A Vision for Evaluations of Responsive Environments in Future Medical Facilities

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Abstract –

Medical facilities in the United States (US) are facing growing demands due to shifts in patient demographics, healthcare policies, costs of care, and medical technologies. An emerging trend is the growing importance of outpatient and ambulatory care relative to inpatient care. Whereas the term "inpatient" involves a patient needing admission into a hospital over an extended period of time, ambulatory care (i.e., outpatient clinics, dialysis clinics, ambulatory surgical centers, etc.) generally involves medical and surgical services performed outside a hospital environment, with the overall patient visit duration typically lasting less than a few hours. Changes in healthcare policy and advances in medical technologies are driving the need for ambulatory facilities to be more flexible in terms of functionalities and environmental qualities (e.g., light, acoustics, etc.). Responsive environments, as a design approach focusing on how spaces can change in response to user and environmental input (e.g., user interfaces, sensors), can uniquely address these changing and contemporary needs of medical practices. Architectural robotics, a key element of responsive environments, can facilitate rapid changes in building component configurations, such as interior wall, display screen, and furnishing layout, enabling spatial flexibility for medical staff. In this paper, we envision a novel application of responsive environments in the context of outpatient clinics and ambulatory care facilities. We present two ambulatory practice scenarios demonstrating architectural robotics use cases, based on preliminary observations of six ambulatory care medical staff and their patterns of interactions with existing technologies, building spaces, and navigation between spaces. Virtual environments, modeling those two scenarios, have been scripted and tested with an initial group of nine medical professionals activating architectural robotic transformations and experiencing the changes in configurations, with feedback collected through a follow-up questionnaire. Collected data on participants' feedback on the scenarios' applicability to healthcare practice and usability are presented in this paper. We expect to develop subsequent responsive environments to serve specialized medical practices as we identify them by shadowing a larger cohort of medical staff. Outcomes will be helpful for design practitioners as our findings suggest updates to the typical medical building layouts given digital technology advancements in healthcare practice. This work serves as an initial proof of concept for how responsive environments and architectural robotics can improve the spatial flexibility of future ambulatory care settings in particular and medical facilities overall, and how these are positively perceived by medical staff.

Keywords –

responsive environments; immersive virtual environments; healthcare; architectural robotics

1 Introduction

Medical facilities in the United States (US) face numerous challenges amidst a changing landscape of policy, demographics, and technology. An emerging trend is the growing importance of outpatient and ambulatory care relative to inpatient care. Inpatient care typically refers to hospitals, where a patient stays for an extended period of time under significant levels of monitoring and treatment. Outpatient and ambulatory care (i.e., outpatient clinics, dialysis clinics, ambulatory surgical centers, etc.) generally involves medical and surgical services performed outside a hospital environment, with the overall patient visit duration typically lasting less than a few hours. Within the last fifteen years, the number of outpatient facilities in the US has increased 51% due to numerous factors including an aging population, changes in US healthcare policy, and rising costs of inpatient care [1] [2]. These trends motivate us to specifically focus within the context of healthcare on improving the built environment of outpatient and ambulatory care facilities. While the terms "outpatient" and "ambulatory" have nuanced definitions in medical research, for the purposes of simplicity, this paper use “outpatient clinics” to refer to both terms.

Outpatient clinics are starting to involve new digital technologies, raising questions of how the existing and future facilities can be better designed. For example, the predominant use of electronic health records (EHR) has created a challenge for physicians to balance their attention to EHR computer screens while making sure the patient still feels a sense of connection [3]. This has led to various investigations in how the built environment can be better designed with optimal positioning of furniture and EHR screens within an exam room [4]. EHRs are also getting integrated with wearable health technologies to capture more data on patients and streamline medical staff workflows [5]. Telemedicine has changed the relationship between people and the built environment, allowing patients to check in with their doctors without having to visit an outpatient care facility [6] [7]. Driven by these changes in technology, expectations of patients, and medical staff workflows, outpatient practices need flexibility in terms of the amount of space, variations in environmental qualities (e.g. lighting, acoustics, temperature), and ability to use the same space for multiple purposes [2]. The need for flexibility in outpatient clinics compels us to re-evaluate what medical staff and patients currently require from their environments.

