



# Interprofessional Simulations to Inform Perioperative Facility Planning and Design

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**OBJECTIVE:** The purpose of this study is to report our experience with interprofessional simulations, executed in a mock-up of a proposed perioperative space, that were designed to elicit valuable end-user feedback on the design of the perioperative space.

**DESIGN:** A styrofoam, life-sized model of a perioperative unit was constructed. Various medical professionals and support staff participated in interactive sessions, including workflow simulations, and provided feedback on the perioperative design. Based on participant feedback, the perioperative design was modified, and the styrofoam model was re-constructed. A second round of sessions was conducted, and the change in participant feedback was analyzed.

**SETTING:** This study took place under the auspices of the University of Pennsylvania in Philadelphia, Pennsylvania, within Penn Medicine.

**PARTICIPANTS:** One-hundred and ninety-three medical professionals and front line operating room staff participated in the initial round of interactive sessions, and 134 participated in the second round (after re-construction).

**RESULTS:** In the first round of simulations and interactive sessions, participants spent 560 hours engaging with the space. Modifications were then made to the perioperative design based on participant feedback, and a second round was conducted, in which participants spent 403 hours in the space. Floor plans for round 2 show significant changes compared with round 1, and mean design satisfaction scores for round 2 ( $3.78 \pm 0.41$ ) were significantly higher than for round 1 ( $3.61 \pm 0.49$ ) ( $p = 0.02$ ). The quality of feedback was associated with the type of interactive session the user participated in.

**CONCLUSIONS:** This study suggests that simulations and other interactive sessions, when executed in a mock-up of a proposed perioperative space, can elicit valuable end-user feedback that impacts the final design of the perioperative space and that would traditionally

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**KEY WORDS:** simulation, mockup, design, perioperative, end-user

**COMPETENCIES:** System Based Practice, Interpersonal and Communication Skills

## INTRODUCTION

A growing body of evidence supports the notion that the physical layout of a hospital has a major influence on clinical outcomes and on patient and staff safety.<sup>1,2</sup> For example, patient room design directly impacts the frequency of nosocomial infections.<sup>1</sup> Although the design of a healthcare space contributes to acute failures by healthcare providers, it is rare that system-centered solutions, rather than solutions focusing on provider behavior, are implemented.<sup>3,4</sup> Even when system-centered solutions (e.g. changing the architectural layout of a room) are sought, implementing them is often prohibitively expensive.<sup>5</sup>

The relationship between outcomes and healthcare facility architecture is readily apparent in perioperative spaces. The ramifications of the architectural design of an operating room (OR), in terms of both patient safety and economic burden, can be enormous.<sup>6,7</sup> OR time is expensive, and the average incremental OR profit per procedure is approximately \$1500 per hour.<sup>8</sup> By improving a single OR's design to increase throughput, hospitals can increase profit by hundreds of thousands of dollars per year.<sup>6,9</sup> However, it is often difficult to identify design modifications within an OR that would increase throughput and reduce safety threats until end-users perform their actual workflow in the OR itself.<sup>10</sup> Therefore, an ideal perioperative design process would find a way to gain end-user feedback at a stage where design modifications are still relatively cheap and practical.

Historically, other industries (e.g. aerospace) have used simulations and mock-ups to achieve this end, and more recently those in healthcare design have begun to do the same.<sup>11,12</sup> Mock-ups are physical representations of real-life settings, which allow stakeholders to interact with the setting and provide feedback, allowing designers to subsequently modify the setting in a short inception-revision cycle.<sup>13</sup> In healthcare design, full-scale mock-ups of patient rooms have been built to evaluate proposed room designs before construction begins, with favorable results.<sup>14,15</sup> For example, as a result of the mock-up process, one group changed the location of the hand sanitizer to significantly increase compliance with hand-hygiene policies.<sup>15</sup>

The purpose of this study is to demonstrate the feasibility and utility of constructing a mock-up of a proposed perioperative space. By conducting simulations and other interactive sessions in the mock-up space, we aim to demonstrate that valuable end-user feedback can be gained, and this feedback can subsequently be used to impact the design of perioperative spaces within a new hospital setting.

