SHARE-C: Social Healthcare Assistive Robot within a Lebanese Engagement Context

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Patients in isolation rooms fall into two groups: immunocompromised individuals, who are vulnerable to infections from others, and highly contagious patients, who pose a risk to others. To mitigate these risks, reducing physical interactions is essential. While medical professionals are needed for critical tasks, other routine tasks can be performed by less-skilled workers. This study focuses on designing a social-service healthcare robot that can handle basic tasks, serving as an *assistive* device rather than a replacement for medical professionals. The goal is to create a self-disinfecting, socially acceptable robot tailored for Lebanese patients in isolation rooms using the Social Robot Co-design Canvasses (SRCC) framework, grounded in human-centered design (HCD) principles. Insights from interviews with patients and medical staff informed the robot's design, which was subsequently validated through additional interviews with similar groups. The design process considered users' preferences for appearance, operation, and communication, balancing these with functional and engineering constraints. The article details the robot's mechanical design, manufacturing, and assembly, providing a template for future development. Results show that the SRCC-based design meets the necessary requirements and, with proposed improvements, would be suitable for broader hospital deployment.

CCS Concepts: • **Human-centered computing** → *User centered design*; *Field studies*; *Participatory design*; **User interface design**; • **Applied computing** → Consumer health;

Additional Key Words and Phrases: Social robots, Service robots, Human-robot interaction, Co-design framework, Healthcare assistive robots, Self-disinfecting, Isolation room

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1 Introduction

Social robots are robots that can communicate and interact with people while maintaining social rules. They could be used to stimulate feelings and to be companions [1]. It is not uncommon for social robots to also perform assistive tasks (e.g., delivery), which places them under the "service" robot category, becoming social-service robots. The application of such robots in hospitals has steadily increased since 2011 [2], mirroring the overall rise in the use of robots in healthcare [3], with a surge during the **Coronavirus disease (COVID-19)** pandemic when they were used as assistive tools. Implementing robots in medical facilities aims to improve healthcare services by relieving medical staff from routine tasks and allowing them to dedicate more time to care for their patients. Minimizing the risk of spreading infectious diseases between patients and staff is also a priority. According to the **World Health Organization (WHO)** [4], implementing social robots in healthcare has positively affected the mental health of patients and staff by improving communication, decreasing pain, lowering stress levels, and fostering emotional connections.

These robots could also operate in hospital departments that deal with critical cases, such as immunocompromised (e.g., cancer, acquired immunodeficiency syndrome, and transplant recipients on immunosuppressants) or highly contagious (e.g., COVID-19, severe acute respiratory syndrome, methicillin-resistant staphylococcus aureus) patients. These environments are well documented to have adverse effects on isolated patients, especially when it comes to mental health and negative emotions [5]. Fear of illness tends to be one of the driving factors of the negative outcomes in patients and medical staff alike [6]. Such fears persist because, despite precautions, multiple accidents still occur, as witnessed during the COVID-19 pandemic with the large number of infections among healthcare workers. The WHO reported that around 1,15,000 healthcare workers lost their lives due to COVID-19 between January 2020 and May 2021 [4]. Furthermore, the mental health of medical staff was also a significant concern during the pandemic. In Lebanon, the target country for this study, Youssef et al. [7] stated that 86.3% of respondents from the 1,751 active healthcare worker participants reported personal burnout. Healthcare workers also feared exposure to pathogens, faced communication difficulties due to **Personal Protective Equipment (PPE)**, and experienced discomfort dealing with the logistical challenges of wearing PPE. The study noted, "the requirement to wear PPE added extra time to tasks and triggered concern about the risk of contracting the virus if mistakes were made." From the patients' side, it was reported that those in isolation rooms "experience more preventable adverse events and express greater dissatisfaction with their treatment" [8]. Bendjelloul et al. [9] stated that patients were disappointed with delayed responses from healthcare workers, and Digby et al. [10] highlighted concerns about the patients' nutrition due to their food being often left outside isolation rooms until a clinician, while taking necessary precautions, could bring it inside, sometimes hours later.

Shen et al. [11] highlighted the advantages of using robots during the pandemic, including reducing unnecessary contact and automating tasks. Georgadarellis et al. [12] also highlighted that robots could reduce burnout and that "nurses welcome robotic technology that reduces their workload." As these robots would inevitably be in contact with patients and medical staff, special attention must be paid to their social aspects. To gain further insight into the state-of-the-art of social robots in healthcare, a literature survey was conducted and its results are summarized in Table 1. From these results, trends in social interactive robots in hospital and healthcare settings can be categorized into three main types based on their aims and functionalities, as explained next.

- Social support, mental health, and emotional care robots aim to socially engage with people using interactive features to promote positive emotions, wellness, and mental health improvements. These robots are without telepresence capabilities; even if possessing the features, their application for telepresence is not mentioned, demonstrated, or intended. They also do

Table 1. Examples of Surveyed Social Robots in Healthcare Settings

Type of Robot	Robot	Features
Social support, mental health, and emotional care robots	Arash [15]	Humanoid mobile robot buddy developed to interact with children aged 5–12
	Haru [16, 17]	Social communication robot with large language model (LLM) speech abilities
	PARO [18]	Therapeutic seal-shaped robot for stimulating patients with cognitive disorders
	Silbot [19]	Humanoid social robot for helping elderly people with mild cognitive impairment
	RYAN [20]	A social robot with a distinctive face display system for elderly care
	ROBIN the Robot [21]	A social robot for mental health support in pediatrics and geriatrics
	Little Casper (MBOT) [22]	Autonomous telepresence robot with social features (eyes, mouth, speech)
Social telepresence robots	Pepper [23]	Socially interactive robot that performs autonomously and provides virtual contact
	ARI robot [24, 25]	Humanoid socially assistive robot with a focus on elderly care, with gaze and telepresence features
	Tommy [26]	Social humanoid telepresence robot that can also allow for tele-monitoring equipment in the room
	Welli [27]	Social telepresence robot with communication features and autonomous operation
	InMoov Explorer [28]	A social robot for sick children to tour areas using virtual reality (VR)
Service active worker social robots	Moxi [29]	A nurse assisting social robot with an arm and autonomous navigation for items delivery
	Robear [30]	Social care robot with a bear's face and the ability to lift a human
	Aeo [31]	Social robot nurse with two arms and an autonomous system to perform a variety of tasks
	Garmi [32]	Social robot nurse with two arms to perform diagnostics and support for geriatric care
	Florence [33]	Social nurse assisting robot that can take patients' vital signs
	Aucari [34]	Hospital delivery robot with social aspects and intelligent conversation skills
	Wassi [35]	Walking aid therapeutic robot with social interactive features
	Sayabot V3 [36]	Humanoid hospital delivery robot that can also support patients in walking
	Sona 2.5 [37]	Humanoid hospital delivery robot

not undertake active tasks, as per the date of this study. In general, the social aspect of robots in this category is more developed than most of the robots in the remaining two categories because it is their main function.

- Social telepresence interactive robots allow patients, healthcare staff, and family members to be virtually present in a different location, whether in the patient's room, family home, or other places, while also being able to generate interaction using only their social features without telepresence (some more than others). These robots also do not perform any active tasks, as per the date of this study.
- Service active worker social robots are interactive and perform specific tasks that are usually part of the nurses' daily routine, typically requiring locomotion and manipulation.

Remark. As robots' capabilities advance, the three categories above become more intertwined, with fewer strictly single-purpose robots, as demonstrated in [29]. The robot designed in this article also does not strictly fall into a single category. Additionally, the listed robots can gain new functionalities via new hardware or software, enabling them to perform expanded tasks. The proposed categorization aims to simplify detecting prior trends and approaches in designing social robots to achieve their intended goals.

The robots considered relevant to be classified under the above categories have clearly recognizable social and interaction features, including but not limited to, the presence of a face, humanoid-ism, pet- or animal-likeness, conversational ability, and the allocation of noticeable effort into the "form" side of the *form-function* balance. In essence, the considered robots are ones that are able to generate interaction on their own using their aforementioned social features. With the increasing number of social robots across various industries, including healthcare, it is no longer sufficient to only have a microphone, screen, and camera for interactivity, as newer non-social robots already have these components. For example, multiple non-social pure telepresence robots that lack the aforementioned social features, such as Beam, Giraffe, and Double 3 [13], were used during the COVID-19 pandemic in a research context, and Ava [14] was used in real hospital settings. While these robots facilitate social interaction between humans, they cannot be considered social robots that can generate social interactions independently, unlike the social telepresence robots mentioned in Table 1. Pure telepresence robots function essentially as "tablets on wheels," offering minimal social presence or user embodiment, often due to limited control by the remote person. Social telepresence robots, in contrast, exhibit a spectrum of representations. They can act as distinct social entities facilitating telepresence (e.g., Pepper) or become direct avatars when their native identity is suspended for full remote control (e.g., InMoov Explorer's "virtual world to real-world transformation," potentially via VR). This dynamic representational flexibility is unique to social telepresence robots, distinguishing them from the minimal embodiment of pure telepresence units and the consistent personas of other non-telepresence social robots.

This also applies to active worker robots without a significant social interactive aspect, such as the Human Support Robot [38] and Valky [39], as well as delivery robots like the Tug [40], HOPSI [41], and Cheetah Mobile robots [42]. Even the national health service Milton Helper Bot [43], which has the external appearance of a large penguin, cannot be considered a social interactive robot as it only delivers medication to patients and does not use its appearance to generate interaction. That said, such robots cannot be discounted as not useful for designing social interactive robots in hospitals and healthcare, as they have proven efficacy or adoption in those settings. It is also important to keep in mind the various social robots found outside of direct healthcare in places like households, restaurants, hotels, and educational institutions, both in ones on the market (e.g., Lovot [44] and Orihime [45]), as well as from the research community (e.g., MeBot [46], Robovie [47], Tega [48], and Snackbot [49]). However, given the unique demands of hospital environments, it is crucial to carefully assess design concepts from non-medical robots. These may not meet strict safety, regulatory, or sanitation standards nor be optimized for patient care or clinical workflows.