Updating medical staff and patient requirements on the usage of facilities will inform the design of outpatient clinic environments that work in conjunction with the information technologies being used. In fact, those same technologies that reduce the number of in-person visits also present an opportunity for improving outpatient clinic environments for situations when an in-person visit is necessary. As technologies become more interconnected, more ubiquitous computing ecosystems and cyber-physical systems may become possible to incorporate into the design of outpatient clinic environments. We anticipate that these new technologies can enable the spatial and environmental flexibility desired by current outpatient practices through a responsive environment design approach.

Specifically, we see potential for architectural robotics to be involved in medical staff workflows, allowing for greater functionality within a given floor area. We present in this paper preliminary demonstrations of architectural robotics in virtual environments of outpatient clinic spaces, use cases of space transformations that were identified through field observations in medical facilities, and evaluate the feedback we received from medical professionals who navigated within those VEs. Overall, these VEs provide a means for evaluating whether the needs of outpatient medical staff are well identified and addressed.

For this study, we performed preliminary ethnographic studies observing medical staff working in current outpatient care facilities. Based on those observations, we developed two scenarios of how architectural robotics can transform clinic spaces. We then present feedback from nine medical professionals after they walk through virtual environments demonstrating those two scenarios. While the focus of this paper is on outpatient and ambulatory care facilities, we expect that the findings are applicable to medical facilities in general.

2 Related Work

2.1 Responsive Environments

While the term “responsive environments” has varied over time and different contexts, it generally refers to elements of a built environment that react to a stimulus of social (e.g., a person) or environmental (e.g., air temperature) nature [8]. Within these responsive environments, a range of explicit (e.g., a person turning on an air conditioner) and implicit (e.g., a thermostat determining space cooling needs) interactions providing that stimuli are possible [9]. A more specific definition of interest to our research is a responsive environment that can perceive people’s changing needs through a system of sensors [10] [11] [12]. Past research in responsive environments has developed means of modulating visual and auditory stimuli in office environments [13].

At the same time, forward thinking designs of outpatient clinics has focused attention on the static placements of digital screens and medical devices in the patient-centered experience [14] [15]. While much research has focused attention on optimal environmental features (e.g., lighting, noise levels, color, optimal room layouts, etc.), not much has been investigated on how those features could change in response to changes in people’s needs [3] [16] [17]. Similarly, past research has investigated flexibility strategies for inpatient medical facilities, presenting a gap in how responsive environment design approaches can improve outpatient clinic environments [2] [18]. Our work seeks to develop responsive features that enable dynamic interactions between users of outpatient clinics (e.g., medical staff and patients) and their surrounding environment. This approach will integrate clinics’ emerging technologies and ultimately enable more flexibility in how spaces can serve users’ needs.

2.2 Architectural Robotics

We consider responsive environments as an overall design approach. Architectural robotics, a term referring to intelligent machines at the scale of built physical environments, can be considered a cornerstone of

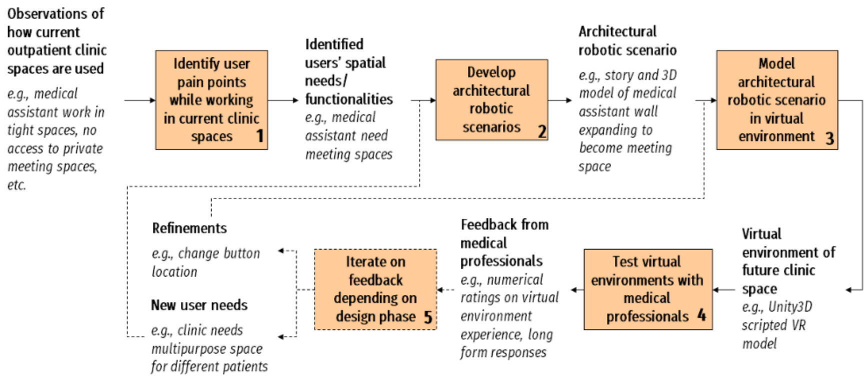


Figure 1. General process followed to identify architectural robotics use case scenarios for future outpatient clinics. Dashed lines indicate steps that lie beyond the scope of this paper to be pursued in future work.

responsive environments [12] [19] [20]. Architectural robotics, as a concept, proposes a connection between conventionally analog building features, such as interior wall partitions, and technologies typically categorized as building control systems (BCS). Two notable works serve as a point of departure for our vision in this paper. Houayek, et al. developed physical architectural robotic prototypes for novel work environments for designers in response to emerging technologies within the architectural design and office work domains [21]. In the context of healthcare, Threatt et al. envisioned an ecosystem of architectural robotics for a rehabilitation inpatient setting [22]. In contrast, our study focuses more on the needs of outpatient clinic spaces and developed architectural robotic use cases in response to emerging technologies in the healthcare domain.