## METHODS

### Construction of the Mock-up

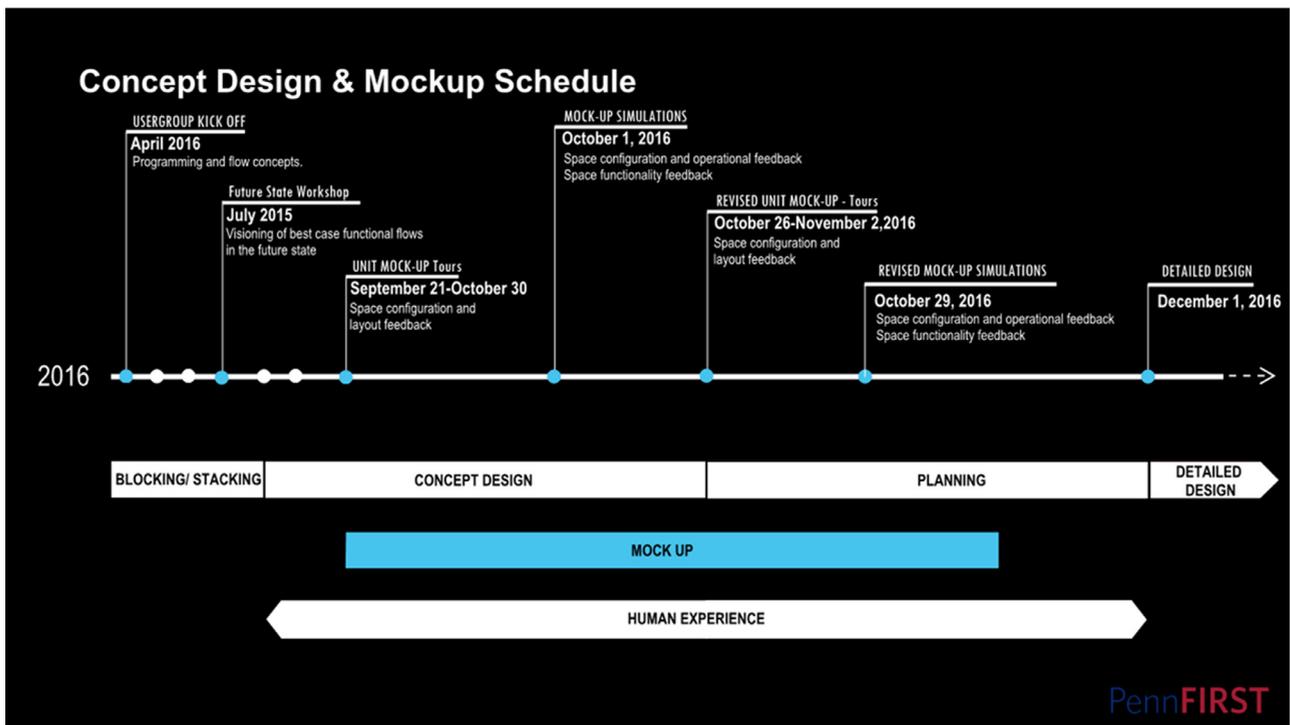
Our large, metropolitan, academic health system employed two design firms, one engineering firm and a joint venture of two construction firms to assist in designing a new hospital. Over the course of several months (Fig. 1), and with stakeholder input, a preliminary floorplan of the hospital was developed. Each patient floor in the new hospital was to be 64,000-square foot and consist of two, mirrored 32,000-square foot units placed end-to-end (Fig. 2). Based on the floorplan created by the inpatient floor, a full-scale, 32,000-square foot mock-up of a composite of three OR floors was constructed in a large warehouse that served as a testing environment to evaluate the feasibility and functionality of the proposed design.

This 32,000-square foot, full-scale, three-dimensional mock-up was erected using styrofoam and was built to the specifications of the architectural floor plans. The physical space was further equipped with real OR equipment (Fig. 3). The mock-up floorplan was a composite representation of key perioperative spaces, procedure rooms, and their relationships with critical areas such as travel corridors, elevator bays, control rooms, the visitor waiting room, consult rooms, and a sterile core.

The floor design of the mock-up was modular, such that one floor plan could be tailored to serve as any floor in the new hospital regardless of which departments were housed on which floors after final construction. Nine designated zones of interest were identified for the generic floorplan, which would be common to every floor regardless of occupancy: (1) Waiting Room, (2) Communication Station, (3) Prep, Post Anesthesia Care Unit (PACU) and Recovery (Configuration A), (4) Prep, PACU and Recovery (Configuration B), (5) Multipurpose Room, (6) Clinical Support Area, (7) Clean Core, (8) Operating and Procedure Rooms, and (9) Staff and Team Space (Fig. 2).

### Interactive Sessions and Data Collection

Over a six-week time period following construction of the mock-up (September 21, 2016 to November 3,



