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Health Environments Research & Design Journal
2024, Vol. 17(2) 57-76

DOI: 10.1177/19375867231226438
journals.sagepub.com/home/her
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Improving the Mental Health of Surgical Teams Through Operating Room Design

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Abstract

Objective: In this study, we aim to develop and propose an evaluation method for analyzing the design of operating rooms (ORs) from the perspective of surgical teams' reported experiences and stress levels. **Background:** Stress and burnout of surgical team members can lead to diminished performance and medical errors, which endangers the safety of both the patients and team members. The design and layout of the OR play a critical role in managing such stress. **Methods:** To understand surgical teams' spatial needs related to their experiences and stress, we administered a survey and in-depth focus group discussions to three surgical teams from the same organization. The identified spatial needs were translated into functional scenarios and spatial metrics, essentially viewing the OR through the perspective of users. **Results:** Our analysis revealed four integral sections—patient flow, room organization, access to facilities/medical equipment/support staff/team members, and staff well-being—identified as critical design factors associated with the experiences and stress levels of the surgical teams in the ORs. **Conclusions:** We expect this method to serve as a tool for evaluating the effect of the design of OR layouts on stress, thereby supporting the well-being and resiliency of surgical teams.

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Keywords
evidence-based design, operating room, surgical teams, stress, burnout, resilience

In the high-stakes and high-stress environment of healthcare facilities, the well-being of healthcare professionals is often overlooked. For instance, the symptoms of burnout driven by work-related stress (Shanafelt & Noseworthy, 2017) are very common among healthcare professionals, who have burnout rates nearly twice those of other U.S. workers (Shanafelt et al., 2019). This phenomenon worsened during the COVID-19 pandemic, and approximately 70% of nurses reported burnout after the pandemic (Wei et al., 2022).

In particular, stress and burnout persist in the surgical environment, and it is well-documented that surgical professionals are highly susceptible to burnout (Chati et al., 2017; Galaiya et al., 2020; Naviaux et al., 2022; Shakir et al., 2018). Burnout symptoms lead to increases in medical errors by surgical staff (Al-Ghunaim et al., 2022; Crijns et al., 2020; Shanafelt et al., 2010), increases in ineffective performance (Arora et al., 2010), a higher likelihood of alcohol use disorders (Oreskovich et al., 2012), and exacerbation of work-home conflicts (Dyrbye et al., 2011). Ensuring that surgeons, the anesthesia team and nursing staff can perform their duties under optimal conditions is crucial not only for their own mental and physical health but also for the successful outcomes of the procedures they conduct.

The physical environments of healthcare facilities have a significant potential to impact the stress or burnout levels of individuals. Physical facilities may work as stressors that negatively impact individuals' mental health (Nejati et al., 2016; Valipoor & Bosch, 2021), or they may support staff through restorative or healing work spaces (Gregory et al., 2022; Nejati et al., 2016; Valipoor & Bosch, 2021). A recent literature review presents empirical studies that report an association between the physical environment and psychological health in health professionals (Jin et al., 2023). For instance, the design of healthcare facilities, including floor/unit layout, workspaces, break areas, access to nature, light, and odor, was found to be significantly associated with healthcare professionals' mental health (Jin et al., 2023). In this context, the design and layout of the operating room (OR) itself emerge as pivotal factors that can significantly influence workplace stress. Therefore, these spaces should be created following the careful examination of needs and with thoughtful design. To date, little attention has been given to the design of ORs to reduce the stress and improve the well-being of surgical teams.

In this study, our objective is to establish a quantifiable approach for assessing the design of ORs from the viewpoint of OR team members with an emphasis on supporting their mental health and reducing their stress levels. Our ultimate goal is to use this assessment as a tool to foster improved well-being among surgical staff.

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Method

The project involves a mixed-method study using survey, focus group, and functional scenario (FS) spatial analysis approaches to investigate the design of the three ORs and their association with surgical team experiences and stress levels.

Study Settings

The study focuses on the analysis of three ORs at the same healthcare organization. The specific layouts of these ORs are depicted in Figure 1. The selected ORs are housed within two connecting buildings located on the same floor (Figure 2). These ORs were selected since they represent a range of OR design covering a broad spectrum of

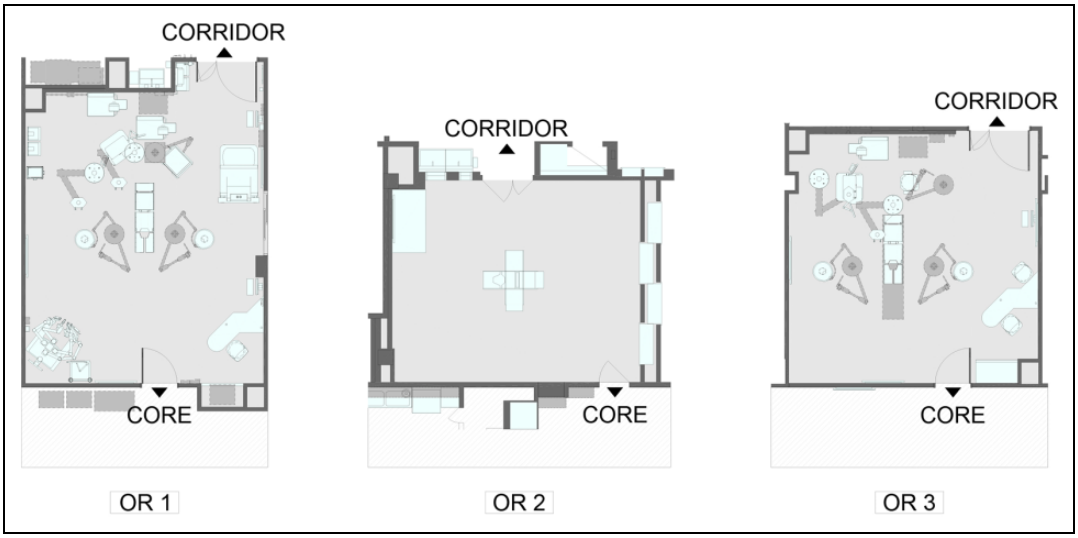


Figure 1. Layout of three operating rooms selected in the study.

possible room configurations, enhancing the robustness of the analysis. The floor area varied across the units; OR-1 was 712.59 square feet, OR-2 was 498.05 square feet, and OR-3 was 600.46 square feet. However, due to a scarcity of detailed information concerning the floor plan and furnishings of OR-2, it was occasionally omitted from analyses.

All ORs are designed, so that they link to a general corridor on the one side and to a clean core on the other (colored green in Figure 1). ORs are strategically grouped around what is referred to as a clean core, which serves as a storage area for sterile supplies. In this context, a core can be conceptualized as a common corridor or hub connecting several ORs. The three units we have analyzed share this structural pattern; each unit is connected to both a general corridor and a core. However, these connections lead to different cores, each located at unique points within the site, as described in Figure 2.

The three ORs were purposely chosen for their varied geographical location and relationships and accessibility to other essential facilities, such as restrooms, postanesthesia care units (PACUs), and dictation rooms. Hence, our analysis covers two aspects of OR design: the individual OR design through the lens of their specific configurations, accounting for the arrangement of people and furniture, and their geographical position within the overall site.