It is important to emphasize that this paper concerns the role robotics can play beyond anthropomorphic (i.e., human-like) forms and outside of heavy surgery and intensive care applications in healthcare. Numerous research work has been done on how human-like robots can assist with healthcare, both as standalone assistants and arms for robotic surgery [23]. The term "architectural robotics" is used here to refer to autonomous and ubiquitous computing available for transforming the built environment [24]. Our study focuses on understanding the unique requirements of outpatient healthcare settings and how robotics at the scale of the built environment can satisfy them.

2.3 Virtual Environments

One major barrier to the implementation of architectural robotics is the cost of prototyping and mockups. While early/rapid prototyping is deemed essential for iterating on design options, designers are limited by the time and costs to produce high fidelity prototypes and mockups. Virtual reality (VR) is aptly suited for creating game-like environments for stakeholders to preview how to interact with architectural robotics in outpatient care facilities. Early virtual environment (VE) walkthroughs by medical staff can clarify their workflow requirements and point to better use cases for architectural robotics in outpatient care. Later in the design process, these virtual environments can inform specific usability and interface decisions (e.g., should a button be placed on a wall?) (Figure 1).

Notable among virtual environments research in healthcare is the study by Dunston et al., which used a cave automatic virtual environment (CAVE) set up to preview mockups of a hospital patient room [25]. Previous studies have used virtual environments for developing robotic prototypes both for healthcare and outside that domain [26] [27]. Our study utilizes virtual environments for testing architectural robotics and responsive environments, beyond the physical scale of human-like robot forms. Virtual environments afford designers the opportunity to test room-scale interactions, rather than passively previewing an architectural design.

3 Methodology

Steps taken to identify how architectural robotics could improve outpatient clinics are summarized in Figure 1. First, we set out to understand how current outpatient clinic spaces are used through firsthand observations of medical staff. These observations focused on how people interacted with the built environment (e.g., space usage patterns, sequence of navigations between spaces, etc.). Based on these observations, key workflow pain points were pinpointed using the identified patterns of interactions with existing technologies, clinic spaces, and space-to-space navigations (Figure 1, box 1). If multiple pain points all indicated a particular subset of clinic spaces, a scenario would be developed outlining how the architectural robotic transformations could resolve those pain points

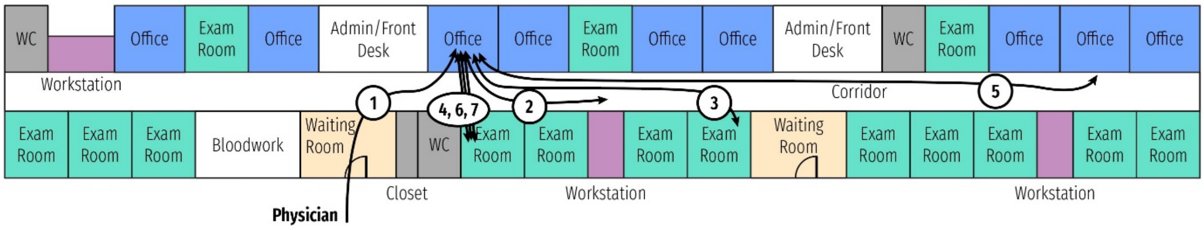


Figure 2. Navigation pattern mapping of physician in primary care clinic.

by changing a room's layout from one space type to the other (Figure 1, box 2). Two scenarios developed from this process are presented in this paper: *Scenario 1:* a physician's private office transforming into a patient exam room; and *Scenario 2:* a medical assistant work area transforming into a larger meeting space. Virtual environments demonstrating these scenarios were then built in a game engine platform, showing the transformations and user interactions needed to trigger them (Figure 1, box 3). Finally, an initial group of nine medical professionals were invited to test the scenarios in the virtual environments and provide feedback on the transformations enabled, its potential value to healthcare practices, and specific usability issues (Figure 1, box 4). This study utilizes virtual environments to test two specific architectural robotic use case scenarios in outpatient clinic spaces. Future studies will refine those designs to be more practical and usable while also identifying additional use cases, based on medical professionals' feedback (Figure 1, box 5).