Being *social* robots means that **Human-Robot Interaction (HRI)** is crucial, with many factors influencing its quality. Vichitkraivin et al. [50] identified several barriers to the acceptance of social robots by healthcare workers, including resistance to change, implementation and adaptation time, and technological illiteracy. Resistance to change occurs when medical staff do not see the need for new tools or do not appreciate their benefits. The implementation and adaptation barrier arises from the lengthy process required to prepare a robot for deployment in a specific department. The barrier of insufficient technological knowledge stems from a lack of familiarity with robots and inadequate staff training where Such issues could be effectively addressed through proper mentorship and training programs.

Similarly, there are barriers to patients accepting healthcare robots. According to Cresswell et al. [51], a main hurdle is patients' lack of previous exposure to robots since many hospital robots deployed today do not interact with humans. Another significant barrier is the robot's physical appearance where some human-like traits are desirable, but excessive anthropomorphism can quickly decrease acceptance. This decline occurs for two reasons: highly human-like robots create unrealistic functional expectations, leading to disappointment; and they increase fear of human replacement by robots [51]. Previous studies have emphasized that a robot's appearance can significantly influence a user's expectations, perceptions, and evaluations of its behavior and capabilities. Masahiro Mori proposed the "Uncanny Valley" concept [52], which illustrates that as a robot's appearance and actions become more human-like, emotional responses improve until a certain point, after which they become negative.

An important factor for achieving harmonious acceptance of robots and a smooth HRI experience is understanding the background, culture, and attitudes of the targeted population. Previous cross-cultural studies in HRI have motivated this research aspect, but in the absence of studies specifically focused on the Lebanese population or conducted within Lebanon, this work references research from the broader Arab or **Middle East and North Africa (MENA)** region—where Lebanon is situated—as well as studies involving Lebanese participants residing abroad. These sources served to establish a preliminary evidence base to inform the project's conceptual orientation and methodological approach prior to its formal commencement. In a series of studies on the impact of culture on HRI participants from Egypt and Japan engaged in simulated video conferences with robots speaking Arabic or Japanese [53]. Experimenters assessed likability, cultural closeness, and perceived safety. The results showed that participants preferred robots that matched their cultural background and exhibited discomfort when interacting with robots that did not comply with their cultural norms. Culture also influences how people generally perceive and accept robots. For example, an exploratory study [54] in Arab countries within the MENA region used Ibn Sina—a humanoid robot designed to converse in Arabic and modeled after a historical figure. The study found that people across the region generally held positive attitudes toward the robot. In particular, participants from the Gulf region had more positive attitudes toward this humanoid robot than those from Northern Africa, which is logical because MENA countries represent a wide range of cultural views, even though they are generally referred to as "Arabs." The participants (18) from the specified Shaam region, which includes Lebanon, showed a slightly lower **Culture Education and Domestic Attitudes toward Robots (CEDAR)** scale average score than those from the Gulf (a higher score reflects more positive attitude) with a slightly larger spread as well as a higher average with less spread than those from Northern Africa. However, the study was more focused on developing methods for the attitude assessment (CEDAR questionnaire) than explaining the reasons behind the attitudes (technological literacy, exposure, etc.).

An interesting study by Mavirdas et al. [55] explored acceptance attitudes toward human-like robots in the Middle East, with a focus on the robot's location and its tasks, by administering a questionnaire to participants (355 from various regions) who had interacted with the same Ibn Sina robot. The results showed that participants preferred the human-like robot when it "cleaned their house" and "was (present) in their workplace" more than "treated them at the hospital," but participants from the Shaam region (eight of them were Lebanese) had neutral responses to the hospital context. However, the study posed the question as the robot "treating" the participants in the hospital without specifying the exact tasks performed, which could have been understood as the robot fully replacing the human doctor/nurse, possibly contributing to the attitudes. This formulation and ambiguity leaves room for further exploration and motivates this study to be more specific about the tasks that the robot performs.

To that cultural end, a deeper understanding of Lebanese culture and its aspects was required for the progression of this study. Boujarwah et al. [56] provide insight on the implication of cultural nuances on assistive technology through their framework that exposed these nuances in aspects like linguistic, social integration, monetary concerns, and so on. In an attempt to mirror that approach and explore those nuances for the case of Lebanon, it was noticed from the research that there is, in essence, no presence of a singular unified or dominant Lebanese culture. Instead, Lebanon can be characterized by the "presence of diverse and unintegrated subcultures" [57]. In that sense, it would be more relevant to think of this multi-subcultural aspect as a Lebanese cultural context, as adopted by Soubra et al. [58]. However, this is not to say that there is a lack of overlapping points between the subcultures that could be used to enhance robot acceptance, but it is to say that the intended cultural features of the robot must be observed from that subcultural context to make sure that it does not unintentionally stray in one direction and lose relevance to the others.

Furthermore, not all components of this context are relevant to the hospital environment or to the design of social robots—for instance, political dynamics or the complexities of a multi-religious society. Hence, it becomes important to select, with the stakeholder profiles in mind, the cultural components to be considered for features in the robots and the ones to be avoided. This narrows focus down from the overarching cultural abstraction to the immediate day-to-day manifestations and reductions of these abstractions in the real world. For example, while language and mannerism is an overarching cultural theme, when it is applied to this use case, it reduces into greeting, facial expressions, approach, as well as other manifestations that can be observed and designed for. The same holds true for the esthetic and materially tangible aspects of culture, which reduces to color, attire, gender expression, body shape, among others. With this reduction in complexity, it becomes easier to find the overlapping points between subcultures, like phrases that every Lebanese person can understand and to identify cases when this overlap does not exist, like the lack of culturally universal attire. Designing a robot with cultural awareness does not necessarily mean only the addition of culturally relevant features, it could also be the reduction or avoidance of culturally polarizing or irrelative ones. The latter aspect is supported by Cumbal et al. [59] who stated that stereotypical nationality representations have an overall weak effect in the interactions with their participants, and that the robot's appearance may be less relevant than other factors like behavior. Another study by Makatchev et al. [60] conducted on the effect of Arabic and American ethnically expressive robots also speculated that obvious and excessive ethnic cues like clothing or appearance could be potentially offensive and undesirable, while also concluding that ethnic representation though behaviors affected attribution but not homophily (bonding through similarities). This indicates that making the robot stereotyped in appearance could have an overall negative effect and best be avoided.

It is important to note that a clearly defined, culturally significant perception or attitude toward robots has yet to meaningfully emerge in Lebanon, where exposure to robotics remains limited as compared to countries with more exposure like Japan or America [61]. Most of the exposure to robots comes from Western or Eastern media, which results in vast differences in that exposure between individuals based on their consumption of that media. This lack creates a gap in the number of features that can be ascertained from the cultural component alone, which necessitates the use of conclusions about these features from literature that may be culturally agnostic or based on the consensus from the global multicultural environment. This study, therefore, provides insights on how well the features from that literature hold up in the Lebanese context, and it seeks to contribute to the understanding of how the Lebanese cultural attitude toward robots evolves, as robots gradually become more mainstream.

One approach that integrates aspects of cultural awareness into the product development process is the **Human-Centered Design (HCD)** method, where "the main goal of HCD is to increase the usability of the product to create maximum user satisfaction and increase the safety performance of the device" [62]. The HCD method is an extension of the user-centered design method where the target was expanded from the end users alone to cover all of the relevant stakeholders [62]. This is important in the context of social robots in healthcare as there are multiple stakeholders including the patients, medical staff, and hospital administrators. In recent years, several attempts were made to add special contexts to the HCD process; in the context of social robots, a notable framework—**Social Robot Co-design Canvasses (SRCC)**—was proposed by Minja et al. [63].

When designing robots that interact with humans, the SRCC framework, which is iterative like HCD, is particularly suitable as it facilitates integrating the multidisciplinary aspects of social robots to ensure that the final product is well accepted by the target stakeholders.

This work draws inspiration from the various works in HRI that focus on designing robots accepted by humans and incorporating relevant cultural identities. The main goal is to improve healthcare services, using assistive technology, by designing a social delivery service robot that aids in hospitals and is accepted by healthcare workers and patients. The motivation behind the concocted robot stems from the hypothesis that immunocompromised and highly contagious patients placed in isolation rooms, and their healthcare providers, perceive a lack of a safe and efficient method to deliver and retrieve noncritical items during the isolation period, and are burdened by this perception.

The hereby proposed robot's name, SHARE-C (pronounced "sharik," which means "to share" in Arabic), embodies its purpose of *sharing* the concerns of patients and healthcare workers by aiming to reduce the risk of disease transmission from limited encounters with human subjects. SHARE-C is an *assistive* robot designed to help nurses with their routine tasks that do not require their expertise, such as delivering and retrieving non-medical items from patient rooms. It features the design of a novel self-disinfecting system intended to allow it to safely enter and exit patient rooms, which could possibly limit the spread of contagions due to the reduced contact between patients and healthcare workers, thus minimizing their negative experiences. It is worth noting that we focus on the human factor/acceptance aspect of the self-disinfection feature and not the sterilization efficacy aspect in a microbiological sense, which remains to be validated in subsequent iterations. This focus stems from a human-centered belief that the self-disinfection system must be first accepted by the medical staff and patients to value its benefits; otherwise, they would reject the solution even if it is flawlessly engineered. Numerous examples exist of well-engineered medical products that ultimately failed due to lack of user acceptance, even within research and academic contexts, we discuss a few next. A study by Eccles et al. [64] attributed the lack of noticeable effect of a novel computerized decision support system for asthma and angina management to "low levels of use of the software, despite the system being optimized as far as was technically possible." Another study by Theis et al. [65] examined a failed trial of a diabetes self-management application. Although the application was adopted and launched based on promising clinical outcomes, it ultimately proved unsuitable for users. The failure was due to the lack of validation of the human factor and user acceptance, which could have revealed the mismatch earlier. On the other hand, Schwartz-Lasfargues et al. [66] reported the successful deployment of a user-centric connected sensor system in colorectal surgery, emphasizing the importance of early adoption indicators and avoiding irrelevant technical developments. They also noted that starting with technical work can be counterproductive, if not aligned with real-world needs. Therefore, it is crucial to validate SHARE-C's acceptance before delving into the self-disinfection system's efficacy and investigating the types and numbers of eliminated contagions, which is the next step in the iterative design process.