Survey

The survey was administered to potential focus group participants prior to the focus group sessions (Table 1). As part of a larger study, the survey included questions regarding multiple topics, including demographics, resilience, teamwork, and unit layout/design perception. Among these topics, this article focuses on unit layout/design perception-related questions.

For unit layout/design perception, a total of 11 questions were incorporated into the survey. The first set of questions, inspired by a previous study (Fay et al., 2017), were carefully crafted to evaluate the impact of the OR's layout on team collaboration, movement efficiency, and accessibility to key areas, with a broad scope encompassing both the interior and exterior environments of the OR. Additionally, we introduced four additional items to better apprehend perceptions concerning the broader clinical area beyond the unit. The concluding question was structured as a multiple-choice selection from provided options, adopted by another previous study (Lupo et al., 2021). This question was

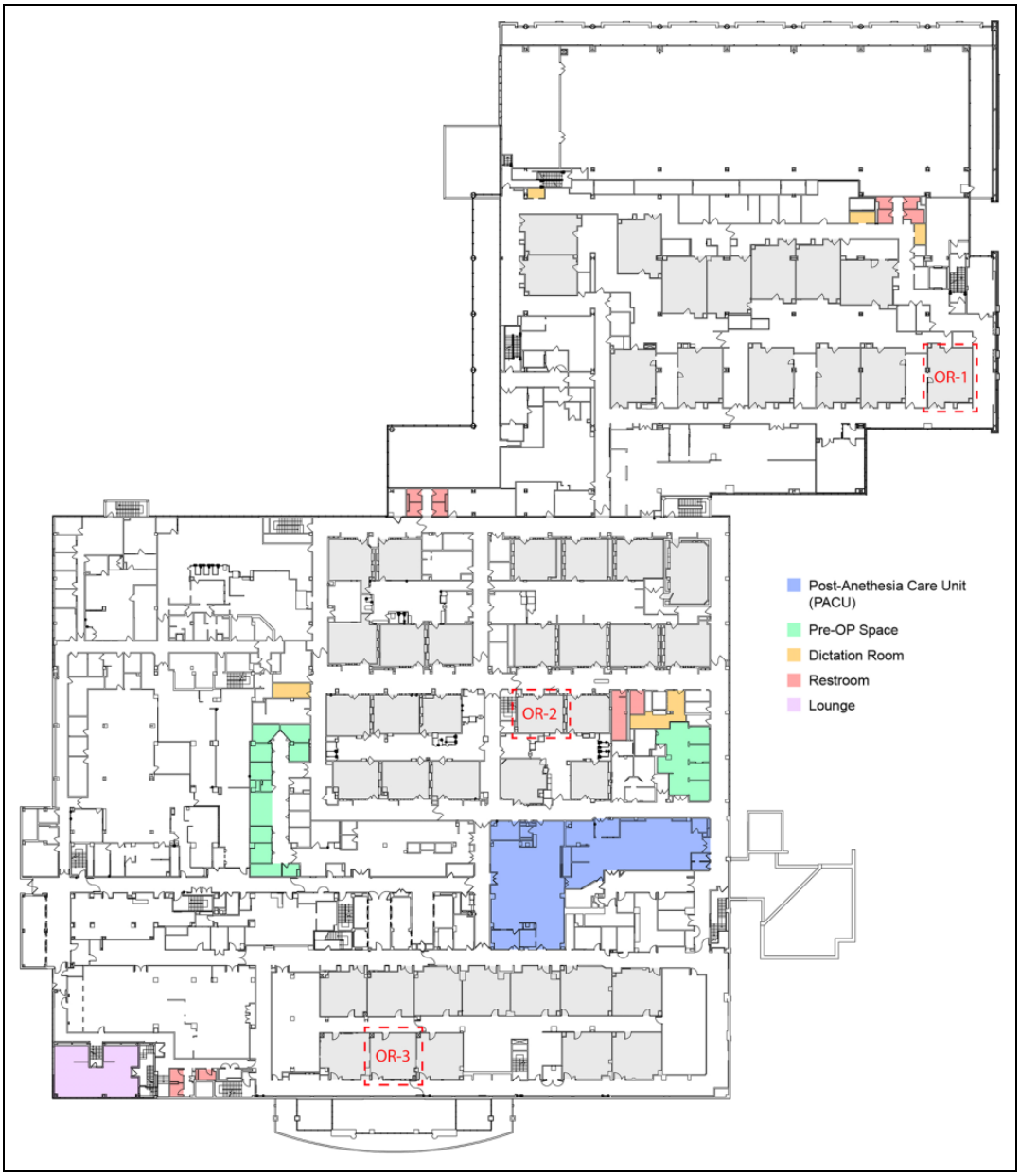


Figure 2. Location of three selected operating rooms on the same floor of the building.

intended to pinpoint potential stressors linked to the built environment.

Focus Group

Focus groups were organized with staff who were working in the relevant ORs to gain insight into their experiences and needs. In October and November 2022, a total of five focus group sessions were organized to prevent hierarchical influence between staff members. One session was for surgeons of all ORs, another session was for anesthesia providers, and three other sessions were for allied health staff in each OR. All

Table 1. Survey Items.

Number	Question	Reference
1	The layout of the operating room (OR) room that I am working in facilitates my ability to work as a team	Fay et al., 2017
2	In this OR room, the location of supplies is convenient and easily accessible	
3	The layout of the entire OR area (including locker room and break rooms) facilitates my ability to work as a team	
4	In this entire OR area, walking distances between OR room and other spaces such as locker room and break rooms are reasonable	
5	In this entire OR area, the location of supplies is convenient and easily accessible	
6	In this entire OR area, I could easily access spaces that provide privacy for me to take care of personal matters (e.g., phone calls)	
7	In this entire OR area, I feel comfortable to debrief families and have private communications	Lupo et al., 2021
8	The layout of the entire OR area is conducive to my sense of well-being	
9	The layout of the entire OR area allows me to be aware of where other individuals are and what they are doing	
10	The layout of the entire OR area supports frequent communication between individuals I work with in this OR	
11	Which among these elements can be the cause of stress caused by the environment? (options: disorganized patient flow, patient safety, narrow environments, noisy environments, poor lighting, inadequate technological instrumentation, Poor organization of the room, collaboration between colleagues, company organization, lack of facilities, medical equipment and support staff, and others)	

sessions were facilitated by the same researcher using a semi-structured group interview format that allowed for open-ended discussion and targeted questioning.

Each focus group session lasted approximately 45 min and was conducted in a physical meeting room close to the ORs with members of the research team attending either physically or virtually to take notes for detailed analysis. Additionally, a digital tablet was supplied to the participants to allow them to add comments anonymously. The focus group questions sought to deepen the answers from the survey results.

Analysts took notes on the verbal responses, which were later reviewed in addition to the digital submissions. A deductive strategy was used to organize data from these notes, which represented multiple participants' perspectives, into a separate matrix for each focus group. Each matrix was then synthesized and coded to identify content on key themes identified from the survey results and participants' perceptions of to stress and resilience that emerged during the focus group discussion.