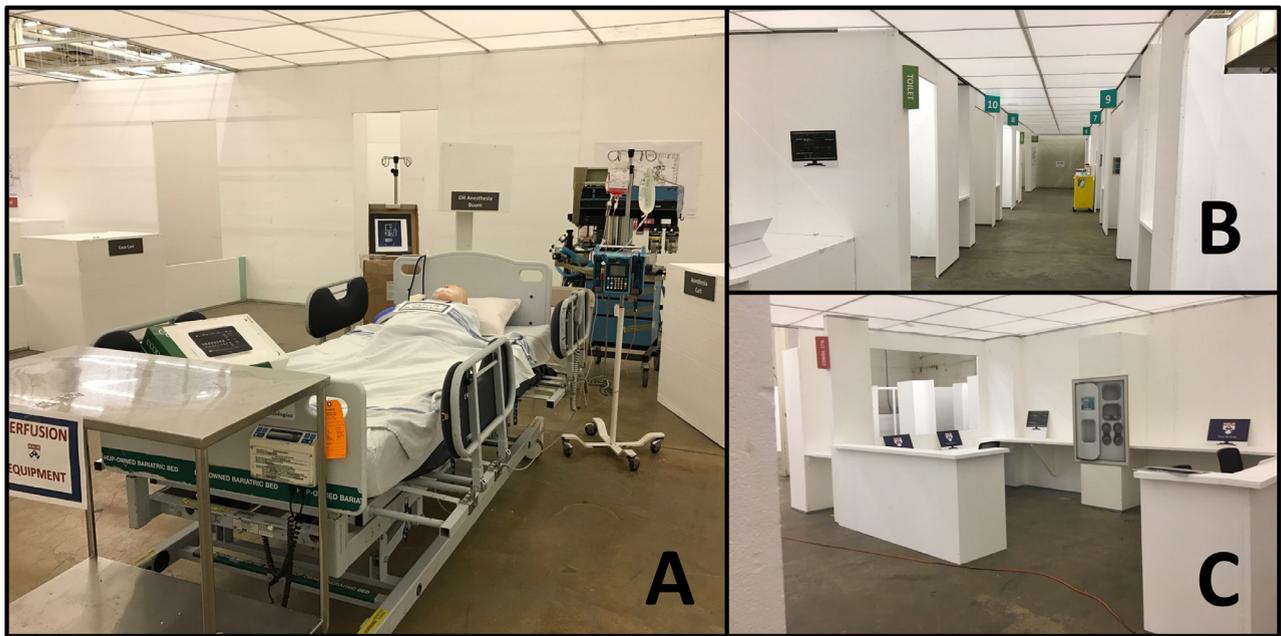
**FIGURE 1.** Design process timeline. Representing the steps and timing of the complete process.

2016) twelve interactive sessions were held to gain end-user feedback on the new perioperative construction design. The interactive sessions consisted of guided tours (GT), facilitated experiences (FE), and simulated case scenarios (SCS). There were four sessions of each type (GT, FE, and SCS), and each session had a duration of one to four hours. The twelve interactive sessions were divided into two rounds. The first round of sessions lasted from September 21, 2016 until October 1, 2016. At this time, the design team comprehensively

categorized and interpreted over 7000 data points collected from participant feedback. All participant comments were categorized by mock-up zone, tone, and event. Based on this feedback, a revised floorplan was developed, and the mock-up was renovated to reflect the new modified design. The second round of sessions took place in the renovated mock-up, and took place from October 26, 2016 to November 3, 2016, with a similar data collection process employed to enable the planning and design team to further modify the layout and



**FIGURE 2.** Blueprints of Mockup round 1 and round 2. (A) illustrates the mock-up design of round 1 with the nine designated zones of interest: 1. Waiting Room, 2. Communication Station, 3. Prep, Post Anesthesia Care Unit (PACU) and Recovery (Configuration A), 4. Prep, PACU and Recovery (Configuration B), 5. Multipurpose Room, 6. Clinical Support Area, 7. Clean Core, 8. Operating and Procedure Rooms, and 9. Staff and Team Space. (B) illustrates the mock-up design of round 2 (B) with the five major zones that required substantial modification based on the feedback received: 1. Waiting Room, 2. Prep, PACU and Recovery, 3. Inpatient Elevators, 4. Cardiac Catheterization and Electrophysiology Lab Control and Clean Core, and 5. Staff and Team Space.



**FIGURE 3.** Real mockup space. (A) OR before simulation sessions; (B) hallway to patient rooms; (c) nurse station with pneumatic tube.

plans of the proposed new OR space. All three engagement modalities (GT, FE, and SCS) were used in rounds 1 and 2. Detailed schedules are given in Fig. 4. All interactive sessions began with an introduction to the mock-up and design project, and data collection occurred throughout the sessions as described below.

### Guided Tours

All OR employees, including executives, physicians, administrators, nurses, allied health care providers, and non-clinical roles (e.g. environmental and transport service employees), were invited by email to participate in one of four scheduled GTs of the newly erected mock-up space. Participants were provided with a brief tour of the space (approximately one hour) and then completed an on-site survey before leaving the warehouse to offer feedback on the feasibility and functionality of performing their job in the proposed design.

### Facilitated Experiences

FE sessions were targeted for perioperative leadership, faculty, and administrators. Participants were divided into interprofessional groups and paired with a facilitator who provided a structured tour and hosted mini focus groups to address specific design questions within each designated area, such as the optimal waiting room configuration. One recorder accompanied each tour and focus group in order to write down evaluative comments made by the team members regarding the design

of the space. Additionally, Post-it<sup>R</sup> notes were supplied at designated checkpoints for participants to write down any positive or negative feedback they may have had. Finally, participants completed an on-site survey before leaving the warehouse to offer feedback on the proposed design.