Regarding the first step of observations, the research team conducted in-person observation of a primary care physician and his medical team over the course of an afternoon at an outpatient clinic. Field notes were taken recording the physician's actions and general notes about how the space was used by all medical staff. Observations focused on tracking the navigation patterns between spaces in anticipation that future spaces could minimize the time medical staff need to spend walking between spaces and improve their work efficiency. The physician's walking patterns within the outpatient clinic were recorded as shown in Figure 2 on the floor plan of the medical facility. Each line in Figure 2 shows an approximate walk path direction, labeled in the chronological order taken during the workday. Paths 3, 4, 6, and 7 show the physician walking between exam rooms to see patients. Path 2 occurred when the physician needed to check on a patient's status with a medical assistant at their workstation. Path 5 occurred when the physician's colleague needed help finding an empty office for a private meeting. These trends illustrate how the physician needs to primarily walk to exam rooms but also other areas for impromptu tasks. Field notes obtained from a different research study examining computer screen and equipment usage in an obstetrics and gynecology (OBGYN) clinic were also analyzed for identifying the patterns of how spaces were used. The walking paths of various staff (physician, physician assistant, etc.) were plotted onto the clinic floorplan (Figure 3). Similar to Figure 2, it was also observed that the physician primarily walks between exam room and office spaces as shown with red colored paths. Unlike the primary care physician, however, the OBGYN physician also occasionally sees patients in their office. Figure 3 also examined the walk path of other clinic staff. Physician assistants (Figure 3 in purple) and medical assistants (Figure 3 in blue) tended to also converge at the exam rooms, while surgical coordinators (Figure 3 in pink) remained in their office during the observed period.

These observations and navigation pattern mappings directly informed the development of architectural robotic scenarios for user testing. *Scenario 1: Office to Exam Room* was developed in response to alleviate the physician's need to walk between office and exam room, as illustrated in both Figures 2 and 3. By combining office and exam room into a single reconfigurable space, physicians can potentially save time walking. In *Scenario 1*, with a press of a button on the physician's desk, a sliding partition opens to reveal an exam table, consult desk, and display screen. The exam table reclines into a seated position and the display screen turn on automatically, providing an area for the physician to consult the patient while viewing electronic health records. Pressing the button again returns the room to the original office layout. *Scenario 2: Workstation to Meeting Space* was developed from observations in the primary care physician's clinic, where medical assistants

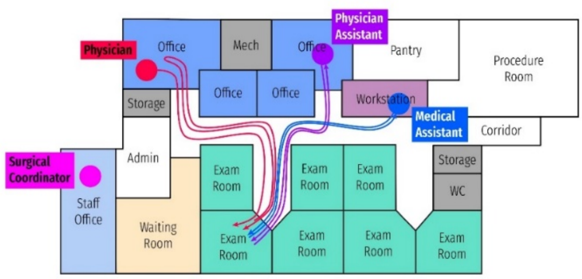
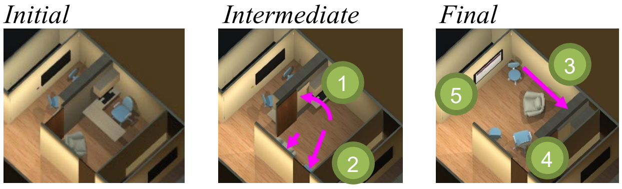
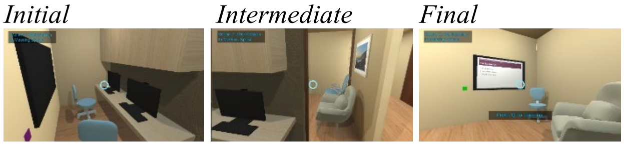


Figure 3. Navigation pattern mapping of medical staff in OBGYN clinic.

use the empty offices for privacy during lunch breaks and individual staff meetings. These pain points collectively suggested a need for medical assistants to have spaces to meet, especially given the smaller spaces given to medical assistant workstations (Figure 2). In *Scenario 2*, the medical assistant can press a button to activate a sliding partition wall, expanding their small workstation area into a larger meeting space. The expansion necessitates the adjacent office space to be compressed, requiring the office desk to fold up and chairs to be clear of the sliding partition wall before the transformation can be completed. The user is expected to press the button twice: once to begin the overall transformation, and again after confirming the office space area is clear and ready to be compressed. The same logic applies to returning the rooms to their initial layout but in reverse. Table 1 summarizes the details of these transformation sequences Both scenarios were developed from related paint points involving a pair of spaces (office/exam room, workstation/meeting space), which indicated the potential to be combined into a single reconfigurable space using architectural robotics. Scenarios were developed initially as stories defining a premise (i.e., when do medical staff need spatial transformations to occur) and a transformation sequence (e.g., "desk folds up, chair moves, etc.") (Table 1). The scenarios were then modeled in a 3D modeling software, where the exact sequence of transformations was planned to fit within spatial constraints (e.g., chairs fit through door, desk folds to provide more space, etc.). Both scenarios were modeled to occur within the same general area of a hypothetical outpatient clinic, with room sizes based on the floor plan of an existing outpatient clinic familiar to the research team. The 3D models were then imported into a game engine software, where the exact movements of the architectural robotic elements and interactions were scripted.