FS Analysis

To fully understand and evaluate the OR layout from the perspective of users, in the last step of the study, we employed the FS analysis approach (Denham et al., 2018; Matić et al., 2022). FS analysis is an effective tool for understanding how users interact with their environment. It encapsulates a wide range of uses to help examine the existing environment from the users' perspective.

This is particularly crucial in the OR context. An OR is a complex setting involving numerous stakeholders, each performing distinct tasks and possessing unique operational needs. Surgeons, anesthesiologists, nurses, and technical staff operate in the same environment, yet their interaction with the space, the tools, and each other can be vastly different. Understanding these interactions can reveal a multitude of insights about how the environment can support, impede, or influence communication, collaboration, and workflow.

The list of FSs of actual users of the selected ORs is derived from the interactive focus group sessions with staff members who routinely

Table 2. Methodology List and Summary.

Method	Purpose	Process	Contributions
Focus Group	To gather qualitative insights from operating room (OR) staff	In-depth discussions with OR teams	Identified key themes and specific concerns
Survey	To quantify staff perceptions and experiences	Distributed to OR staff, including Likert-type scale questions	Provided statistical data to support themes
Functional scenario	To translate qualitative data into measurable scenarios	Developed and evaluated scenarios based on focus group and survey data	Quantified the impact of OR design on staff well-being

perform surgeries in the three units under analysis. Through this interactive discussion, we were able to gather invaluable insights into their spatial demands and their lived experiences within the built environment, especially in relation to their stress and mental health. These scenarios were subsequently refined into quantifiable and comparable criteria, measuring and evaluating the respective ORs. The results were then compared to draw implications for design improvements.

To provide a clear and comprehensive understanding of our mixed-methods approach, we summarize the methodologies used in this study in Table 2. These include focus groups, surveys, and functional scenarios, each of which served a unique purpose in our research.

Table 3. Survey Demographics.

	N	%
Title		
Nurse	6	31.6
Physician	7	36.8
CRNA	3	15.8
Other	3	15.8
Employment status		
Full-time	19	100
Part-time	0	0
Year of experience		
1–3 years	4	21.1
4–7 years	4	21.1
8–10 years	0	0
10+ years	11	57.9

Results

Survey Results

As a result of the survey of the healthcare professionals working in the selected OR rooms, a total of 19 valid responses were collected (Table 3). Depending on the role, there are individuals who work at multiple OR rooms among the three selected rooms, and these were grouped as "multiple ORs" for further analyses.

All participants in the focus group were full-time employees. The majority of the respondents had substantial experience, with 11 of them having served for over 10 years. In addition, five participants had 3–5 years of experience, two had between 1 and 2 years, and one had less than a year. This distribution allowed for a broad spectrum of insights, balancing the seasoned understanding of long-serving team members with the fresh perspectives of newer recruits.

In the questionnaire regarding unit layout/design perception, the means of the responses for the ten items were calculated and analyzed. As seen in Table 4, the mean scores of all ten items gravitate around the neutral value of 3, suggesting a moderate level of perception from the team members concerning the unit layout and design. Notably, the mean value of the response to item 3 was significantly lower than the expected value of 3, with a mean value of 2.3. This result highlights that the design of the entire OR area and other essential spaces play a critical role for survey participants in terms of their relationships with other team members. A Kruskal–Wallis test was performed to compare the mean values between the OR rooms. However, the results indicated no significant variance among the rooms.

Table 4. Descriptive Results of the Survey Items.

Item	OR-1	OR-2	OR-3	Multiple Ors	Total	Kruskal-Wallis *p* Value	*t*	Sig. (Two-Tailed)
1. The layout of the OR room that I am working in facilitates my ability to work as a team								
N	6	4	4	5	19		1.637[a]	.119
Mean (*SD*)	3.8 (1.17)	3.5 (1.00)	2.5 (1.00)	3.6 (1.14)	3.4 (1.12)	0.3165		
2. In this OR room, the location of supplies is convenient and easily accessible								
N	6	4	4	5	19		0.357[a]	.725
Mean (*SD*)	3.0 (1.67)	3.0 (1.15)	3.8 (0.50)	2.8 (1.48)	3.1 (1.29)	0.6915		
3. The layout of the entire OR area (including locker room and break rooms) facilitates my ability to work as a team								
N	6	4	4	5	19		−2.106[a]	.050
Mean (*SD*)	2.7 (1.86)	1.8 (0.50)	2.8 (1.50)	2.0 (1.41)	2.3 (1.42)	0.7561		
4. In this entire OR area, walking distances between OR room and other spaces, such as locker room and break rooms, are reasonable								
N	6	4	4	5	19		−1.714[a]	.104
Mean (*SD*)	2.5 (1.97)	2.5 (1.73)	3.3 (1.50)	1.4 (0.89)	2.4 (1.61)	0.3612		
5. In this entire OR area, the location of supplies is convenient and easily accessible								
N	6	4	4	5	19		−1.102[a]	.285
Mean (*SD*)	2.8 (1.72)	3.0 (0.82)	3.0 (1.15)	2.0 (1.00)	2.7 (1.25)	0.5379		
6. In this entire OR area, I could easily access spaces that provide privacy for me to take care of personal matters (e.g., phone calls)								
N	6	4	4	5	19		−1.531[a]	.143
Mean (*SD*)	3.2 (1.72)	1.8 (0.50)	3.5 (1.00)	1.6 (0.55)	2.5 (1.35)	0.0894		
7. In this entire OR area, I feel comfortable to debrief families and have private communications								
N	6	4	3	5	18		−0.394[b]	.696
Mean (*SD*)	3.0 (1.67)	2.8 (1.26)	3.3 (1.15)	2.6 (0.89)	2.9 (1.23)	0.8658		
8. The layout of the entire OR area is conducive to my sense of well-being								
N	6	4	4	5	19		−0.889[a]	.385
Mean (*SD*)	3.3 (1.37)	2.5 (0.58)	2.5 (1.00)	2.6 (0.89)	2.8 (1.03)	0.5929		
9. The layout of the entire OR area allows me to be aware of where other individuals are and what they are doing								
N	6	4	4	5	19		0[a]	1
Mean (*SD*)	3.3 (1.63)	3.0 (0.82)	3.3 (0.96)	2.4 (1.14)	3.0 (1.20)	0.6088		
10. The layout of the entire OR area supports frequent communication between individuals I work with in this OR								
N	6	4	4	5	19		0.776[a]	.448
Mean (*SD*)	3.5 (1.64)	3.3 (0.96)	3.3 (0.96)	2.8 (1.10)	3.2 (1.18)	0.7113		

Note. OR = operating room.
[a] $df = 18$. [b] $df = 17$.

The last question regarding the unit layout/design perception asked, "Which among these elements can be the source of stress caused by the environment?" with a multiselection method from given options. Table 5 illustrates the number of instances of being selected from all participants for each given option. As highlighted in Table 5, the top selected options (over 10%) were noisy environments, disorganized patient flow, poor lighting, poor organization of the room, and lack of facilities, medical equipment, and support staff.

Focus Group Results

A total of 13 individuals participated in the focus group sessions. As a result of all focus group sessions, a handful of the built environment factors related to their experiences and stress levels were identified, as illustrated in Table 6. We divided the identified elements into two levels: design elements that are (1) within the OR and (2) related to the entire floor, including the three ORs and other essential spaces.