Another potential significant benefit of the self-disinfection feature, as perceived by the medical staff, could be reduced PPE usage including gloves, face masks, gowns, head covers, and shoe covers. Additionally, the robot could decrease the time needed to attend to patients' needs, as staff could use the robot to deliver or retrieve items without the need to don PPE. Furthermore, SHARE-C's design supports the future utilization of telepresence capabilities, enabling safe socialization for isolated patients with their visitors and facilitating safe interactions with doctors during regular checkups. Also, given that humans tend to favor robots that match their cultural backgrounds, linguistic features (in the Lebanese dialect) were implemented to better position SHARE-C within the Lebanese cultural context. To the best of the authors' knowledge, this study presents the

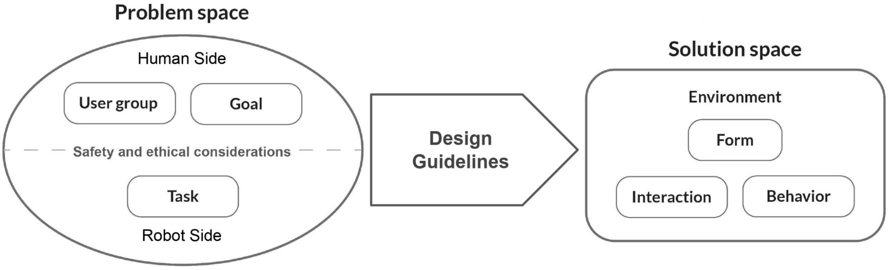


Fig. 1. SRCC framework overview (adapted from [63]).

first attempt at implementing a social healthcare robot that is custom-designed for acceptance by patients in Lebanon. Furthermore, this work provides a detailed framework for designing such robots, which could be adopted by other researchers or engineers for similar applications.

The rest of this article is structured as follows. Section 2 details the SRCC framework that was followed to design the main features of the robot, by going through the main steps of the design process, the information gathered from human subjects, the mechatronic design of the robotic system, and the validation of the concocted design. Section 3 discusses additional aspects of the obtained results to demonstrate the robot's ability to meet the design specifications and stipulated requirements. Section 4 provides an outlook into future work to improve the robot's design based on the iterative nature of the SRCC process, and Section 5 concludes the article.

2 Method

Robot SHARE-C was designed by following the SRCC framework and applying its main steps, shown in Figure 1, to arrive at a suitable prototype that satisfies the needs of all stakeholders. There are three stages to the SRCC framework: definition of the problem space, creation of the design guidelines, and integration into the solution space.

2.1 Definition of the Problem Space

To define the *Problem space*, the problem must be examined from both the users' and the robot's perspectives, and then ethical considerations must be examined.

2.1.1 Users and Robot Perspectives. The problems discussed in Section 1 include negative perception of health safety risks, loneliness feelings, and inefficiency when items are being delivered to/from patients placed in isolation rooms. This problem statement identifies two user groups: the patients and the medical staff, and the proposed solution entails a social robot. To further understand the users' needs and characteristics, as well as the robot's tasks and advantages, interviews were conducted with patients and medical staff members of the **Bone Marrow Transplantation (BMT)** unit at the **American University of Beirut Medical Center (AUBMC)**. Ten patients who had already checked out of their isolation rooms and 10 medical staff who were/are (at the time) directly involved with isolated patients were interviewed to assess the problem's significance and gather their feedback on using a social robot as a solution. They were asked about their preferences for the robot's shape, tasks, and the adaptability of healthcare workers to new technologies.

In this step, the data obtained from interviews with patients and medical staff were analyzed. Since the collected data are qualitative, the thematic content analysis method [67] was employed given that it deals with the analysis of verbal, written, or visual communication messages and is commonly used in interview analysis [68]. The method first performs open coding of qualitative

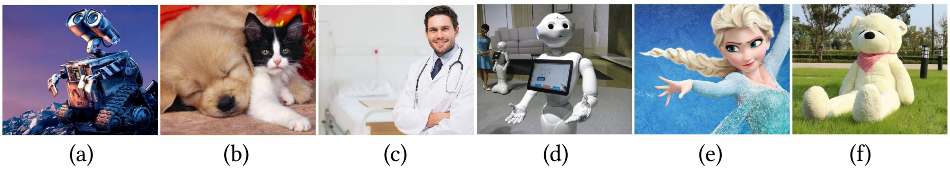

(a) (b) (c) (d) (e) (f)

Fig. 2. Samples of photos shown to patients to choose from (Phase-1). (a) Wall-E, (b) cat and dog, (c) doctor, (d) Pepper, (e) Elsa, (f) teddy bear.

data, which was in the form of conversations, to assign concise labels, for example words like "mahdoum" (meaning cute in Arabic) were assigned the code "Positive_Cute" and mentions of risks from non-medical staff were assigned the code "NonMedStaff_Risk." Then, axial coding was utilized to classify the *open codes* into *broader categories*, for example "Positive_Cute," "Positive_Friendly", and "Positive_GnrlAppearance" were grouped under the broader category of "Aesthetic Appeal"; while "NonMedStaff_Risk," "MedStaff_Risk," and "AllVisitor_Risk" were grouped under "Perceived_PhysicalRisk." These were tracked through frequency (number of mentions) and valence (positive or negative). Finally, the broader categories were synthesized into high-level *themes*, which were used as the primary inferences from the data; for example: "Patients perceived physical risk when anyone, clinical or not, entered their room."

The interviews were conducted over a period of 2 months based on the availability of experienced isolation room medical staff members and former isolation room patients. The interviews were conducted in a meeting room at AUBMC, the language used during the interviews was in the Lebanese Arabic dialect, and the results were translated to English to be included in this study.

Patients' Data Analysis. Ten Lebanese patients were interviewed in the first phase of this study: six females and four males, whose ages varied between 24 and 60 years old. It is important to highlight that the number of participants is relatively small due to the small number of BMT patients during the interview phase. Seven primary questions (Q1–Q7) were posed to former BMT isolation room patients; each question and its recorded responses are shown next. These questions were asked as-is, and clarifications were only provided in case any aspects were considered unclear. To ensure that the interview analysis covered the needed information, follow-up questions were formulated to help transform qualitative data into quantitative data.

Q1: What problems or risks did you (the patient) face during the isolation period?

This question was asked to identify each patient's discomforts and main pain points; 60% of the participants stated that there is a risk to their health when people enter their rooms. Further, the biggest concern was the lack of safe methods when the cleaning staff members cleaned their rooms or when non-medical staff members entered to deliver non-medicine items.

Q2: (a) Do you (the patient) consider a robot a good solution for the existing problems? (b) What is your attitude toward such robots?

This question was to validate whether a robotic approach could be accepted, or if there is a need to pivot. 90% of the participants considered that using an assistive robot could help reduce health risks by performing some of the tasks usually performed by the staff, consequently decreasing the number of persons inessentially entering their rooms. In addition, 78% had a positive attitude toward robots and were supportive, as long as the robots do not completely replace the medical staff, but rather assist them, which is in line with the scope of this work.

Q3: Of the six images shown in Figure 2*, which is the closest to your mind when you think of a robot in the hospital that could have interacted with you when you were inside the isolation room?*

This question serves to provide an understanding of the perceptions that patients have of what a robot could look like and to guide the design process in that direction: Wall-E (Figure 2(a))

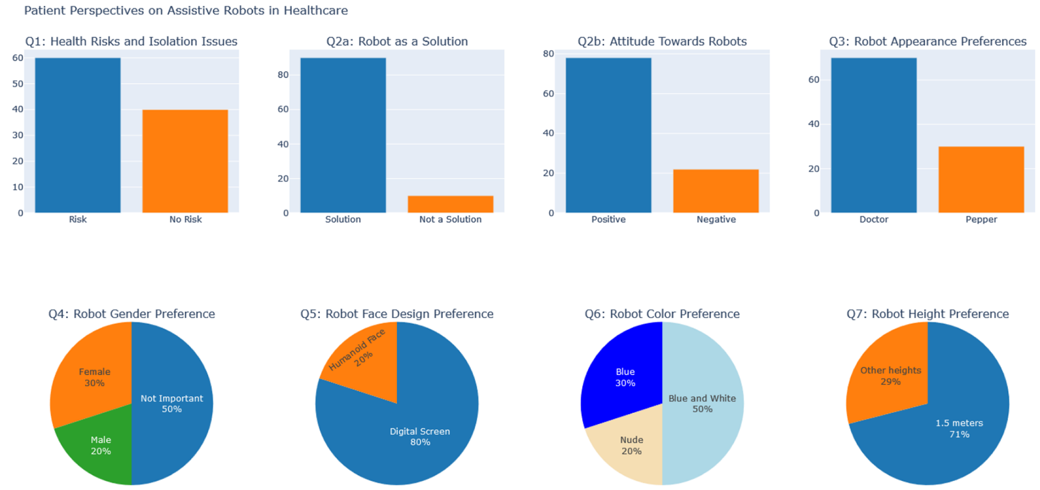


Fig. 3. Results of patient interviews.

indicates a preference for a more mechanical and less humanoid appearance on the robot, similar to the non-social active worker robots in [38–40] and [41]. The cat and dog image (Figure 2(b)) indicates a preference for a pet-style fluffy robot like PARO [18]. The doctor image (Figure 2(c)) indicates a preference for a humanoid robot closer to a doctor/care worker appearance. Pepper [23] (Figure 2(d)) indicates a preference for aspects of modern social humanoid robots like the ones in Table 1. Elsa (from the movie *Frozen* in Figure 2(e)) indicates a preference for cartoon-inspired humanoid robots. The teddy bear (Figure 2(f)) indicates a preference for more toy-shaped or animal-inspired robots like Robear [30]. The most chosen characters were the doctor in Figure 2(c) (70%) and Pepper in Figure 2(d) (30%). As stated by the patients, the doctor figure was chosen based on their familiarity with doctors and their daily interaction with them, whereas "Pepper" was chosen because they perceived it as an *assistive* robot that could carry on such a job. Also, patients stated here that they preferred the robot to have arms and shoulders in its upper torso like Pepper. This was understood to be a preference for a humanoid robot with modern social features and closeness to doctors.