Nine medical professionals (8 physicians, 1 nurse informaticist), were invited to walk through the VEs demonstrating the two scenarios in individual testing sessions. During the testing sessions, participants ran the application on their own personal computer while sharing their screen to a researcher over web conference. Participants went through a training scene before the two

Table 1. Scenarios demonstrating future clinic spaces utilizing architectural robotics.

Scenario Name and Description	***Transformations***
Scenario 1: Office-to-Exam Room ***Premise:*** Participants were asked to imagine themselves as a *physician* in their private office. With all exam rooms full, the physician can transform their private office space into an exam room to consult patient. ***Transformations:*** (1) User presses button, office desk folds up. (2) Hidden partition wall slides up. (3) Exam table, consultation table, and large display screen comes out of hidden wall partition. (4) Exam table reclines upwards for patient to sit while facing display screen. (5) Display screen turns on showing health information and teleconference consult.	***Plan View*** *Initial* *Intermediate* *Final*  ***First Person Point-of-View (POV)*** *Initial* *Intermediate* *Final* 
Scenario 2: Workstation-to-Meeting Room ***Premise:*** Participants were asked to imagine themselves as a *medical assistant* at their workstation. With conference and meeting rooms all occupied, they must convert their space to a small group meeting room. ***Transformations:*** (1) User presses button, office desk folds up. (2) Office chairs move automatically towards the wall. (3) User presses button again, workstation-office wall partition moves. (4) Office chairs move automatically into place, grouped with medical assistant chairs. (5) Large display screen automatically turns on.	***Plan View*** *Initial* *Intermediate* *Final*  ***First Person Point-of-View (POV)*** *Initial* *Intermediate* *Final* 

scenarios to get acquainted with the VE interface (e.g., arrow keys for movement, how to press buttons, etc.). On screen instructions indicated possible actions to the participants while the researcher guided them through the transformations. Participants could stand, walk around, or sit in chairs to get a sense of space in as much time as they wanted before moving on to the next scenario. Afterwards, participants filled out a standard questionnaire to provide feedback on the robotic transformations, their potential value to healthcare practices, and point to possible scenarios to explore in the future. Initial findings are provided in this paper. Overall, the study focused on evaluating whether the architectural transformations met the needs of medical staff. Future studies may refine specific robotic features in each scenario, such as button interactions and self-moving furniture, to determine which are needed and practical for medical professionals to use.

4 Results and Discussion

Nine medical professionals gave feedback on the two scenarios. A majority (N=6) of the participants were primary care physicians. Two participants considered themselves specialist physicians (e.g., pulmonary medicine, etc.), one listed themselves as a nurse informaticist. Most participants (N=6) have more than 15 years of professional experience beyond medical school, while the rest had less. The questionnaire asked them to also specify the percentage of their time spent in various clinic space types (e.g., exam room, private office). An aggregated percentage of time spent by all the participants is presented in Figure 4. Participants spent a majority of their time (81%) in an exam room, private office (i.e., a room used only by the participant), or shared office (i.e., a room used by multiple people simultaneously or different times over a workweek). Only 2% of the clinic workday was spent by all participants at an auxiliary workstation like the starting space for *Scenario 2*. When asked on their experience with 3D modeling/game applications, most participants stated having some experience (N=6) while the rest stated no experience (N=3).

When asked to rate the statement “I find the transformations presented in both scenes to be a necessity, given limited space within current clinics and trends in medical practice,” 55% of participants strongly or somewhat agreed (N=5), and 44% neither agreed or disagreed (N=4). When asked specific questions about each scene’s transformations’ potential value to healthcare practices, participants had consistent responses as seen in Figure 5. A majority of participants agreed (strongly/somewhat) the premise of *Scenario 1* (N=7) and *Scenario 2* (N=6) were commonly observed in their clinics. A majority (N=8) of participants agreed that *Scenario 1*’s transformations could provide a better experience for patients, but some (N=3) questioned whether the scenario would help physicians work more efficiently. Six of the respondents felt that *Scenario 2*’s transformations would help staff with finding meeting space and work together, and hence improve work efficiency (Figure 5).