Table 5. Survey Results Regarding Stress-Causing Environment Elements.

Which among these elements can be the cause of stress caused by the environment?	Count	Percentage
Noisy environments	10	12
Disorganized patient flow	9	11
Poor lighting	9	11
Poor organization of the room	9	11
Lack of facilities, medical equipment, and support staff	9	11
Patient safety	7	8
Narrow environments	7	8
Inadequate technological instrumentation	6	7
Inadequate/obsolete furniture	5	6
Collaboration between colleagues	5	6
Company organization	4	5
Other	4	5
Total	84	100

Table 6. Identified Spatial Elements During Focus Group Sessions.

Topic	OR-1	OR-2	OR-3
Within the OR			
Entrance to the OR		X	X
Pathway within the OR and sterile field	X		X
Crowdedness and clutter within the OR		X	X
Access to screens needed	X		X
Enhanced lighting	X		X
Power outlets and cords	X		X
Equipment (sharps container, whiteboard, and nurse charting island)	X		
Overall layout			
Emergency equipment location		X	
Pre-op area location	X		
PACU location	X	X	
Dictation room location	X	X	X
Lounge, break room, and locker room location	X	X	X
Restroom location		X	X
Cafeteria location		X	
Windows			X
Storage space			X
Desired behaviors for resilience			
Natural light	X		X
Briefings before operation		X	X
Social interactions with coworkers	X	X	X

Note. OR = operating room.

FS Analysis Results

Drawing upon the insights gained from the survey and focus group discussions, we formulated 15 FSs, each complemented by the respective set of spatial metrics for quantification and evaluation. Our analysis is structured into four distinct categories: patient flow, room organization, access to facilities/medical equipment/support staff/team members, and staff well-being. These themes emerged as salient topics from our survey and the focus group findings. The FSs, respective spatial metrics, and analysis results of the three ORs are presented in Table 7.

Patient flow. Survey results revealed that staff members identified disorganized patient flow as a primary environmental factor contributing to stress. This point was further reinforced by feedback from the focus groups, which underscored the challenges participants experienced related to accessibility within ORs. An additional aspect highlighted by the focus groups was the importance of accessible pre-op and PACU areas to enhance patient flow efficiency. The corridors must be designed in a way that allows for beds to be easily turned and maneuvered, ensuring smooth patient transport (Tan & Rao, 2019). As such, we formulated three FSs (FS 1, 2, and 3) to represent these concerns.

The first FS (FS 1) centered on the movement of the patient bed from the pre-op area to the OR, which is a critical path that must be smooth and uninterrupted. The first criterion of this scenario measures the breadth of the doorway, providing a quantifiable value for entrance and exit accessibility. The second criterion gauges the spatial distance between the doorway and the surgical table, a critical aspect influencing patient transfer efficiency. Finally, the third criterion quantifies the

Table 7. Summary of Functional Scenario (FS) Analysis Results.

FS/Criteria (C)	OR-1	OR-2	OR-3
Theme 1. Patient flow			
FS 1. Team members must be able to move the bed in and out of the room efficiently			
C1. Width of the doorway (feet)	6	6	6
C2. Distance between the doorway and operation table (feet)	19.4	8.1	16.1
C3. Number of turns required from the entrance to the operation table	2	1	2
FS 2. Team members need to access preop area from the OR efficiently			
C1. Distance from each OR to pre-Op space (in feet)	570	249	488
C2. Number of turns required to reach the pre-Op space	5	4	5
FS 3. Team members must access PACU area from the OR efficiently			
C1. Distance from each OR to PACU area (in feet)	566	156	588
C2. Number of turns required to reach the PACU area	5	4	8
Theme 2. Organization of the room			
FS 4. Team members need enough space in the OR to move around during the operation			
C1. Obstructed zone (with people and equipment) in minimum capacity (sq ft and %)	256 (36%)	—	226 (37.7%)
C2. Obstructed zone in maximum capacity (sq ft and %)	378 (53%)	—	291 (48.5%)
FS 5. Team members need a clear area to move equipment around without obstructing the sterile field in the room			
C1. Distance from registered nurse's (RN) seat to the doorway (feet)	40	—	28
C2. The area of exit clearance that is obstructed by other objects in minimum capacity (%)	16.4 sf (11.6%)	—	10.7 sf (10.4%)
C3. The area of exit clearance that is obstructed by other objects in maximum capacity (%)	34.3 sf (24.2%)		29.3 sf (28.5%)
Theme 3. Access to facilities, medical equipment, support staff, and team members			
FS 6. RN needs to chart and attend to the needs of the OR			
C1. The angle the RN would need to turn their head to view the center of the operating table (degree)	13.5	—	9.5
FS 7. Surgeons need to access a whiteboard to illustrate things during the operation			
C1. Distance from the center of the operating table to the whiteboard (in feet)	18.7	—	14

(continued)

Table 7. (continued)

FS/Criteria (C)	OR-1	OR-2	OR-3
FS 8. Team members should be able to visually access screens and monitors during the operation			
C1. The angle of view from the wall-mounted monitors to the operating table (degree)	9.69, 20.62, and 21.16	26.85	4.14, 8.62, and 9.04
C2. Viewing area from all monitors (sq ft and %)	712.59 (100%)	428.33 (86%)	600.46 (100%)
FS 9. Team members need to have lightings that provide sufficient visibility to the operating table			
C1. The total area within OR that is not covered with lighting (sq ft)	1.77	—	16.62
C2. The average number of lighting covering the operation table	4.04	—	12.82
FS 10. Surgeons need to access dictation rooms to chart and attend to the needs of the OR			
C1. Distance from each OR to dictation rooms (feet)	204	80	577
C2. Number of turns required to reach the dictation rooms	7	2	7
FS 11. Team members need to access other team members for work-related and nonwork-related interactions			
C1. Accumulative distance from each OR to each collaboration space; dictation room, anesthesiologist charting room, and nurse charging station (in feet)	724	540	1,224
C2. Number of turns required to reach all collaboration spaces	23	11	15
Theme 4. Staff Well-being			
FS 12. Team members need to access restrooms from the OR efficiently			
C1. Distance from each OR to restrooms (in feet)	220	68	131
C2. Number of turns required to reach restrooms	9	2	4
FS 13. Team members need to access lounge/break rooms from the OR efficiently			
C1. Distance from each OR to the lounge (in feet)	962	534	205
C2. Number of turns required to reach the lounge	15	11	7
FS 14. Team members need to access stairways from the OR efficiently in order to use the amenity spaces on other floors, such as locker room and cafeteria			
C1. Distance from each OR to the staircase (in feet)	139	31	136
C2. Number of turns required to reach the staircase	5	2	3
FS 15. Team members need to access windows from the OR efficiently			
C1. Distance from each OR to the nearest window (in feet)	12	142	205
C2. The average length of window encountered while traveling to key spaces (in feet)	76	0	0

Note. OR = operating room.