Q4: Do you (the patient) prefer a specific gender for the robot?

The goal of this question was to determine whether gendered features on the robot should be included in the initial design stages or not; 50% of the participants considered that the robot's gender was of no importance to them. The ones who chose the female gender (30%) based on their feelings that females are usually "gentler" while dealing with patients. Had the results been skewed in favor of a gendered robot, further investigation into the specifics of that aspect would have been conducted.

Q5: Do you (the patient) prefer a digital screen for the face design or a humanoid face?

Given that the face of a social robot is one of the most important and interactive features, it was crucial to understand its preferences at an early stage. The preference for the face design was to use a digital screen, as indicated by 80% of the patients who chose that option. It was claimed that the facial expressions would look "cuter" with a screen. Others considered that having a screen would allow more than one facial expression. Had the results been the opposite, further investigation would have been needed to determine the preference for a static humanoid face, an animated one, or something along the lines of Ryan [20] with a face that has both humanoid features and a digital screen.

Q6: What color should the robot have?

As the robot's color is a clearly noticeable feature, it can provide insight into the patients' preferred first impressions of the robot upon seeing it. This question also has a qualitative component: if the answer follows a style of "Brown like a furry bear" or "Grey like a big metal machine," it would provide further insight into the design preference more than the color itself. While this question was somehow open-ended, all of the answers centered around three colors: all blue, a mix of blue and white (similar to the color of the nurse's clothes at AUBMC), and Lebanese/Mediterranean skin complexion locally referred to as "Nude." The blue and white mix choice (50%) was preferred because patients indicated that such "relaxing" colors make them feel comfortable, where the blue is preferred to be of a lighter shade, which is in line with the findings in Liberman-Pincu et al. [69] that darker colors are perceived as more threatening than lighter ones.

Q7: What should the robot's height be?

This question was important for the design process as it determines the external appearance, internal structures, and whether the robot requires a mechanism to elevate or lower the delivered item to bed level. While this question was open-ended, the results ranged between 150 cm and 160 cm, as patients considered that the robot's height should not exceed their own, and it should be a bit shorter than an average adult, thus 71% thought that it should be around 1.5 m.

To gain more insights into the robot's features, further open questions were asked to patients to provide their suggestions. For instance, the surveyed patients considered that having an interactive robot (with audio communication and varying facial features) would make them more inclined to accept it, and it can be used for entertainment during their relatively long stays in isolation (21–28 days post-BMT procedure). As for the shape, they indicated that it would be better for the robot to have shoulders and a contoured waist.

Since SHARE-C was intended to be a robot with a Lebanese engagement context, it was also important to understand whether there are cultural influences in the patients' answers to the questions. Cultural variables can be explicit or implicit with cultural biases being relevant to both [70]. An example of an explicit cultural bias would be a patient's preference for the robot to be clothed in the country's or culture's traditional attire, something not uncommon in social robots (e.g., Sophia wears a traditional Korean outfit [71]). On the other hand, implicit cultural biases are harder to detect and could go unnoticed until testing or even after deployment. For instance, in a culture where the job title "doctor" is held in very high regard, this would have a unique influence on the choice of robot color (most doctors wear white coats). The influence could present opposing views: some cultures would be more likely against choosing white for a robot because of the high regard for doctors; while other cultures might prefer white because it makes the robot closer to a doctor, and thus more prestigious and trusted. These nuances of implicit biases make them harder to detect; therefore, it was assumed that implicit biases could exist in the recorded answers and that those could propagate into the robot design.

Visualizations of the results are shown in Figure 3. In summary, the primary inferences derived from the patients' interviews are:

- The research hypothesis and problem statement are confirmed: patients perceive a risk to their health due to the presence of non-medical personnel and the larger-than-necessary number of individuals entering their rooms during isolation.
- The most commonly reported concern by patients is their fear when non-medical staff members, like cleaning staff or service personnel who transport items from and to the isolation room, enter their rooms due to the perceived or observed lower rate of compliance with and awareness of the precautions put in place to limit disease transmission.

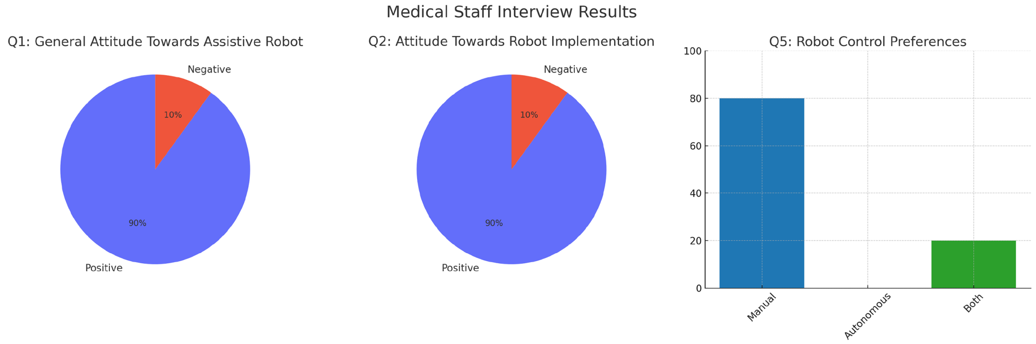


Fig. 4. Results of the medical staff interviews.

- There was a positive attitude toward implementing a robotic solution to the identified problem, as long as it does not completely replace the medical staff.
- The robot's physical appearance is important as it affects the patient's tendency to accept the robotic solution.
- Patients did not place great value on the robot's gender, thus a gender-neutral robot is to be designed, which can be changed or kept the same after a second round of patient feedback.

Medical Staff's Data Analysis. Ten medical staff members from the AUBMC BMT unit, including nurses, doctors, and fellows, were interviewed in this study. The participants included three males and seven females, whose ages varied between 30 and 60 years old, all were Lebanese. As with patients, the following questions were formulated for quotation. These questions were asked as-is, and clarifications were only provided in case any aspects were considered unclear.

Q1: What is your (medical staff) general attitude toward an assistive robot?

Initially, the medical staff expressed valid concerns toward robots taking over their work and fully replacing them. In particular, critical medical tasks such as administering medicine or taking vitals were rejected as tasks the robot could perform. When the follow-up question: "what if the robot is a strictly *assistive* tool that can only perform specific tasks?" was posed, it caused their attitudes to overwhelmingly shift toward being accepting, where 90% considered that using a robot would be very helpful to serve as an assistant and enthusiastically welcomed the idea.

Q2: Should an assistive robot be implemented in the proposed context of isolation rooms?

In this question, the context of isolation room operation was explained as the robot being equipped to operate inside the rooms and can enter or exit. 90% of the interviewees had a positive attitude toward implementing an assistive robot in that environment. They stated that implementing any tool or device that would help protect patients and reduce the usage of PPE is beneficial and would help them save time so that they could focus on more critical tasks.

Q3: Are you (medical staff) able to adapt to the use and presence of a robot?

All of the interviewees confirmed that they can adapt to the use of new technologies in their work environment. Several discussed a new software platform for medical management (MyChart by Epic), which was implemented at AUBMC in 2018 to make all patient records digitally accessible, as an example of their ability to adapt to new technology in the workplace. They also indicated that the integration of a robot would not be difficult, as long as they receive adequate training to guide them on its proper operation.

Q4: Do you (medical staff) think that patients would accept a robot serving them?

Based on their knowledge and experience in dealing with patients, the interviewed nurses and doctors claimed that patients would accept the robot, in general. However, some raised concerns that the patients' mental health could be affected by limited socialization during isolation periods. One interviewee stated, "BMT patients mostly interact with us daily, so using a robot could increase their feelings of loneliness due to isolation." When asked: "Would you (medical staff) be less concerned, if the robot did not replace any essential (medical) interactions?", those expressing concern ultimately agreed that the robot could be a valuable addition, provided it complements, rather than replaces, critical human contact. The concern was further alleviated after the telepresence features were explained, since the ability to establish virtual communication with patients via the robot was considered a welcome feature.

Q5: Should the robot be autonomous or manually controlled?

For safety and precision reasons, the medical staff believed that it would be better for them to fully control the robot. Sometimes, patients have critical needs that the robot cannot perform while autonomously following a predetermined set of actions. For example, the medical staff believed that if the patient had a certain request while the robot was delivering food, only a non-autonomous fully controlled robot could respond to that request. Only 20% of the staff participants considered that tasks could be divided into two parts: ones that need manual control (majority of tasks) while others can be performed autonomously based on their needs (a select few tasks).

However, when it came to the robot disinfection function, the medical staff indicated that the disinfection and sterilization system must function without external assistance or manual control beyond a start signal, which means that the robot has to self-disinfect in an automated fashion. Also, the medical staff prioritized implementing a disinfection system that would save time and reduce PPE use. Alternatives such as staff-sterilized robots, disposable plastic wraps [72], or PPE-covered robots [39] were discounted since they do not satisfy the second requirement.

In summary, interviews with medical staff showed that:

- There was a concern about the mental health of isolated patients.
- The medical staff can adapt to the use of new technology in their workplace.
- A robotic solution was considered acceptable as long as it does not risk replacing jobs or limiting critical interaction with the patients.
- The robot should be remotely controlled by an operator (manual, not autonomous).
- The robot should not perform medical tasks related to a patient's health (giving medication, measuring blood pressure, and similar).
- Acceptance was favored when the robot is presented as, and functions similar to, other aiding devices or tools—as opposed to being its own independent entity. Ultimately, a robot designed explicitly to support and enhance staff duties—one that remains ineffective without their involvement—has the potential to promote greater acceptance than a robot that emphasizes advanced capabilities, which may signal the risk of job displacement or replacement.
- An automated self-disinfection system should be implemented for the possibility of saving time, reducing PPE usage, and increasing protection against pathogen transmission.

The interviews above provided a better understanding of the *problem space* and its central aspects, they also provided content for the creation of the design requirements.

