinicians to imagine these complex interactions in a future state through reviews of building plans and perspectives that are typically used to communicate proposed design to end-users. While there are many different ways of engaging teams during the design process, evaluations of physical mock-ups have been shown to be particularly effective in

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https://doi.org/10.1016/j.apergo.2018.03.011
Received 25 August 2017; Received in revised form 8 December 2017; Accepted 16 March 2018

identifying and remediating potential safety concerns (Taylor et al., 2014), as they improve understanding and communication between healthcare providers and designers (Keys et al., 2016).

As such, mock-ups are increasingly being used in the healthcare facility design process to support and validate design decisions. Mock-ups are defined as full-scale models of a design that are used for teaching, demonstration, evaluation, or other purposes to enable testing of a design (HQCA, 2016). Simulation-based mock-up evaluation involves testing various aspects of a proposed design by simulating clinical scenarios or enactment of relevant clinical tasks (HQCA, 2016).

The Health Quality Council of Alberta (HQCA) has published a framework for conducting simulation based mock-up evaluations during the healthcare facility design process (HQCA, 2016). The HQCA framework puts forth a systematic approach for collecting and analyzing data from full scale-mock-ups using simulation. This framework includes recommendations on timing and planning for the mock up, construction of the mock-up, development of scenarios, running the evaluations as well as analyzing the evaluations to obtain evidence-based feedback for design. However, this framework does not include specific tools or methods for conducting the evaluation or for developing design recommendations to support an iterative design process.

The current study builds upon the HQCA framework to develop protocols and evaluation tools that were utilized while conducting simulation-based mock-up evaluations to test a range of design ideas. This work was conducted as part of a four-year multidisciplinary patient safety-learning lab focused on designing safer and more ergonomic ORs. The findings from this learning lab, including the prototype OR design, are informing the development of two new ambulatory surgical centers (pediatric and orthopedic) for the health system partner on this project. The purpose of this paper is to present the protocols and tools developed to evaluate prototype OR designs and to present the findings from this process.

## 2. Methods and procedures

To evaluate OR design prototypes, an evaluation toolkit was developed based on the mock-up evaluation framework from the Health Quality Council of Alberta (HQCA, 2016). The HQCA framework includes six guiding principles:

1. A simulation-based mock-up evaluation should be considered, and if applicable, planned, as part of the pre-design stage for inclusion in the design stage.
2. The mock-up evaluation should be thoroughly planned to maximize effectiveness.
3. Building of the mock-up should align with evaluation timing and objectives.
4. Roles and responsibilities for those involved in the evaluation should be clearly defined.
5. The simulation scenarios that are created and enacted should test the evaluation objectives.
6. Recommendations should be informed by evidence-based data from scenario enactments.

The HQCA framework was expanded and customized for the current project based on the specific objectives around OR design. The mock-up evaluation protocol was also designed to facilitate the maximum involvement and input from the surgical teams that might eventually use the spaces being designed. The key steps that were undertaken based on the HQCA framework include:

- Timing and planning
- Tool development
  - o Overall goals
  - o Master protocol
  - o Note Taker's template
  - o Simulation director guide
- Constructing the physical mock-up and conducting the simulations
- Evaluation: Conducting the mock-up evaluation with clinicians

### 2.1. Timing and planning

The research findings from the first year of the learning lab were used to create a knowledge base document to support a design project focused on OR design. This document includes a literature review on OR environments, OR workflows, and best practice case studies, to understand roles and workflows for all key surgical personnel. Second year graduate Architecture students were tasked with working with this multidisciplinary learning lab team to develop evidence-based design solutions for an innovative, safe, operationally efficient, and flexible OR that could fit any OR suite configuration. The design project began with a multidisciplinary design workshop, which included students, the multidisciplinary learning lab team, and national experts in architecture and healthcare. In this workshop a systematic brainstorming session about the OR environment was conducted to facilitate exploration of ideas through structured questions and answers on post-it notes. Architects and clinicians helped students think through the issues pertaining to the OR and how those issues may be addressed through potential solutions.

The team of researchers and educators determined the scope of the mock-up construction and evaluation as two phases (tape-on-the-floor and cardboard mock-up) as well as parallel iterative mock-up evaluation phases in a semester-long studio course. The studio project predetermined the timing of the mock-up in consideration with conceptual design, design development, and design strategies refinement phases.

Parallel to the studio assignment, the research team developed a systematic simulation-based mock-up evaluation protocol to support the iterative evaluation of the proposed designs in a timely manner to facilitate the next round of design strategies refinements.

### 2.2. Tool development: developing an evaluation protocol to obtain clinician input

#### 2.2.1. Overall goals

The first and most critical step in developing the evaluation tool for the mock-up simulations was to establish key design guidelines based on the research objectives to guide the development and evaluation of design prototypes. Using the evidence base that was developed prior to the workshop, the input from the brainstorming session as well as additional literature reviews and case studies of surgery centers, the students developed a set of overarching objectives and evidence-based design guidelines to support the design process. . The design guidelines included five overarching goals (see Fig. 1):

- optimize the ability to change over time
- optimize sustainable strategies
- optimize clinical outcomes and health & safety
- optimize positive experience for all users
- optimize efficiency

Each of the 9 evidence-based design workshop are linked to one or more goals and address key aspects of OR design that impact workflow, disruptions, and other safety concerns, such as surface contamination (Fig. 1). The design guidelines were stated such that they could be achieved through implementation of one or more design strategies.

The design strategies that were evaluated (evaluation objectives) had to align with the design phase and mock-up fidelity; therefore, some of them were repeated across three rounds of evaluation and some were phase-specific. Also, the evaluation tool evolved with each consecutive mock-up phase to better respond to the evaluation objectives and mock-up fidelity. Table 1 shows how the overall goals and evidence-based design guidelines that were developed, the rationale for