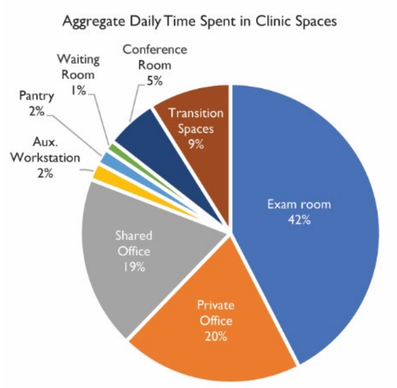


Figure 4. Percentage of time spent in clinic spaces by all VR user test participants.

Long form questions asked participants to elaborate on their ratings of overall experience and applicability to healthcare and their responses were generally positive. One participant especially liked *Scenario 1*’s concept, noting from their experience that patients tend to feel more comfortable speaking to their physician in a private office. Those who disagreed that *Scenario 1: Office to Exam Room* (N=2) would help physicians work efficiently stated concerns that the folding desk would have to be clear of items before the transformations began, and exam table surfaces would need to be sanitized after patient visit, per common health safety practices. While they noted that they see an increasing prevalence of “multiuse spaces” over private offices, some questioned the relevance of these scenarios given COVID19 and the prevalence of telemedicine. Though some participants saw *Scenario 2: Workstation to Meeting Space* as potentially helpful to nurses and medical assistants, others raised concerns regarding how the transformations could be used for natural ad hoc meetings and maintaining privacy. These responses conveyed that while participants found the general idea of space transformations valuable and applicable, they questioned the two specific scenarios presented in the virtual environments.

Overall, the virtual environment experiences spurred participants to point to other clinic use cases to consider at larger scales, such as how these transformations could assist the rest of the patient experience beyond the exam room and the entire clinic floor space. These suggestions indicate while there is a general positive interest among medical professionals in responsive environments, there

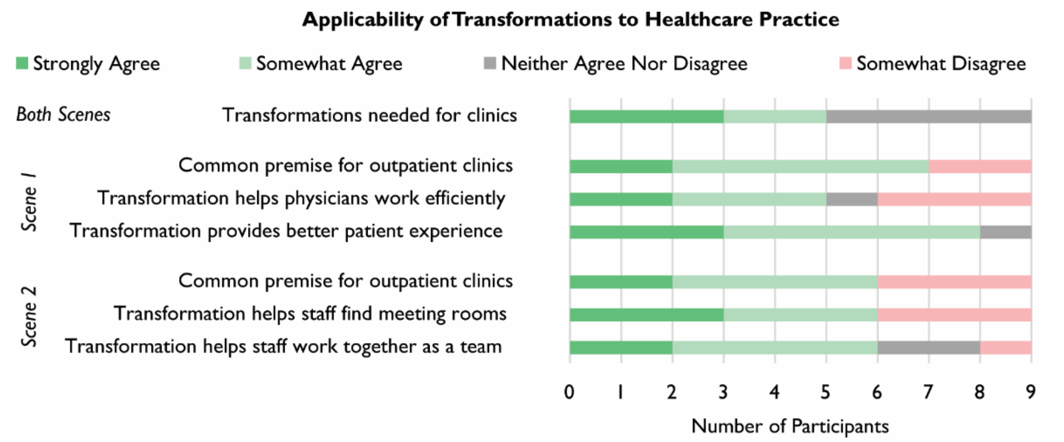


Figure 5. Participant responses on how applicable architectural robotic transformations are to healthcare.

are potentially other architectural robotic use cases that can better address the needs of outpatient medical staff. Additionally, scenarios demonstrated here are examples of explicit interaction between users and environments, where changes in layout are activated by button presses. New use cases in outpatient clinics and implicit interaction mechanisms for changing environment layouts will be developed and presented in future publications.

5 Conclusion

Responsive environments and architectural robotics have a potential to address the need for greater flexibility in medical facility spaces, especially in outpatient and ambulatory care settings. Our preliminary study showed a positive interest among medical professionals for the applicability of responsive environments and architectural robotics in medical settings. Their feedback provided specific concerns and suggestions, which prompt us to investigate other potential use cases in clinic spaces in future studies, beyond the two scenarios presented here.

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