2.1.2 Needs Establishment. The interviewed patients' primary concern was their perception of the risk when non-medical staff, like cleaners or food delivery staff, enter their rooms. While this particular risk is addressed less directly in the literature [73] compared to other concerns such as psychological isolation or mental health issues [9, 10, 21, 74], it emerged as the primary need among the patients interviewed for this robot. Naturally, on their own merit, the other concerns do not point to a robotic solution, as there are known options of counseling or psychiatric interventions, with or without technology. But for the sake of reducing the perceived risk from non-medical staff members entering the room, the solution must effectively reduce the number of times those staff enter the room; in which case, a robotic solution is one of the more clear options. This, however, does not mean that the other concerns do not also establish a need for this robot, only that it is not as direct. The robot should also be able to address those after the main need has been dealt with.

From an ethical motivation standpoint, the specific concern mentioned above was considered under the banner of fear, which is a strong emotional trigger that patients experience, especially related to their illness and their future well-being [75]. The issue regarding non-medical staff became more apparent when studies, such as Chau et al. [73], highlighted claims of lower compliance with preventative regulations among these staff compared to their medically trained counterparts. Whether this concern arises from predisposed stereotypes or observations of noncompliant behavior (such as noncompliance with PPE gown usage [73]), it presents a significant risk of exacerbating existing fears, potentially leading to worse mental health outcomes. These outcomes could be avoided with robot use, presenting an ethical argument for it.

For the medical staff, the need was preceded by concerns about job security and patient interaction. Once those were integrated as design requirements, the need presented as a desire for a tool or a device that helps them save time and focus on more critical tasks, with the added benefit of reducing PPE usage. While it was not as clear of a need for a robot as it was with the patients, a robot designed with awareness of these needs would satisfy the requirements. Ethically, the possibility of reducing staff burnout [7] and environmental damage from PPE waste provided sufficient argument for the exploration of this solution.

2.1.3 Ethical Considerations. In the SRCC, ethical considerations are claimed to be derived from the interaction between the user and the robots as opposed to "artificial notions." Keeping that in mind, while going through the *Ethical Considerations Canvass* [63], early on in the design process, helps avoid serious design flaws at later stages when makeovers due to mistakes are more costly and time-consuming. For robot SHARE-C, its ethical considerations are described below:

- *Physical Safety*: SHARE-C is to be designed in a way where it is incapable of hurting the patients or medical staff.
- *Data Security*: SHARE-C should not collect any active data about the patients. Passive data or inferences remain inside the confines of the hospital databases.
- *Transparency*: Since SHARE-C is manually controlled, there are no transparency concerns associated with autonomous actions, and it does not perform any medical procedures on patients.
- *Equality across Users*: SHARE-C is not intended to have any perception of the user; therefore, it cannot have biases toward them.
- *Emotional Consideration*: Since SHARE-C would be regarded as part of the staff and its interaction with patients is minimal, the risk of patients forming an emotional attachment is negligible. On the medical staff's side, it is designed to be perceived primarily as an assistive tool, which eliminates any risk of emotional attachment.
- *Behavior Enforcement*: SHARE-C is not designed to have any learning capabilities and will not develop any behaviors on its own.
- *Cultural Considerations*: As outlined in the Introduction, cultural features to be integrated into the robot must be thoroughly examined to ensure they are neither biased nor exclusionary within the Lebanese cultural context.

Further, from the medical staff interviews, inferences about the ethical functionality of the robot are to be drawn. In terms of tasks, to avoid ethical contingencies, the robot must be designed to only be capable of strictly performing tasks that do not generate a job replacement risk without the capability of expansion. For example, the robot having an articulated dexterous arm, which is perceived as capable of measuring a patient's pulse or performing injections, could have a negative effect even if these functionalities are not implemented. In a sense, the robot cannot be overly capable or even perceived as such.

In terms of patient interactions, the robot's implementation and tasks must be evaluated on a case-by-case basis. For example, if medical staff primarily interact with patients during lunch breaks, the robot should not replace this valued interaction, as doing so could negatively impact patients' mental health more than a routine task performed later in the evening. Overall, ethical risks can be mitigated if the robot is developed as a tool from the medical staff's perspective and as a low-skill, less-demanding, yet safer, alternative to non-medical staff from the patients' perspective.

Based on the above, the design process reached a stage where it could proceed backed by established and ethically relevant needs, without concerns about ethical issues arising from a lack of consideration.

2.2 Design Guidelines

This section of the framework outlines the path to the *solution space*, after which two paths must be chosen: a prototype that could lead to a **minimum viable product (MVP)** approach or an in-depth design approach leading to an outcome closer to the final market-ready product. Given the scope of this project, the viable prototype approach is chosen. The results of the *Design Guidelines Canvass* are detailed below:

- *Advantages*: SHARE-C aims at potentially reducing the risk of disease transmission by limiting contact with patients and through its unique self-disinfection feature. It also aims to reduce mental health strain of patients and staff, reduce the time that medical staff spend on delivery tasks, and decrease the amount of used PPE.
- *Ethical*: SHARE-C adheres to the requirements in the *Ethical Considerations* section of Stage 1.
- *Form*: SHARE-C's appearance follows the conclusions made from interviews with Lebanese patients and medical staff members, in addition to the surveyed literature.
- *Environment*: SHARE-C accommodates isolation room environments by employing a self-disinfection function and a locomotion system suitable for hospitals.
- *Interaction*: SHARE-C can speak to patients in the Lebanese dialect and interact with them through various facial expressions.
- *Behavior*: SHARE-C's behavior is pre-programmed and all of its actions are manually controlled by the medical staff.

2.3 Solution Space Integration

This section covers the engineering work performed to achieve a viable prototype. Although the decision was made to pursue the MVP path, substantial engineering effort was dedicated to realizing a dependable solution. The efforts are presented as a reference to transitioning from the design guidelines to a prototype, highlighting the engineering concepts used. The prototype implementation itself was chosen to be low-resolution only aimed at generating perceptions that can be tested to validate the design choices. The design and implementation process spanned over a period of twelve months.

The SRCC framework was developed to support multidisciplinary collaboration in design. Since SHARE-C is a social robot operating within a hospital setting, its multidisciplinary considerations go beyond those typically found in robots deployed in other environments. The following outlines the interactions between the various multidisciplinary aspects of the robot's design.

Table 2. Robot's Preferred Features (Interviews and Literature Review Findings)

Source	**Characteristic**	**Preferred Option**
Interviews	Height and appearance	1.5 m, Humanoid
	Face	Screen
	Color	Lighter blue and white
	Body	With arms and shoulders
	Gender	Neutral
Literature review	Voice	High pitched [76]
	Gender	Feminine [77, 78, and 79]
	Height	1.4 m (longer than patients on bed) [80, 81]
	Hair	No hair [82]
	Number of facial features	Greater than four features [83]
	Dimension of the head	Width > height [83]
	Proportionality of the head	Little space for forehead and jaw [83]
	Ears	No ears [82]
	Face color	Black [82]
	Eyebrows	No eyebrows [82]
	Eyes	Spacing (eye-to-eye): Baseline [82]
		Dimension (radius): Baseline [82]
		Shape (eye geometry): Baseline (round) [82]
		Eyelids: No static eyelids [82]
		Pupils: With pupils [82]
		Iris: No iris [82]
		Color: Baseline (white) [82]
	Nose	No nose [82]
	Cheeks	With cheeks [82]
	Mouth	With mouth [82]
	Interface type	Screen [82, 84]

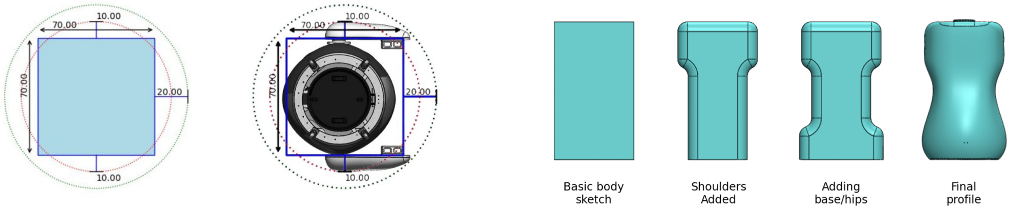
2.3.1 *Features Assessment.*

Table 2 summarizes the robot's preferred features based on interviews with patients and medical staff members, as well as findings from the reviewed literature. The table combines insights from both sources to present a comprehensive overview of the different aspects that should be considered for the robot's physical appearance. This combined approach ensures that the design of SHARE-C is informed by the end users and the critical findings of previous research works.

2.3.2 *Robot's Mechanical Design.*

The first step in the mechanical design of the robot was determining its dimensional bounds: the height is 150 cm as per Table 2, and the maximum depth and width are both bounded in a square with sides of 70 cm to allow the internal components to fit inside the robot's cavity (discussed later). The robot has forward-extending arms that protrude 10 cm on the sides (shoulders' outermost part) and up to 20 cm to the front (between the chest and the tips of arms). The final dimensional bounds are shown in Figure 5(a) using **Computer-Aided Design (CAD)** software (SolidWorks).