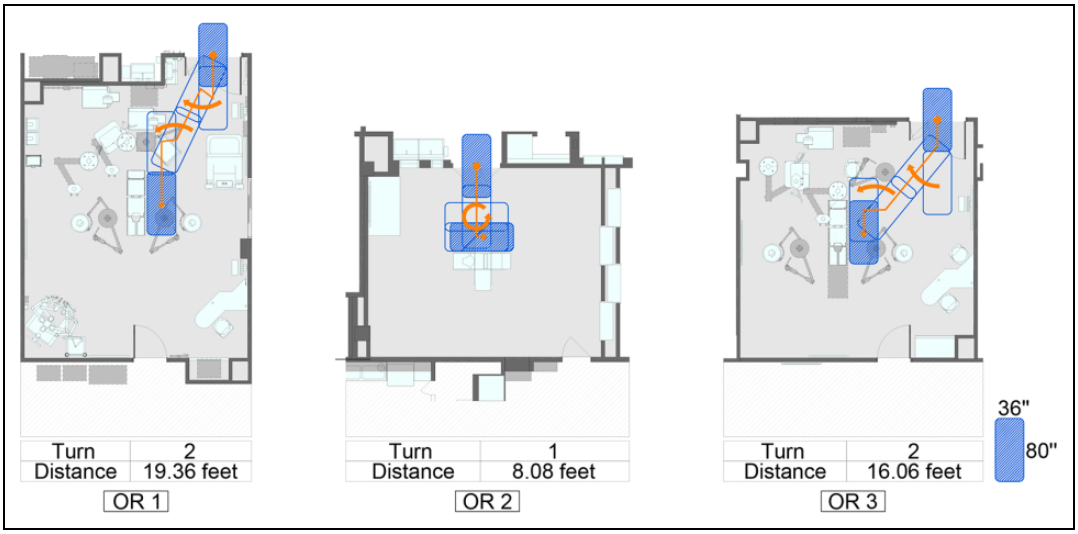


Figure 3. Analysis results of patient bed movement (Functional Scenario 1).

number of turns required to navigate from the entrance to the surgical table, a factor that directly impacts maneuverability and smooth patient transport within the room. This analysis was conducted based on the standard average patient bed size, measuring 36 × 80 inches. The analysis results are illustrated in Figure 3.

As shown in Table 7, the results reveal that the width of the doorways is consistently 6 feet across all three OR floor plans. However, the outcomes for the other two criteria demonstrate some variation, as shown in Figure 3. The measurement for patient bed movement shows a distance of 19.4 feet in OR-1, 8.1 feet in OR-2, and 16.1 feet in OR-3. For the number of turns necessary, both OR-1 and OR-3 require two turns, while OR-2 requires only one. Thus, when assessed based on these criteria, OR-2 exhibits better performance in facilitating patient bed movement within the room.

The second FS (FS 2) looked at the complexity of navigating within the OR itself, with the layout and location of equipment playing significant roles. Last, the third FS (FS 3) emphasized the path from the OR to the PACU, considering the importance of timely and efficient transitions after the completion of surgeries. Together, these scenarios highlight key points in the patient's journey to and from the OR that can affect the workflow and stress levels of the surgical team.

Organization of the room. The organization of the room emerged as another significant theme, both in the initial survey responses and during the focus group discussions. Respondents reported that clutter within the room, specifically due to the overcrowding of people and equipment, causes stress. Moreover, concerns were raised about potential breaches of the sterile field owing to the need to relocate equipment. A previous study underscores the critical importance of preserving a sterile field during surgery, as it plays a vital role in reducing the risk of infection (Labrague et al., 2012). Another study identified flow disruptions in surgical rooms specifically caused by the layout and placement of equipment, especially in areas near anesthesia stations (Joseph et al., 2019). To address these issues, we developed two FSs (FS 4 and 5) that encapsulate the challenges presented by room organization and provide insights for improvements.

Our fourth FS (FS 4) addresses the clutter issues arising from the overcrowding of people and equipment during operating procedures. The scenario quantifies the unobstructed area available when the room is operating at its maximum capacity, including all necessary equipment and

personnel. Conversely, as a second criterion, we also evaluated the unobstructed space when the room was at its minimum occupancy with five individuals in the room, including a certified surgical technologist (CST), certified surgical assistant (CSA), surgeon, circulating nurse, and anesthesia provider, according to the organization's protocol. At maximum capacity, the number of people rises to approximately 14, consisting of two certified surgical technologists (CSTs), a CSA, a resident surgeon, a surgeon, two trainees, a circulating nurse, a trainee circulating nurse, an anesthesiologist, an anesthesia provider, a student nurse anesthetist, and two radiology technicians. Additional equipment, such as a c-arm, is also brought into the OR when it is operating at full capacity.

Building on FS 4, our fifth FS 5 centers on comfortable and efficient movement within the OR during the procedure. The criteria for this FS are based on a hypothetical situation, where the circulating nurse needs to exit the room during a procedure (in both maximum and minimum occupancy situations). For each OR, we charted a trajectory from the circulating nurse's position to the room's exit toward the general corridor. From this line, we accounted for a specific clearance distance, which represents the space required for safe and unobstructed movement. In our analysis, we considered a specific clearance distance of 26.5 inches, aligning with the architectural graphics standards for a horizontal reach that accommodates an average female population (Hedges, 2017). This distance represents the essential space required for safe and unencumbered movement within the environment. We then measured the area where this clearance line intersects with the placement of equipment and personnel within the room (Figure 4). This process allows us to visualize and quantify potential obstructions and congestion points in the OR.

When examining the obstructed area during the registered nurse's (RN) exit from the room, we observed that the egress distance was 40 feet in OR-1 and 28 feet in OR-3. In OR-1, the RN egress path was blocked by other objects, accounting for 11.6% (16.4 sf) of the clearance area in the minimum capacity scenario and up to 24.2% (34.3 sf) in the maximum capacity scenario. In OR-3, these proportions were slightly lower, with 10.4% (10.7 sf) of the egress path obstructed in the minimum capacity scenario, rising to 28.5% (29.3 sf) at maximum capacity. However, it should be noted that OR-1 possesses a greater square footage than OR-3, resulting in a more expansive absolute area of obstruction.

Access to facilities, medical equipment, support staff, and team members. Issues surrounding access to facilities, medical equipment, support staff, and team members were prominent in both the survey and focus group discussions. The survey responses identified inadequate access to facilities, medical equipment, and support staff and poor lighting as stress-causing elements of the OR environment. Moreover, respondents indicated that the layout of the overall OR area, including locker rooms and break rooms, impacted team collaboration. During the focus group sessions, staff members voiced specific concerns, such as the need for clear visual access from the RNs to the OR, surgeons' accessibility to whiteboards, screens and monitors, adequate lighting, and easy access to dictation rooms. Previous studies revealed that surgeons require access to whiteboards for various essential tasks, such as sharing information and visualizing workload (Xiao et al., 2001). Furthermore, a recent literature study emphasized the significance of proper illumination during surgery, noting its impact on surgical staff performance and satisfaction (Joseph et al., 2018). To comprehensively address these concerns, we developed six FSs that encapsulate these diverse facets of accessibility within and beyond the ORs.