### Simulated Case Scenarios

Specific groups of providers involved in perioperative clinical and non-clinical roles were recruited to perform SCSs in the mock-up during scheduled times over a two-month time period. These providers were given dispensation from their normal work duties during these times and were bussed to and from the warehouse. They were grouped into interprofessional teams and asked to complete specific SCSs within the mock-up space.

The SCSs were developed and carefully designed to reflect real OR situations and workflows of the providers. These scenarios were created by an interprofessional team including senior OR managers and physicians with extensive clinical experience. The goal was to provide team members with the opportunity to interact with their colleagues just as they would during emergent and non-emergent daily tasks in a real clinical environment, and ask them to evaluate how well the design of the new hospital facilitated their ability to perform their tasks.

Data were collected in the same way as it was during FEs (recorders, Post-it<sup>R</sup> notes (voluntary comments), and

Date	Modality	Length	Clinical Focus Area	Roles	# of participants
<b>Round 1 - Simulation Schedule (193 participants)</b>					
9/21 & 9/28	Facilitated Experience (FE)	3 hrs	Perioperative	Faculty, Leadership and Administration: Surgery, Anesthesia, Perioperative Nursing & Support Services	74
9/22, 9/26 & 9/29	Guided Tours (GT)	2 hrs	Perioperative	Anesthesia Tech, AV Specialist, EVS, Instrument Processing, Intraoperative Monitoring, Nursing Coordinator, Perioperative Nursing, Perfusion, Pharmacist, Pharmacy Tech, Supply Chain/Inventory, PeriOp Facilitator, Service Partner, Surgical Support Associate, Technical Officer, Transport, Manager, Educator	69
10/1	Case Scenarios (CS)	4 hrs	Perioperative	Anesthesia Tech, AV Specialist, EVS, Instrument Processing, Intraoperative Monitoring, Nursing Coordinator, Perioperative Nursing, Perfusion, Pharmacist, Pharmacy Tech, Supply Chain/Inventory, PeriOp Facilitator, Service Partner, Surgical Support Associate, Technical Officer, Transport, Manager, Educator	50
<b>Analysis/Planning → Design/Redesign → Build/Rebuild</b>					
<b>Round 2 – Modified Design Simulation Schedule (134 participants)</b>					
10/26 & 11/2	Facilitated Experience (FE)	3 hrs	Perioperative	Same as 9/21 & 9/28	45
10/27 & 11/3	Guided Tours (GT)	2 hrs	Perioperative	Same as 9/22, 9/26 & 9/29	44
10/29	Case Scenarios (CS)	4 hrs	Perioperative	Same as 10/1	45

**FIGURE 4.** Mock-up schedule. This figure illustrates in detail the type, duration and dates of the interactive sessions, as well as the type of participants and total number of participants in round 1 and round 2.

on-site surveys). Additionally, eleven cameras were strategically placed throughout the mock-up to record audio-visual data of the providers, performing their workflows. Finally, the SCSs added a large debriefing session led by facilitators after the case scenarios were complete, and this discussion was recorded by multiple recorders.

### Embedded Observation Method

Facilitators and recorders in the FEs and SCSs included licensed health care professionals, designers, and architects, as well as process improvement and simulation specialists. Facilitators asked targeted questions during focus groups and debriefing sessions to solicit responses regarding areas of interest to the design team, including (1) orientation and adjacency of rooms; (2) accessibility of spaces and equipment involved in key processes such as case preparation and room turnover; (3) facilitation of processes such as case preparation and room turnover; (4) mobilization of patients, visitors, staffing, and equipment resources at peak times and during emergencies including elevator size and position; (5) flow of patients, visitors, and staff along critical and frequented paths; and (6) adequacy of shared amenities such as natural light, waiting, and consult rooms, teaming spaces, bath-rooms and break rooms.

The on-site survey given to all participants at the end of their interactive sessions was developed based on the The Messick Validity Framework<sup>16</sup> and comprised 33 questions in round 1 and 22 questions in round 2. Nineteen questions were shared in common between the two surveys (Table 1) that were used to evaluate the efficacy of involving end user feedback for the design of a new perioperative healthcare facility.

### Design and Redesign Process

The design team sought to align the wants, needs, and visions conveyed by staff with evidence-based healthcare facility design principles, established healthcare facility building codes and regulations, and the projected needs of the future of healthcare. Multiple iterations of the perioperative design were drafted, vetted, and refined via multi-disciplinary future state workshops and planning sessions with perioperative leadership before inviting frontline staff to experientially evaluate the space with simulation. Furthermore, shared design elements such as elevator location and building footprint had already been determined by the predetermined inpatient unit design.