Mobile Platform. Multiple locomotion methods were considered for robot SHARE-C. First, motions that starkly contradict humanoid robots, like quadrupeds, snake motion, or tracks, were discounted. Bipedal legs were also discounted because they require significant development and increase human likeness [69], which risks falling into the uncanny valley as the gait would inevitably vary



(a) Robot dimensions in *cm*. Left: Initial boundary dimensions assessment. Right: Final robot fits inside the boundaries

(b) Profile progression of the robot's body

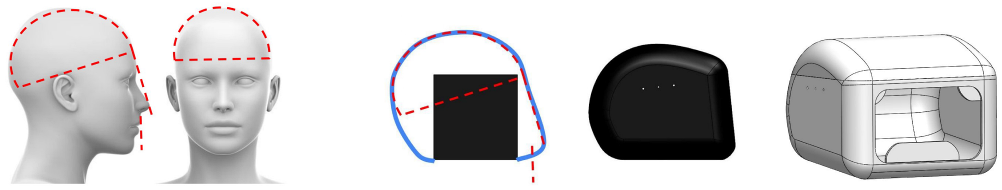
Fig. 5. Combined figures of robot dimensions and body profile progression.

from that of a human. The remaining option was using motorized wheels, which are the most common among robots that operate in environments with flat floor surfaces like hospitals, noting that the majority of the mobile robots considered in Section 1 use wheels and motors. Given that the goal was to produce a low-resolution prototype, an off-the-shelf mobile platform was utilized instead of developing a specialized wheeled locomotion system. The readily available Kobuki mobile platform [85] was selected, which is a re-purposed Locobot [86] along with its computer (Intel NUC NUC7i5BNH) and power supply (MAXOAK Laptop Power Bank 185 Wh/50,000 mAh). It is noted that for the scope of this work, given the preference for a manually controlled robot (staff Q5), not all factors that are relevant to autonomous navigation from the software and hardware sides were considered; for instance, a stereo camera was not used for simultaneous localization and mapping (SLAM). However, the intention is to leverage these features in subsequent prototypes even if the preference for manual control remains, as it could be required that the robot can navigate autonomously when moving in tasks outside of patient or staff contact, such as going back to the charging station.

A main downside of the Kobuki base is its small payload of 3 kg, which cannot carry the robot's weight (~29 kg). Also, it has four wheels that are close to each other (two within 20 mm and two within 17.5 mm), which means there are not enough contact points with the ground to prevent the robot from tipping over when an impact force is applied to it. To solve both problems, four caster wheels were incorporated to bear the robot's weight and reduce the tip-over risk. Caster wheels were chosen over other options since they do not significantly affect the kinematics of the differential drive mobile platform [87].

Body Design. With the bounds set and drive platform chosen, the robot's body was shaped starting from the anterior view with a rectangle (Figure 5(a)), following the interviewed patients' preferences that asserted the importance of humanoid-ism and having shoulders, which were sculpted to give the body its T-shaped design. To conceal the mobile platform, the bottom of the body was given slightly more width. Further adjustments included replacing sharp edges with natural curves to yield a more esthetically pleasing profile [69], as shown in Figure 5(b). The final design of the body's outer shell resembled an hourglass shape with a waist-to-height ratio of 0.33, a waist-to-shoulder ratio of 0.75, and a waist-to-bottom ratio of 0.75. The hourglass shape was considered to be the least threatening, least massive, and most friendly shape in [69].

The lateral view of the body was tackled next. Given that the mobile platform is disk-shaped, the robot's bottom was given a circular profile with a diameter that accommodates the platform's diameter. The waist's diameter (circular profile) was obtained by maintaining a waist-to-bottom ratio of 0.75. For the shoulders, the option of preserving the same hourglass shape as the anterior view was discounted to avoid the robot having an undesired dumbbell shape. Instead, a humanoid robot approach was followed by making the shoulder depth slightly larger than the waist depth,



(a) Human head contours: side and front views

(b) Final head design

Fig. 6. Comparison between human head contours and final head design.

resulting in a lateral waist-to-shoulder ratio of 0.92. The final body became a curved progression from a circular bottom and waist to a slightly cubic torso with a more recognizable chest and shoulders, as seen in Figure 5(b).

Head Design. A design that stems from the standard human head was adopted with contours of the general shape of the human head and face, shown in Figure 6(a), created as a starting point.

Overlaying the contours from the side-view of a human head onto a cubic profile allowed the generation of the boundary shape, which was an elevated curve that extends from the upper-right corner to the bottom-left one to mimic the human head's curvature. A small forehead area was also added to provide a transition from the head curve to the face screen. The plane of the screen was slightly slanted to compensate for the absence of a nose and provide room for the jaw. A fillet was added to the bottom-right corner to turn it into a jaw.

For the front view of the head, several design iterations showed that mimicking the top curve of the human skull produced a disproportionate head-to-face dimensional relationship. It is noted that since the displayed face of the robot (discussed later in Section 2.3.6) was more simple and cartoonish, having an excessively human-like head shape would contradict that approach. Further, changing the face to be more human-like to fit that head shape would increase the possibility of falling into the uncanny valley and "stark anthropomorphism"; therefore, it was discarded. Minor adjustments were applied to the front view by placing a cavity for the face screen and rounding the sharp edges. The final head was further adjusted to accommodate the dimensions of the chosen screen, a 7-inch tablet with a front-facing camera that could be used for telepresence features. The screen was placed in a horizontal configuration to make the head more proportional to the body and facilitate video display and conference calling [69]. The head was split into top and bottom parts for easier disassembly to service the screen and other internal components that enable communication with humans. A microphone and speakers were placed inside the head cavity directly behind the screen facing toward the person to be interacted with. The final head size that accommodates the components was 30 × 40 × 30 cm and was 3D printed via **Fused Deposition Modeling (FDM)** using **Poly-Lactic Acid (PLA)** filament. The progression of the head design and the final design are shown in Figure 6(b). Actuating the head to allow actions like nodding was discounted based on the work in Johanson et al. [88], which showed that nodding does not have significant effects on increasing trust and acceptability.

Arms Design. One of the main tasks of SHARE-C involves carrying a tray to deliver items placed on top of it. Several approaches could be followed integrate this feature, including having an external platform for the tray to rest on or dedicating a cavity inside the body for the tray to slide into. To achieve humanoid-ism, it was only natural to give SHARE-C arms that carry the tray. The follow-up decision was between having the arms carry the entire weight of the tray, splitting the weight between the body and the arms, or having the weight entirely supported by the

(a) Tray supports on the robot and its human equivalent

(b) Left: arm components, a: inner arm (back side view), b: inner arm (front side view), c: outer arm (back side view), d: outer arm (front side view). Right: full arm subassembly as attached to the body

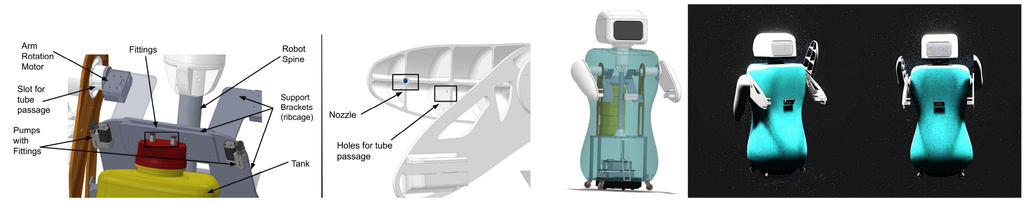
Fig. 7. Tray supports and arm components of the robot.

body. The option of only having a body support was not feasible since the body does not offer a contact area for holding the tray, and adding the needed platform attachments (large) would significantly alter the body esthetics. Having the arms entirely bear the load induces the risk of the robot tipping over due to large loads or impulse forces on the tray. Having the load shared between the arms and the body distributes the force and reduces the risk of tipping over, thus the robot was designed with platforms at the tips of the arms and another support platform on its chest, as shown in Figure 7(a), noting that a similar approach was adopted in Snackbot [49] with proven efficacy.

A minimalist approach was taken in the design of the arms, without elbows, wrists, or fingers to avoid falling into the uncanny valley by giving the impression that the arms can articulate like those of a human. The arms started from the shoulder area of the body and extend down to a plane that is slightly above the waist by following a direct path from the shoulders to the waist. Two reasons were behind this choice: the first was functional, which is having the items not be too high or too low for patients lying in a hospital bed to reach; and the second reason was to replicate the way a human carries a tray. Also, the shoulder part of the arms has a rounded appearance, similar to a human shoulder, and projects outwards from the shoulder area, seamlessly without changing the overall shoulder shape. The tray was supported by rectangular extrusions on the arms and the body (see Figure 7(b)), which is small enough to avoid causing any form changes and is mostly covered by the tray.

Similar to the head, the arms were manufactured using FDM 3D printing and PLA. However, due to weight considerations, printing filled arms is not viable without risking them being too heavy. To address this issue, the arm was separated into two parts, a flat inner arm of 10 mm thickness rigidly attached to the body for carrying the tray payload, and a curved outer arm with a 5 mm wall thickness for giving the arms their desired shape. The latter's casing was hollowed out with ribs connecting the sides, as shown in Figure 7(b). To further reduce the arms' weight, the 3D printing fill ratio is set to 20% for the outer part and 40% for the weight-bearing inner part; furthermore, a topographic study was performed (using SolidWorks's Tosca Optimization Engine) with a 5 kg payload (half of the maximum payload) on a single arm's inner part. The analysis highlighted regions where material can be safely removed without compromising structural integrity. That removal was performed on the inner part of both arms.

Electrical Design Consideration. Since the mechanical design of the robot prototype was already involved, a simple electrical design was chosen to reduce system complexity. This design choice prioritized re-purposing components already found in the Locobot, as it already had functioning electrical integration as well the use of off-the-shelf components, avoiding the need for engineering new electronics and circuit boards. All components were chosen to be compatible with



(a) Left: Labeled self-disinfection internal components. Right: Labeled self-disinfection external components. (tubes and cables omitted for clear view)

(b) Left: Full body internals with the self-disinfecting subsystem mounted (tubes and cables omitted for clear view). Right: Simulation of the self-disinfecting system in action (produced via Blender). The dots represent disinfectant liquid droplets (only for visual aid, not a fluid dynamics simulation)

Fig. 8. Disinfecting system components and simulation.

Locobot power options (20 V/3A, 12 V/2.5A, and 5 V/2.1A) and communication protocols (Bluetooth, Wi-Fi, USB, audio jack, and Dynamixel transistor-transistor logic), which reduced the need for soldering, crimping, and harnessing.

2.3.3 Self-Disinfecting System. One of the most unique features of SHARE-C is its self-disinfecting system, which must be compact enough to fit within its internal cavity, while maintaining esthetics and covering all external surfaces to reduce disease transmission. Since the primary aim of this study is to assess the perceived benefits of the self-disinfecting feature, we have fully detailed its design to gather end-user feedback. However, we did not implement this feature in the first prototype, as doing so without a fully engineered system could lead to negative perceptions; patients might view the feature as incomplete or unreliable, which could affect their trust in the robot. This issue will be addressed in the next iteration.