In FS 6, our primary focus is on gauging the visual accessibility of RNs to the surgery table. This assessment is crucial to ensure effective observation and communication during procedures. Following this, in FS 7, we examine ease of access to the whiteboard, which plays a vital role in illustrating and communicating important details during an operation. FS 8 measures the visible accessibility of screens and monitors within the OR. FS 9 measures the sufficiency of lighting within the OR and around the operating table, a key factor in maintaining visibility during operation. FS 10 assesses the accessibility of

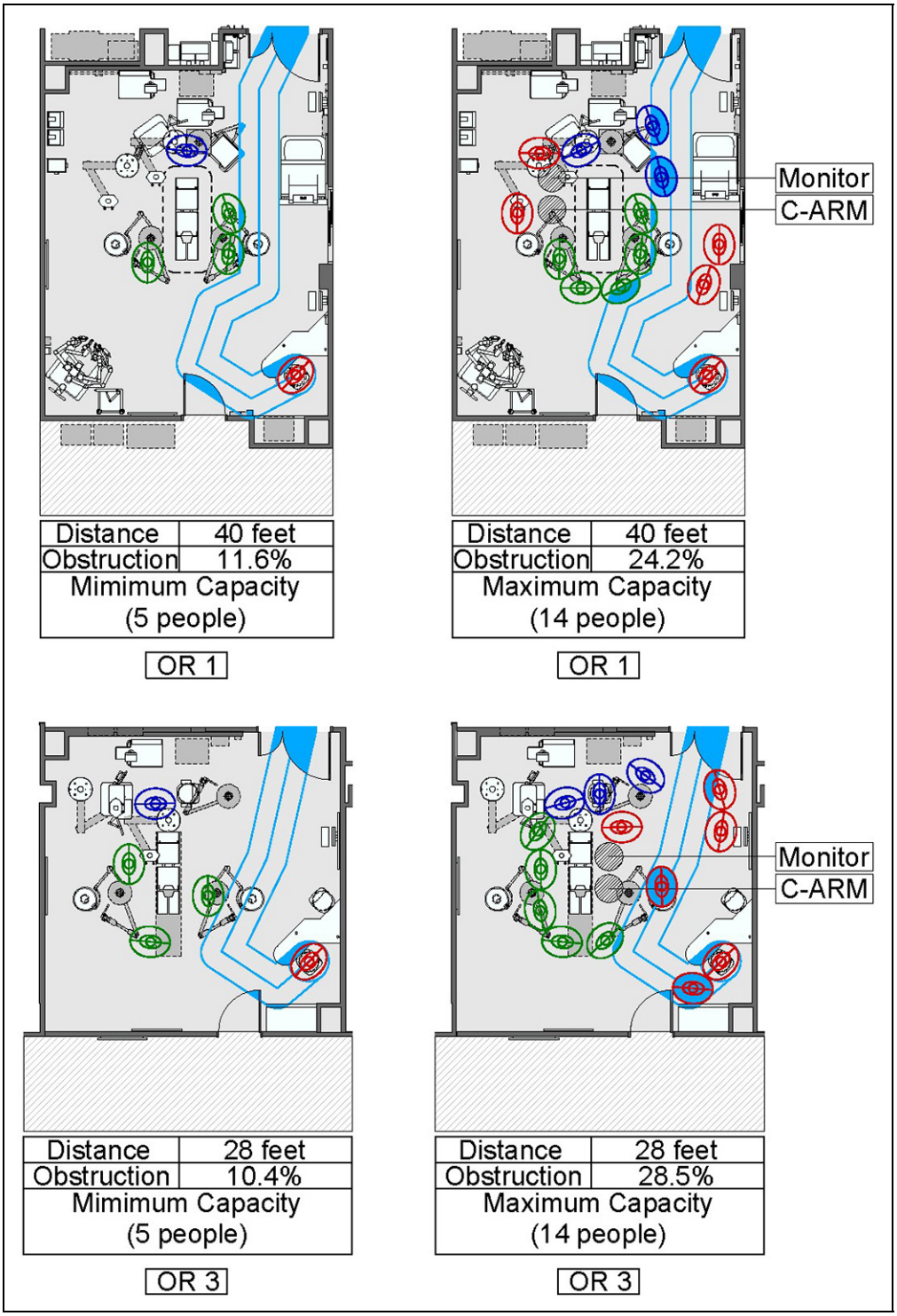
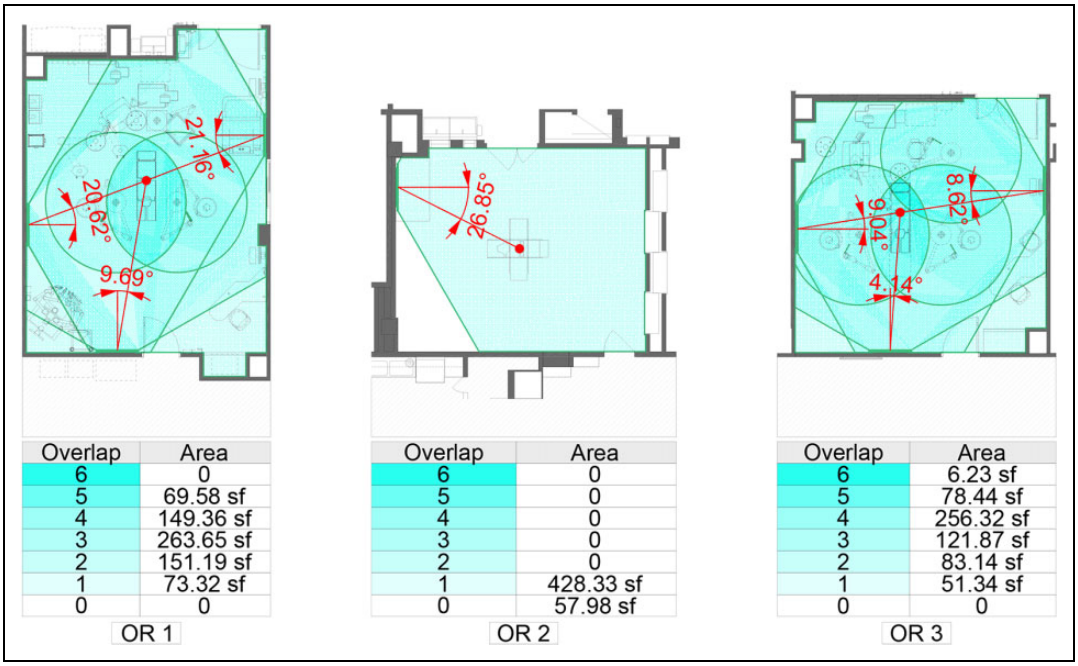


Figure 4. Analysis results of potential obstructions and congestion points (Functional Scenario 5).



Overlap	Area
6	0
5	69.58 sf
4	149.36 sf
3	263.65 sf
2	151.19 sf
1	73.32 sf
0	0

OR 1

Overlap	Area
6	0
5	0
4	0
3	0
2	0
1	428.33 sf
0	57.98 sf

OR 2

Overlap	Area
6	6.23 sf
5	78.44 sf
4	256.32 sf
3	121.87 sf
2	83.14 sf
1	51.34 sf
0	0

OR 3

Figure 5. Analysis results of accessibility to screens (Functional Scenario 8).

dictation rooms, highlighting the necessity of a quiet, private space for entering accurate and uninterrupted post-operation documentation. FS 11 measures distances to areas for work-related and nonwork-related conversation. Each staff group area was directed to a different team interaction area: surgeons in the dictation room, anesthesiologists in the staff charting room, and nurses in the nurse charge station.