Following the conclusion of mock-up round one, the design team spent approximately 3.5 weeks analyzing the participant data and revising the mock-up accordingly. The first iteration of perioperative mock-up

**TABLE 1.** Overlapping Survey Questions and Survey Results from Mockup Rounds 1 and 2

<b>19 overlapping survey questions</b>	<b>Round 1 n = 119 (mean ± SD)</b>	<b>Round 2 n = 72 (mean ± SD)</b>	<b>p value</b>
1. The designed layout of the Waiting Area offers enough variety to accommodate different activities for families/visitors	3.24 ± 1.05	3.90 ± 0.73	<0.001*
2. The central location of the Ptube station is easily accessible for all Pre-Op and Post-Op needs	3.41 ± 0.96	3.43 ± 0.82	0.808
3. The central location of the POC station is easily accessible for all Pre-Op and Post-Op needs	3.51 ± 0.81	3.32 ± 0.93	0.285
4. The transaction counter shown allows for approachability and visibility to the Comm. Station	3.54 ± 0.73	3.72 ± 0.60	0.081
5. The central location of the Trash Chute and Soiled Holding is easily accessible for all Pre-Op and Post-Op needs	3.59 ± 0.81	3.79 ± 0.59	0.199
6. The locations of Touch Down stations in the Prep/Recovery area give appropriate coverage	3.52 ± 0.81	3.59 ± 0.82	0.541
7. The patient has adequate access to toilets	3.45 ± 0.84	4.09 ± 0.67	< 0.001*
8. The P/P/R room size is appropriate for patient care	3.70 ± 0.86	3.93 ± 0.80	0.083
9. This bay is functional for Prep, PACU/Recovery and 24 Hour Short Stay Care	3.70 ± 0.83	4.00 ± 0.60	0.045*
10. The Pharmacy is easily accessible from the P/P/R Area	3.34 ± 0.87	3.53 ± 0.73	0.196
11. The Pharmacy is accessible from the ORs/Sterile Core Area	3.18 ± 0.95	3.55 ± 0.78	0.018*
12. The Clean Room is easily accessible from the P/R/R Area	3.57 ± 0.81	3.75 ± 0.69	0.180
13. The ORs are easily accessible to the Prep/Recovery Area	3.91 ± 0.66	3.93 ± 0.64	0.952
14. The designed layout for the Team Space allows for a variety of functions including: express breaks, collaboration, conferencing, library study, respite, and dining	3.37 ± 1.07	3.78 ± 0.99	0.015*
15. The EVS room is sized appropriately for each OR pod	3.49 ± 0.66	3.75 ± 0.53	0.019*
16. The design will provide a positive experience for: Patients	4.11 ± 1.07	4.11 ± 0.80	0.948
17. The design will provide a positive experience for: Families/Visitors	4.11 ± 0.67	4.10 ± 0.82	0.970
18. The design will provide a positive experience for: Staff	3.84 ± 0.82	3.75 ± 0.84	0.355
19. The SIM Session has enabled evaluation of the physical layout of the space	4.30 ± 0.81	4.20 ± 0.75	0.459
Total	3.61 ± 0.49	3.78 ± 0.41	0.024*

Ptube: Pneumatic Tube; Pre-Op: Preoperative; Post-Op: Postoperative; POC: Point of Care; Comm: Communication; P/P/R: Prep, PACU, and Recovery; PACU: Post-Anesthesia Care Unit; ORs: Operating Rooms; EVS room: Environmental Services.

Responses were rated on a scale of 1 to 5; 1: strongly disagree, 2: disagree, 3: neutral, 4: agree, 5: strongly agree.

\*Statistically significant p value.

simulations yielded consistent feedback by participants for revision of certain design elements, including visibility in prep and recovery areas, elevator door and cab size, configuration of interventional cardiology control rooms, and teaming spaces. The volume of data collected also consisted of changes requested by some end-users that conflicted with changes requested by others. Thus, the design team had to prioritize certain data points over others in deciding how to revise the mock-up.

The methodology guiding this prioritization was based on the Health Quality Council of Alberta's Simulation-Based Mock-up Evaluation Framework.<sup>17</sup> This framework offers widely accepted, evidence-based guidelines on how to collect and analyze data from mock-up healthcare environments. In brief, priority is given to patterns that emerge across multiple data collection modalities, rather than to individual data points. For example, if

participants provided verbal feedback identifying a particular problem (e.g. "the hallways are too narrow"), and this same problem was manifested in observational data (e.g. delays in workflow were observed during simulations because the hallways were too narrow to allow rounding teams to pass each other without disassociating and interrupting the flow of conversation), then addressing that problem in the revised design was prioritized over addressing problems that were present in only a single data collection modality.