Multiple disinfecting approaches were considered including **Ultraviolet (UV)** light, heat, steam, and disinfectant spray. Heat and steam were deemed infeasible due to the robot's size, high energy requirements, and the presence of PLA plastic parts with a glass transition temperature of 60°C, which limits temperature-based sterilization. Although effective in other robots, UV-C rays consume significant power, require frequent battery recharges, and pose health risks such as skin cancer, premature aging, and vision issues [89]. Therefore, UV disinfection was postponed until after the initial **Proof of Concept (POC)** validation. The final solution involved housing a sterilization fluid tank inside the robot and using a pump to spray the disinfectant over its exterior surfaces. The robot's arm structure was utilized for spraying to avoid visible tubes and nozzles on the body, ensuring efficient and esthetic disinfection.

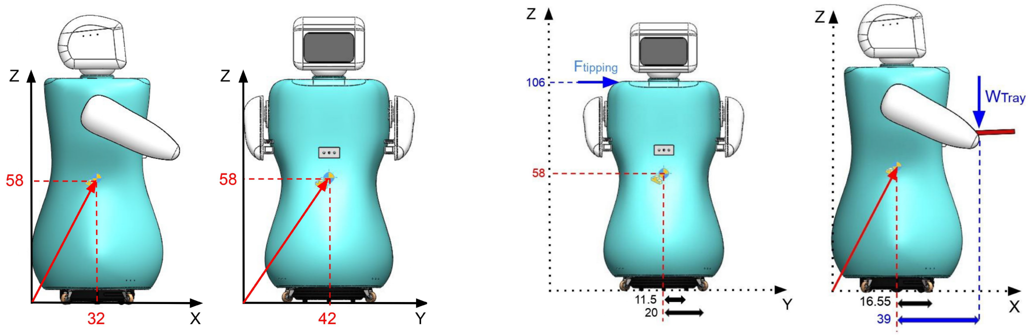
The nozzles were placed at the lower end of the outer arm (Figure 8(a)) with pipes leading into them from the pump that was housed inside the robot's cavity. The nozzles pointed outward but did not over-extend, which keeps them hidden when the robot is not performing the disinfection function. When the disinfection system is activated, motors rotate the outer arms (only) in opposite directions around the shoulder joint, separating them from the inner flat parts and exposing the nozzle to start spraying. As the arms complete a full rotation (Figure 8(b)), the disinfectant spray reaches the different parts of the body in the following order: chest, head, back, and waist; the disinfectant spray reaches the bottom part of the robot through gravity. The self-disinfecting system components include the pumps, pipes, tank, motors, mechanism elements, and nozzles (Figure 8(a)).

Because the Locobot already has a robotic manipulator arm [90], its motors (Dynamixel XM430-W350-T operating at 12 V [91]) were re-purposed for the self-disinfecting system. The stall torque of the motor is 4.1 Nm, which is higher than the torque required to rotate the arm calculated at 1.44 Nm (with all components included). With that said, the motor speed must be set to be slow enough to achieve sufficient disinfection of the surface, but fast enough to cover the entire surface within the disinfection cycle. Given 12 seconds cycles, the motor speed is set to 15 revolutions per minute allowing 1,080° of total rotation per cycle. The arm was to rotate one full rotation clockwise, one full rotation counterclockwise, followed by one half rotation clockwise and one half rotation counterclockwise to return to the home position. The arm should not rotate more than 360° in a given direction to avoid twisting the tubes inside. For pump control, a USB-controlled relay switch board with two channels was chosen. The remaining mechanism components (bushings, bearings, couplings, fixtures) were to be purchased or 3D printed.

Next, we focus on nozzle selection. Given that the self-disinfection system needs to cover as much of the robot as possible, a full-cone nozzle was the obvious choice. To avoid increasing complexity at this stage, hydraulic or pneumatic assistance nozzles were disregarded, and they will only be added if future tests reveal any unexpected issues with the unassisted setup. As for the spray angle, the choice should be one that increases the coverage of the robot while reducing waste. A larger waste factor would result in quick drainage of the tank, so the coverage area must ideally not exceed half the height of the robot (750 mm) because the nozzle moves in a circle around the body to reach the top and bottom sections. A standard nozzle was initially considered having a coverage of 746 mm at 10 cm and 150° spray angle [92]. The final nozzle choice was a 1/4 in MPL low-flow, full-cone nozzle [93], numbered MPL0.21W, where the W stands for wide coverage to achieve a larger spray angle.

To select the size of the tank, it was important to choose the pressure outlet at the nozzles. Based on Deveau [94], an operating pressure of 4 bar provides good performance without overly increasing the size of the pump. This pressure results in a flow rate of 0.93 L/min from the chosen nozzle, achieving a spray angle slightly above 129° (spray angle at 4 bar is assumed to be close to that at of the reported 3 bar). The choice for the tubing was a polytetrafluoroethylene tube of length of 80 cm, outer diameter of 6.35 mm (1/4 in same as the nozzle), and an inner diameter of 0.50 cm to achieve flexibility and chemical resistance to the disinfectant liquid. An 8-L tank was selected based on the consumption rate of both arms, which is explained next. For the specified flow rate, and considering that the disinfecting system is used for 12 seconds on both arms each time it enters/exits a patient's room, an 8-L tank would have to be refilled after 22 cycles (11 visits), making it equivalent to the number of negative pressure rooms in one of the standard AUBMC isolation room wings (11 rooms [95]). Concerning the coverage area, for a nozzle with spray angle of 130° and a distance from the nozzle orifice of 15 cm, the spray from the nozzles can cover a circle with a diameter of 64.3 cm, which—when moved in a circle of radius the length of the outer arm and center at the shoulder of the robot—is sufficient to cover the area inside a circle of diameter 1.44 m ($\approx$1.63 m^2) around the shoulder's center, thus covering most of the robot's surface area, with the rest being reached as the liquid flows down the body due to gravity. To further focus the spray on the robot, the nozzle was oriented inwards with a 10° angle toward the shoulder joint, as opposed to just pointing it straight.

For choosing the pump, it was crucial to understand the characteristics of the disinfecting fluid, but since there are many options available with different efficiencies, an assumption for the sake of simplification had to be made and a standard hospital grade disinfectant was chosen [96], with the aim of optimizing that choice in the future. This choice has a viscosity similar to water. After that, the pump power was chosen based on achieving a 4 bar pressure at the nozzle in the position with the highest head losses (with the arm pointing vertically upward). In this position, gravity resists the flow along with losses from bends and fittings. With a flow rate of 0.93 L/min (1.55×10^{-5} m^3/s) and an inner diameter of 5 mm, the average speed of the liquid was determined to be $\approx$0.79 m/s, the total losses were calculated to be $\approx$41.93 m, which means the required pump's power at 70% efficiency becomes $\approx$9.11 W. It must be noted that the robot has two pumps to independently



(a) Center of mass of the robot (in *cm*)

(b) FBD for tipping force (Left), FDB for tray weight (Right)

Fig. 9. (a) Center of mass of the robot (in cm). (b) FBDs for tipping force and tray weight.

operate each arm's disinfection system, if needed. At 9 W, 12 V DC pump can be chosen to use the same power source as the motors.

2.3.4 Mechanical Design Analysis. Given that the main function of SHARE-C is delivering items on a tray, its tipping behavior was of utmost importance and could be verified from its dimensions ratio, $w/2h$, where w is the maximum distance between the points in contact with the ground, and h is the elevation of the point where the force is applied. If the ratio is <1, the robot tips over; if it is >1, the robot slips when an adequate force is applied. Based on the dimensional bounds discussed in Section 2.3.2, the maximum robot width was 70 cm and the height was 150 cm, which yielded a $w/2h$ ratio of 0.23 indicating that the robot would experience tipping and not slipping when a large-enough force is applied to it.

The weights of the robot parts were estimated via the CAD software based on their material densities. The robot's total weight is ∼29 kg and its center-of-mass is located at X = 32 cm, Y = 42 cm, and Z = 58 cm, as per the coordinate system shown in Figure 9(a). With these parameters, the tipping force is calculated next.

Tipping Force Analysis. The tipping force was calculated while the robot is stationary from three directions: front, side, and diagonal views of the robot. The analysis was completed using both the distance of the Kobuki platform's wheels and the additional caster wheels that are installed in a circular pattern with a 40 cm diameter. Summing the moments using the dimensions shown in Figure 9(b) at the fulcrum (caster wheel contact with the ground), the tipping force, F_{tipping}, is 54.7 N in the front view, 46.6 N in the lateral view, and 73.3 N the diagonal view. The tipping force without caster wheels is smaller (front: 32.4 N, lateral: 31.4 N, and diagonal: 29.4 N).

Maximum Weight on Tray Analysis. The allowable weight on the tray was calculated from the **Free-Body Diagram (FBD)** in Figure 9(b). Applying the force at the middle of the tray, the maximum weight that can be carried by the tray, without tipping over, was calculated to be 13 kg, which is larger than the 5 kg requirement that comes from the fact that the items to be delivered on the tray (e.g., food) would not exceed this limit.