Among the six FSs, we use FS 8 as an example to illustrate the analysis process and results. As noted, FS 8 measures whether the screens and monitors are visible from all areas in the OR. To address this, the first established criterion is the angle view from the wall-mounted monitors to the operating table. The second criterion involves determining the viewing area from the monitor, which is defined as a 120° vision area emanating from the screen. The circles in Figure 5 represent the area within which the movable monitor can be seen.

As shown in Figure 5, we quantified the angles from the wall-mounted screens to the operating tables across the three ORs. For OR-1 (with three wall-mounted and two movable screens), the angles measured were 9.69°, 20.62°, and 21.16°, respectively, for the wall-mounted screens. OR-2 had an angle of 26.85° (with only one wall-mounted screen in the room). Meanwhile, OR-3 (with three wall-mounted and three movable screens) displayed angles of 4.14°, 8.62°, and 9.04°, respectively, for the wall-mounted screens. In terms of screen coverage, OR-1 had a maximum of five screens, providing a coverage area of 70 square feet (9.8%) and a minimum of one screen covering 73 square feet (10.2%). In every part of OR-1, at least one screen was visible. This scenario was similar in OR-3, with a maximum of six screens. In OR-3, the area covered by at least five screens was 85 square feet (14.2%), while an area of 51 square feet was covered by just one screen (8.5%). In contrast, due to the scarcity of data in OR-2, we could only account for one wall-mounted screen as indicated in the floor plan, which covered a large visual area of 428.33 square feet (86%), but not the entire area. The differences in screen coverage across these ORs could have significant impacts on the surgical team's efficiency and collaboration during procedures.

Staff well-being. Finally, the subject of well-being was referenced throughout the focus group discussions. Our survey and focus group discussions elucidated the need for closer proximity to essential amenities, such as restrooms, lounge and break rooms, locker rooms, and the cafeteria. Participants from the focus group emphasized the need for designated spaces to engage in conversations with coworkers, highlighting the importance of fostering more interactions within the team. Furthermore, staff break rooms were associated with higher levels of satisfaction, as well as lower levels of stress (Berry & Parish, 2008).

Access to windows with natural light and viewing was frequently mentioned as a desirable feature. These findings are aligned with previous studies reporting relationships between natural light and lower stress levels (Alimoglu & Donmez, 2005; Berry & Parish, 2008) and improved well-being (Wingler & Hector, 2015). In response to these concerns, we crafted four FSs to address these elements as they relate to staff well-being.

FS 12 measures the distances and the number of turns required to reach restrooms, capturing potential inefficiencies in design. FS 13 focuses on the accessibility of lounge and break rooms from the OR, gauging convenience for staff members during their breaks. FS 14 examines the proximity of stairways from the OR that affects the usability of amenities located on other floors, such as locker rooms and the cafeteria.

Finally, we acknowledged the importance of natural light and viewing through windows, as expressed by the participants (FS 15). Given that staff members can access windows outside the ORs, we quantified the distance to the nearest window from each OR. Additionally, we calculated the ratio of window length to the travel distance to various other key spaces, providing an indication of the amount of daylight exposure during these transitions (Figure 6).

The distance to the nearest window varied across the ORs. For OR-1, the nearest window was a mere 12 feet away. However, for OR-2, the distance was much greater, with the closest window 142 feet away. OR-3 offered the longest distance to a window, which was 205 feet away and situated within the lounge area.

In OR-1, the proportion of window length to total travel distance was 145 feet (25.44%) for the pre-op area, 145 feet (25.62%) for the PACU, 41 feet (20.1%) for the dictation room, 41 feet (18.64%) for the restroom, 43 feet (4.47%) for the lounge/break room, and 41 feet (29.5%) for other amenity spaces. This resulted in an average window length of 76 feet across all travel routes. For OR-2 and OR-3, the proportions were significantly lower due to the absence of windows on the travel routes to other spaces, as illustrated in Figure 6. The length of the windows for all areas including the pre-op area, PACU, dictation room, restroom, lounge/break room, and other amenity spaces was 0 feet.

Discussion

In this study, we developed a total of 15 FSs that offer a comprehensive analysis of the OR layout and design in relation to the experiences and stress of the surgical teams. These scenarios effectively embody the perspectives of the OR team members derived from survey and focus group results. A set of FSs encapsulates distinct aspects of the OR layout: patient flow, room organization, access to facilities/medical equipment/staff, and staff well-being. Given these scenarios, we are able to quantitatively measure the elements of the built environment both inside and outside the ORs. This approach allows robust evaluation of the OR design, transforming anecdotal evidence and experiences into actionable, empirical data that can inform future design improvements in ORs.

Performance Summary and Design Improvements in the Selected ORs

OR-1 demonstrated strong performance in several metrics but would benefit from targeted improvements. There is a need to optimize the arrangement of equipment and people, particularly in maximum capacity scenarios, to minimize obstruction and facilitate smoother workflow. The long distances to key areas such as preop, PACU, lounge/break room, and amenities could be addressed through strategic layout redesign. Additionally, measures could be taken to improve