## Data Analysis

Qualitative data were categorized from objective written, video, and audio recordings using a standardized methodology, which aids the construction of the modified design. To enhance reliability during data collection and ensure standardization, the project team used

**TABLE 2.** Summary Table of Feedback, by Modality

	All modalities (mean ± SD)	Guided tour (mean ± SD)	Facilitated experience (mean ± SD)	Case scenario (mean ± SD)	p value
Survey response rate (n = 191)	57%	41%	44%	92%	< <b>0.001*</b>
Voluntary comments (n = 191)	36%	11%	44%	42%	< <b>0.001*</b>
Mean overall survey score round 1 (n = 119)	3.61 ± 0.49	3.82 ± 0.47	3.56 ± 0.54	3.49 ± 0.39	<b>0.014*</b>
Mean overall survey score round 2 (n = 72)	3.78 ± 0.41	3.71 ± 0.38	3.90 ± 0.38	3.79 ± 0.40	0.465

Overall survey score refers to the average score of all 19 survey questions (range for each question, 1-5) for each participant. Presented in this table is the mean of the overall survey scores for all participants. Survey responses were rated on a scale of 1 to 5; 1: strongly disagree, 2: disagree, 3: neutral, 4: agree, 5: strongly agree.

\*Statistically significant p value.

expert facilitators and observers that included licensed architects and credentialed process improvements experts who were embedded in all aspects of the study. Data were analyzed using the simulation-based mock-up evaluation framework developed by the Health Quality Council of Alberta (HQCA).<sup>17</sup> Statistical analysis was performed to analyze proportional and mean differences. Proportional differences were analyzed using chi-square tests. Mean differences were analyzed using Kruskal–Wallis test for nonparametric data. A p value <0.05 was considered statistically significant. All statistical analyses of quantitative data were performed using STATA version 14.0 IC (College Station, Texas). This was approved as a quality improvement initiative by the University of Pennsylvania Institutional Review Board.

## RESULTS

A total of 193 participants took part in the interactive sessions (GT, FE, and SCS) of round 1 (before renovation of the mock-up). These participants spent 560 participant-hours (1 participant spending 1 hour in an interactive session equals 1 participant-hour) evaluating the mock-up. In the second round of interactive sessions, 134 providers spent 403 participant-hours in the space, for a total of 963 participant-hours spent evaluating the floor plan mock-up. The breakdown of participants by interactive session modality is given in Fig. 4.

**TABLE 3.** Survey Responses to Select Questions

Question	Strongly agree or agree	
	Round 1 (n = 119) (%)	Round 2 (n = 72) (%)
This simulation session enabled evaluation of the physical layout of the space	97	88
The design will provide a positive employee experience	73	76
The design will provide a positive patient experience	87	91
The design will provide a positive visitor experience	85	94

## Survey Results

The overall response rate for the end-of-session on-site survey across all interactive modalities in both rounds was 57% (61% and 53% in round 1 and round 2, respectively). There was a significant difference in the response rates across the three interactive session groups, with the SCS group having the highest response rate (Table 2). The study team also examined the active voluntary comments provided across the three modalities in order to assess the level of engagement for each. There was a statistically significant difference in the voluntary comments across the three groups, with GT participants showing the lowest response rate (Table 2).

In mock-up round 1, 97% of participants strongly agreed or agreed that the sessions enabled evaluation of the physical layout of the space, and 88% said the same in round 2. The participants were asked if they believed the design would provide a positive experience for employees, patients, and visitors. Seventy-three percent of participants in mock-up round 1 and 76% in mock-up round 2, thought the design would provide a positive employee experience (Table 3).

The floor plans for mock-up round 2 show significant changes when compared with mock-up round 1, demonstrating that the input from the employees impacted the design (Fig. 2). Participants rated the overall design of the healthcare space on a five-point scale (5 was the highest score and 1 was the lowest). The overall score

**TABLE 4.** Survey Results by Modality

Modality	Mean overall survey score round 1 n = 119 (mean ± SD)	Mean overall survey score round 2 n = 72 (mean ± SD)	p value
Guided tour	3.82 ± 0.47	3.71 ± 0.38	0.268
Facilitated experience	3.56 ± 0.54	3.90 ± 0.38	<b>0.035*</b>
Case scenarios	3.49 ± 0.39	3.79 ± 0.40	<b>0.003*</b>
All modalities	3.61 ± 0.49	3.78 ± 0.41	<b>0.024*</b>

Overall survey score refers to the average score of all 19 survey questions (range for each question, 1-5) for each participant. Presented in this table is the mean of the overall survey scores for all participants in round 1 and round 2. Survey responses were rated on a scale of 1 to 5; 1: strongly disagree, 2: disagree, 3: neutral, 4: agree, 5: strongly agree.

\* Statistically significant p value.

(mean ± SD) given by participants in all modalities combined was 3.61 ± 0.49 after round 1. After mock-up round 2, the average overall score increased to 3.78 ± 0.41, showing statistical significance ( $p = 0.024$ ). (Table 4).

Subgroup analysis revealed that overall design scores from round 1 to round 2 did not significantly change for GT participants, but significantly increased for FE and simulated case scenario participants. Scores from round 1 to round 2 increased in the FE group from 3.56 ± 0.54 to 3.90 ± 0.38 ( $p = 0.035$ ), and from 3.49 ± 0.39 to 3.79 ± 0.40 ( $p = 0.003$ ) in the simulated case scenario group (Table 4).

Mean scores (scale of 1-5) of all participants for the 19 questions common to round 1 and round 2 on-site surveys were evaluated. The difference in mean score between round 1 and round 2 for all modalities was statistically significant for six of 19 questions, and in each case the score improved (Table 1). Subgroup analysis revealed a statistically significant difference in the mean score from round 1 to round 2 of only one (5%) of the 19 questions for the GTs, four (21%) of the 19 questions in FE, and seven (37%) of the 19 questions in simulated cases scenarios.

## DISCUSSION

This study presents three interactive sessions, including a simulation-based methodology, which utilized an extensive architectural mock-up in order to gain end-user feedback on the design of a new perioperative space. This study demonstrates that the methodology employed herein allowed end-users to generate valuable input that had a substantial impact on the final perioperative space design that would otherwise be difficult to obtain until after final construction. Additionally, results of this study suggest that the quality of the received feedback was impacted by the depth of immersion a participant experienced through the different interactive sessions.

The methodology presented herein adds to traditional pre-construction design approaches, such as hosting end-user meetings and testing performance and function via virtual or miniaturized representations of the finished product. These traditional methods are often ineffective for engaging end-users as change agents and limit opportunities to improve current processes upfront.<sup>18,19</sup> Other groups have identified the need for a multidisciplinary approach, but how to best engage team members from various disciplines in the design process remains unclear.<sup>20</sup> There is precedent in the literature to suggest that latent environmental threats can negatively impact patient care and staff efficiency, and that they are often discovered only after final construction when providers are performing their workflow in the designed space.<sup>10</sup> A recent direct observational study in a cardiothoracic OR shows that present-day ORs are inefficient and overcrowded, and the turnover between cases is often lengthy and variable. By using detailed architectural diagrams, the authors were able to clearly demonstrate the unique role that OR design and equipment layout has on the generation of physical layout flow disruptions, leading to patient harm.<sup>7</sup> Others have seized on this idea and devised a way to gain valuable end-user input before construction of a new facility takes place: by using mock-ups, or full-scale replicas of the proposed environment. Birnbach et al.<sup>15</sup> built full-sized mock-ups of proposed hospital rooms to study the hand hygiene compliance of physicians based on the placement of the hand-rub dispenser. This study showed a dramatic difference in hand sanitation practice based on whether or not the hand-rub dispenser was located in the physician's field of view, and this resulted in a change in the architectural plan before new rooms were built.

The methodology presented in this paper extends that presented by Birnbach et al.<sup>15</sup> but over a longer time-frame and on a larger scale. To our knowledge, the effort described herein represents the largest reported mock-up used in the design of a healthcare space. The success of

the long-term goal of this project—to build a safe and effective perioperative facility—will be objectively assessed after final construction, when outcome data is available. However, the results reported in this study support the notion that the end-user feedback generated by the simulations performed in this mock-up improved the facility design, as the on-site survey scores significantly increased from before to after changes to the design. Because the end-users that identify latent environmental threats in their current workspaces are the same ones reporting that the design changes improved the proposed healthcare facility, there is reason to believe that the better the scores generated by the end-users are, the fewer the environmental threats there will be after final construction. This study thus suggests that it is possible to limit architectural design flaws on a large scale before construction, by allowing large-scale simulations in a mock-up involving all end-users. Also, future studies involving fewer participants in more modifications could potentially provide meaningful feedback at potentially lower cost and achieve similar or improved design goals. The second finding of this study is that the feedback received through the three modalities was impacted by the depth of immersion and participant engagement. Survey response rates and the number of voluntary comments made differed significantly across the three engagement modalities (GTs, FEs, and simulated case scenarios), with GTs (the least immersive of all modalities) showing the lowest values in both cases. Using survey response rates and the offering of voluntary comments as a proxy for engagement, it is clear that participants with more immersive experiences engaged more fully with the simulation project.<sup>12</sup> In a manner that parallels how detailed mock-ups, with walls, doors, ceilings, and actual medical equipment, can solicit better input than simple mock-ups, which feel less realistic, it does not seem far-fetched to believe that a link exists between increased participant engagement and a higher quality of feedback. This is valuable information for other groups seeking to use mock-ups to garner feedback on facility design because it suggests that the best feedback from a mock-up will come when simulations are designed to fully immerse the participants in the experience.