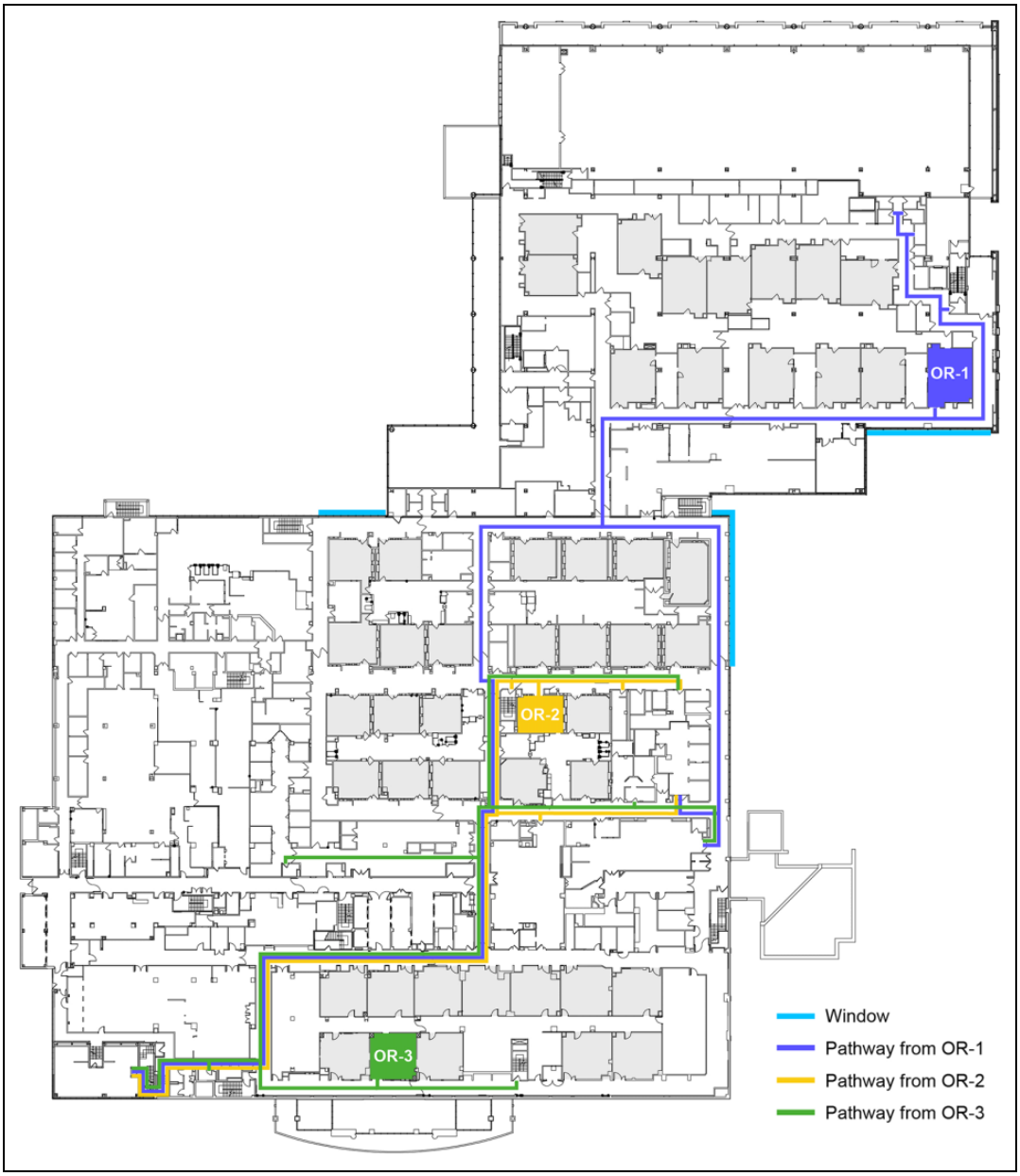


Figure 6. Analysis results of accessibility to windows (Functional Scenario 15).

visual access to screens and monitors and enhance the natural light available near the OR, by reconsidering its position relative to the building's exterior.

Despite showing the best results for patient bed movement, the design of OR-2 was not fully analyzed due to insufficient information. Further analysis regarding the equipment placement and resulting space utilization is needed for a more comprehensive evaluation and improvement plan. Currently, the room's greatest strength lies in its proximity to crucial areas such as the preop area, PACU, and restroom. However, it falls short in terms of natural light and visual access to

screens, which should be addressed to create an environment for staff that is more conducive to health and well-being.

While OR-3 demonstrated some advantages, such as closer proximity to the lounge/break room and the shortest distance to windows for natural light, several areas need attention. There is a higher degree of obstruction in both minimum and maximum capacity scenarios that impedes efficient workflow and staff movement. Improving the arrangement and potential reduction in equipment could address this issue. Moreover, the distances to the preop area, PACU, and amenities are substantial, which may require a larger-scale redesign. Last, enhancing the OR's lighting can improve its overall environment.

Implications

The FSs and the spatial criteria developed in this study could be used in future projects for evaluating the design of current and future ORs and entire operating suite layouts from the perspective of the mental health of healthcare professionals, with the ultimate goal of better patient care. Analyzing a varying range of design options would enable visualization of the performance of various OR rooms. Along with the analysis methods and results, the following are critical lessons we learned from this study's findings, which should be considered for future design projects.

Critically evaluate the design from the perspective of users. We learned many different aspects of the healthcare professionals' experiences and the effects on their mental health through a limited number of focus group sessions. Some unexpected aspects of design and behaviors were identified, which translated to the development of FSs and spatial criteria in this study. Additionally, the careful evaluation of the OR rooms enabled the comparison of the design options, visualizing the pros and cons of the selected design. Conducting such a process would enable a precise understanding of the design performance and guide the design of user-centered healthcare facilities.

Think locally and globally at the same time. During the focus group sessions, many comments regarding the spaces beyond the selected ORs were shared. Considering the scope of built environments that staff members would interact with to achieve their goal of providing care to patients, it is critical to focus not only on the layout of the OR itself but also on the broader floor plan. More importantly, consider how the selected space (OR unit in this study) interacts with other related spaces, such as the pre-op area, PACU, and dictation room to enhance efficient workflow, and external elements, such as break rooms and natural light access for the enhancement of staff well-being.

. . . it is critical to focus not only on the layout of the OR itself but also on the broader floor plan.

Provide spaces that support staff well-being. As identified in the focus group sessions, staff members noted the importance and the need for access to windows and natural light, briefings prior to cases and social interactions with coworkers to support staff mental health. These were recurring themes identified in most OR rooms as desired behaviors for promoting resilience and less stress. Increasing access to natural light in corridors and break areas and providing designated spaces for team briefings and social interactions are recommended for the well-being of staff members. These spaces and elements need to be easily accessed from all OR rooms.

Provide spaces that support staff well-being.

Limitations and Future Direction

There are limitations of this study. This pilot study analyzed only a limited number of OR rooms and participants. Additionally, we acknowledge that there could be other important issues in the design of the OR rooms and the entire floor. The spatial analysis and the results are conducted through the lens of the healthcare professionals of the selected OR rooms, which may be limited in terms of the design variance and the experiences of the participants. Future

studies might expand upon this study to also cover various design options and participants and enable development and refinement of the OR design evaluation method. The continued modification of the proposed FSs and spatial criteria is expected to support the design evaluation and development of ORs and floors for the improved health of healthcare professionals.

One of the key limitations of this study is the restricted data available for OR-2. Unlike other rooms analyzed, our access to comprehensive information about OR-2 was limited, particularly in terms of detailed layout and equipment placement. It is important for future research to address this limitation through more extensive data collection efforts to ensure a holistic understanding of all ORs.

Additionally, while our study utilized the FS method based on floor plan analysis and provided valuable insights, it did not fully address certain aspects crucial to OR dynamics. For instance, the management of power outlets and cords emerged as a significant safety concern in our focus groups but could not be comprehensively explored within the constraints of our methodology. Similarly, the intricate social dynamics within the OR, particularly the impacts of team consistency and coworkers' familiarity on job satisfaction and team efficiency, were beyond the scope of our floor plan-based analysis. A deeper examination of these aspects could yield a more holistic understanding of the factors that contribute to staff well-being in the OR, thereby enhancing the overall effectiveness and safety of these vital healthcare environments.

Implications for Practice

- Health system leaders can monitor and measure the design performance of ORs and the broader floor layout as part of the healthcare organization's and team's quality improvement initiatives.
- Designers and facility managers can utilize the proposed approach for evaluating the design of ORs and floors for the mental health of surgical teams.
- Designers can use the measurable metrics and criteria for evaluating OR and floor design options for improving the design performance during the design process.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received financial support for the research, authorship, and/or publication of this article: This research was supported by Robert D. and Patricia E. Kern Center for the Science of Health Care Delivery, Mayo Clinic.

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