To our knowledge, this is the first published study using mock-ups for healthcare design to present participant groups with varying levels of immersion. Further studies, including other potential data evaluation tools such as motion tracking analysis could increase the knowledge of healthcare design and provide future insightful information. Based on our literature search, few studies have reported the use of simulation for healthcare design and there are no validated tools to evaluate the process. Therefore, an evaluation tool was developed specifically for this study. The survey was

developed in accordance with the Messick Validity Framework, which describes 5 sources that confer validity onto an evaluation tool, of which our survey met three. The first source is content validity, which ensures that the test reflects the characteristics it intends to measure. In order to meet this burden, our survey was created in conjunction with process improvement, human factors engineering, and healthcare design experts. The second source of validity is response process validity, which aims for quality control of the assessment. In order to meet this burden, we standardized our survey's written instructions to minimize bias and used blinded raters for the analysis. The third source of validity is internal structure validity, a burden that our survey was unable to meet due to a lack of external assessment tools that would have allowed us to calculate reliability. The fourth source of validity is relationship to other variables, which involved the correlation of tests scores to independent measurement tools. Given the lack of such tools, we were not able to demonstrate the fourth source of validity. Finally, the fifth source of validity relies on the consequence of the test. In order to achieve validity by this measure, we defined predetermined goals of the assessment tool, which were achieved by use of the survey. The survey created for this project in accordance with the Messick framework, which were administered at the end of each participant's experience, afforded a practicable way to generate objective data that could be analyzed for this initial approach, and further serve as the basis upon that more sophisticated evaluation tools may be developed for future study. Other data collected, including verbal feedback, video observations, and audio recording were also used for the modification. The analysis of this data exceeded the scope of the present study.

By investing in allowing end-users to simulate their workflow in a physical mock-up of a new healthcare space, the hope of this project is to construct a safe environment and realize financial savings through increased provider efficiency. While the ultimate success of this project in achieving cost and time savings will be established after final construction, it is instructive to consider that an initial upfront investment is required for this type of approach. The total cost involved in this process represented a small percent (0.05%) of the anticipated total construction cost for the entire facility. The total cost of the effort described in this paper was approximately \$609,400. The largest investment component was the cost of construction and renovation of the mock-up (\$293,400), followed by the cost of labor for planning, observation, and data analysis (\$163,200), which was estimated at over six weeks of full-time effort from 12 team members. The

warehouse lease/maintenance (\$58,700) and participant and transportation (\$58,900) costs were notable, and miscellaneous costs such as refreshments for the participants, staging of the mock up, and basic cleaning services totaled \$35,200.

The total cost of \$609,400 can be put into perspective when one considers that cost of renovations for healthcare facilities ranges from \$200 to \$1,200 per square foot. The redesign process led to significant layout changes of approximately 17,740 square feet from round 1 to round 2, which in post-construction costs would total \$10,644,000 (assuming a conservative \$600/square foot) for the renovation of a single unit. In line with efforts to act sustainably and in consideration of the environment across the project, all efforts were made to recycle and reuse materials from the mock-up. For some material, the team was able to partner with local non-profits to reuse material. Because of cuts, screw holes, and other construction impacts, some material was not in a condition suitable for reuse. For these items, we sought to recycle the material to make new products.

The results of this study must be interpreted in light of some important limitations. Participation was optional; it was not a requirement for subjects to return to the second round, and the process involved commitment and scheduling staff time. Therefore, a high attrition rate was observed and approximately 7% of the 134 participants in round 1 did not participate in round 2. This important finding underlies the struggle to engage end-users into the design process of healthcare facilities. The need to close the gap between end-users and the design of work spaces has been identified in other areas.<sup>21</sup> Therefore, future studies could focus on developing ways to successfully enhance the engagement of end-users into a design process and overcome this barrier. Also, the survey was created specifically for this study, and we were able to address three of the five sources in the Messick validity framework. As in most studies, not all sources of validity evidence could be addressed in our study.<sup>16</sup>

Because of practical considerations, resource limitations, and specific clinical and non-clinical task assigned for specific jobs within the simulations, not every job group was able to participate in every experience, and thus, different job groups were exposed to different experiences. For GTs and FEs, all personnel were invited. However, not all personnel participated in the simulations, as certain skill sets are needed to be able to replicate life-like clinical scenarios. For this reason, this study is not exempt of selection bias, and we are not able to state if the results would change if every job group would have been exposed to each experience. We acknowledge

that by increasing comparisons with our dataset, the chance of finding significant results increases. However, we believe that presenting the detail of the responses provided more insight, due to the variability of significant results found comparing round 1 to round 2. Finally, not every aspect of the data used for the design modification (verbal feedback, video observations, and audio recordings) is presented, as it exceeds the scope of the study; however, the objective data presented in this manuscript were identified by the design team to have an important impact on the design and most importantly was able to objectively demonstrate the impact of the process.

## CONCLUSIONS

The use of interactive sessions including a simulation based methodology in a mock-up space to facilitate the involvement of end-users in the design of a perioperative space is an effective methodology that can substantially impact the final construction design. This study presents an effective and extensive methodology that can be used to inform the planning of a perioperative space. However, future studies need to be conducted to standardize end-user feedback strategies and objectively evaluate the financial impact of this type of design methodology.

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