Tractive Force Analysis. A comparison between the tractive force and the resistance force was conducted to ensure that the robot can move with ease. The tractive force is mainly influenced by the weight of the base ($N_{\text{base}} = m_{\text{base}} * g = 3.7\,\text{kg} \times 9.81\,\text{m/s}^2 = 36.3\,\text{N}$) and the ground friction coefficient against rubber ribbed wheels (μ_{kobuki}); on the other hand, the resistance force varies based on the weight of the body, which is the total weight minus the base weight plus the tray

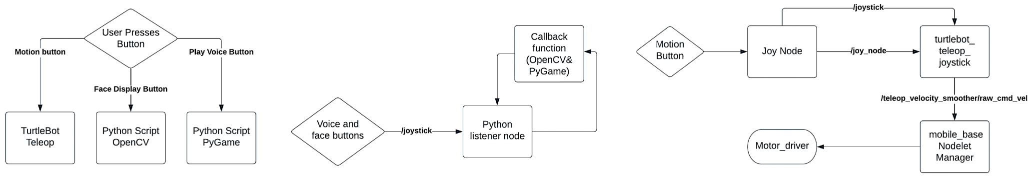


Fig. 10. ROS software operation flowcharts.

payload, ($N_{\text{body}} = m_{\text{body}} * g = (29.0 - 3.7 + 5.0)\,\text{kg} \times 9.81\,\text{m/s}^2 = 297\,\text{N}$) and the friction coefficient of with the polyurethane caster wheels (μ_{caster}). m_{base} is the mass of the base, m_{body} is the difference between the mass of the robot and the mass of the base, and g is the acceleration due to Earth's gravity. The forces are calculated as follows:

$$\text{Traction Force} = N_{\text{base}} \times \mu_{\text{kobuki}}, \tag{1}$$

$$\text{Resistance Force} = N_{\text{body}} \times \mu_{\text{caster}}. \tag{2}$$

To achieve motion, it is important to obtain the following relation:

$$N_{\text{base}} \times \mu_{\text{kobuki}} > N_{\text{body}} \times \mu_{\text{caster}}. \tag{3}$$

With a friction coefficient for ribbed rubber wheels on the test environment floor (μ_{kobuki}) of 0.7 and 0.08 for the polyurethane wheels (μ_{caster}), the tractive and resistance forces are calculated as 25.4 N and 23.8 N, respectively. Since the tractive force is larger than the resistance force, the robot can move without reluctance.

Impact Force Analysis. To ensure that SHARE-C does not tip over due to impact, the impact force (F_{impact}) was calculated via Newton's second law of motion as follows:

$$F_{impact} = m_{\text{robot}} \times \frac{\Delta v}{\Delta t}, \tag{4}$$

where m_{robot} is the robot's mass, Δv is the change in velocity during impact, and Δt is the impact duration. The impact force is dependent on the robot's speed at collision with the maximum speed of the unloaded Kobuki base being 0.7 m/s; however, the robot's operational speed and acceleration are lower due to loading. At full load, the net force on the robot is the difference between the tractive force and the resistance force ($25.4\,\text{N} - 23.8\,\text{N} = 1.6\,\text{N}$). Assuming constant acceleration, a, we use Newton's second law to calculate $a = 0.05\,\text{m/s}^2$. We consider that the robot travels a distance, $d = 2\,\text{m}$ (average empty room space at AUBMC), before making an impact, and the impact duration is 0.5 second due to the compliance of the fiberglass resin body that elastically deforms during impact, thus extending the duration. For a speed, $v = 0.44\,\text{m/s}$ (calculated as $v = \sqrt{2ad}$), an impact force of 37 N is computed, which is indeed less than the minimum force required to tip the robot over. Note that this calculation considers a full tray payload, which is the worst-case scenario since lowering the total weight also reduces the impact force.

2.3.5 *Operating Software.*

In the first phase of the design process, the medical staff indicated their preference for manually controlling the robot and did not favor allowing the robot to perform autonomous tasks (Figure 4). With that in mind, the robot's software, which was developed using the **Robot Operating System (ROS)**, maps buttons on a remote controller (PlayStation 3) to specific actions of the robot (Figure 10).

For the motion action of the robot, the open-source `turtlebot_teleop` ROS package was used to command the Kobuki base to move with the controller. The remaining robot functions, which include changing the facial expressions displayed on the screen, playing pre-recorded audio phrases on the onboard computer's speakers, and activating its self-disinfecting system, were programmed by adding a new node to the motion package. The added node reads the inputs from the controller buttons and sends commands to display a picture of the selected facial expression in full-screen mode and/or play the sound file of the desired audible phrases. The PlayStation 3 controller has two joysticks and 17 buttons (including pressing the joysticks). The button distribution was assigned through the added ROS node as follows: one button and one joystick were for motion (L1 + Left Joystick), one button was reserved for activating the self-disinfecting system, one button for stopping the audio stream, one button for showing or hiding the face on the screen, and the remaining 13 buttons were allocated to six facial expressions and seven audio phrases.

2.3.6 *Interaction Design.*

This section outlines the design decisions behind the features and concepts directly related to the HRI. It concludes by utilizing these features to create a procedural robot demonstration template for future use in Phase-2.

Facial Expressions. Studies of fundamental stimulus qualities establish that display geometry was crucial in communicating emotions, whereby even simple geometric forms with no context have been demonstrated to convey emotion. These geometric forms were distinguished in emotional facial expressions, with angry faces having more angular geometric patterns and happy faces having more roundedness [84]. This was demonstrated through the **Implicit Association Test (IAT)**, showing that there is a significant tendency to correlate "downward-V" shapes with unpleasantness and circles with pleasantness. From a cultural perspective, it is noted that the choice of including a culturally inspired face would be far more difficult due to the constraints on technology and the risk of generating racial or other stereotypes [97]. This was one of those features where refraining from cultural integration is actually a more culturally sensitive approach. For SHARE-C, it was crucial to design facial expressions that communicate pleasant feelings and increase comfort in the interaction with patients. Hence, several facial expressions were generated with the help of graphic designers at AUB. To further achieve those effects, the facial expressions were contoured as the shape of a heart, which is a universally recognized symbol that has been used in marketing for ages given its positive association [98].

It is not uncommon for a social robot to use its eyes and gaze features to facilitate simple or more involved social interactions, even in settings with multiple participants, as demonstrated by Multu et al. on Robovie [99]. When it came to the use of SHARE-C's eyes, it was important to determine their role in the interaction, as well as in the cultural context. Arab cultures, including Lebanon, have a preference for eye contact [100], where even in tele-medicine settings, Lebanese participants overwhelmingly (90.2%) preferred physicians to direct their gaze at the camera (eye contact) as opposed to the screen (looking at something else). With that said, however, when it comes to robotics, there is a significant risk of falling into the uncanny valley if the robot presents unnatural gaze patterns [101]. To avoid those effects, it was decided that the eyes would be reserved for "cute" shapes and animations as opposed to gaze contribution; hence, the robot would attempt to achieve "eye contact" by orienting its entire body toward the patient's face. It must be noted that the facial expressions were first exposed to the nurses and patients directly during the demonstration in Phase-2 interviews; the facial expressions were chosen only by the development team and were not vetted by the latter stakeholders.

Verbal Communication Features. The primary choices to make here were language and voice. Because of the robot's association with the Lebanese cultural context, it was important to understand the relevant literature regarding language. Lebanon is an Arab country with its own dialect, characterized by unique linguistic features that distinguish it from **Modern Standard Arabic (MSA)** and other regional dialects [102].

Andrist et al. [103] conducted two studies investigating how language and cultural context influence the persuasiveness and credibility of robot speech. In the first study, they compared Arabic-speaking robots in Lebanon with English-speaking robots in the United States and found that rhetorical linguistic cues—such as fluency, speech organization, metaphors, and expressions of goodwill—were more important for credibility in Arabic than in English. They also noted that high-context cultures, like Arab societies, are less accepting of robots with limited communication abilities and minimal nonverbal behavior. These conclusions supported the necessity for having verbal and nonverbal abilities in SHARE-C, which were implemented through its speech and facial expressions. In their second study, they compared the effect of MSA with that of the Lebanese dialect in persuasive speech. Results showed that MSA was more persuasive in low-information, low-rhetoric speech, while the Lebanese dialect was more persuasive in high-information, high-rhetoric contexts, especially among male participants. There was no difference between the two when speech had high information but low rhetoric. The study also warned of a potential risk: low-information, high-rhetoric speech might cause the robot to falsely sound like an expert. Since SHARE-C is not designed to be persuasive or convey specialized information, but rather to sound friendly and supportive, we ensured to avoid rhetorical cues that might make it seem overly authoritative, especially if MSA is used as it is more formal and related to official settings [104].

When it came to the other subjective rating of sociability (friendly and sociable), the authors stated no observable difference between MSA and the Lebanese dialect. However, another study by Salem et al. [105] speculated that the robot being able to understand the individual Arabic dialect used by the participants could be one of the reasons behind their strong positive reactions toward it. This was part of their study that they conducted on effects of politeness and culture on robot acceptance, which also concluded that politeness contributed more toward perceiving the robot as close and warm among Arab participants, with a greater effect observed in open-ended “chitchat” conversations. Outside the context of robots, a study by Hadziabdic et al. [106] covering multiple Arabic dialects, including Lebanese, concluded that Arabic-speaking migrant patients in Sweden preferred that the speech of their Swedish-speaking nurses be interpreted into their local dialect. Finally, since most of the communication inside AUBMC happens in the Lebanese Dialect, and based on the surveyed literature, it was decided that the robot should speak the Lebanese dialect, which would be the primary culturally influenced feature about it. The Lebanese dialect would be a unique feature of SHARE-C, which allows the investigation of its effect on the acceptance by patients in the validation stage of the design process.

In addition to the Lebanese dialect, custom-tailored sound features were added to the robot so that it can utter various expressions when it enters a room, greet the patients, introduce itself, and wish them a good day upon leaving. Given that the surveyed patients preferred an ungendered robot, the voice pitch was adjusted into the neutral zone after a female team member recorded the initial sound bits. Furthermore, to avoid excessive human likeness, the audio was manipulated via electronic down-sampling to make it sound more robotic, which also prevented the generation of cultural stereotypes. The reason behind using pre-recorded audio instead of employing a dialogue system with a large language model and a text-to-speech generator, like in Jelinek et al. [16], was to reduce complexity and increase accuracy given that the available language models at the time of testing were not very capable in the Lebanese dialect. However, they are slowly improving in Arabic dialects [107], which could be tackled in future works with models that could be tuned to be aware of SHARE-C’s cultural context and incorporate more trust-inducing statements of empathy in its audible interactions [88].

Greeting Exploration. Since greeting is a culturally dependent behavior, it was beneficial to explore the cultural literature before creating the greeting routine with interactive social features of the robot. Even with cultural differences, generalized greeting theories were proposed. Heenan et al. [108] combined the greeting theories of Kendon [68] and Hall [109] into a single greeting model consisting of sighting, distance salutation, approach, close salutation, and transition into interaction, which was useful for designing robotic greeting behaviors. Implementing this model on the NAO robot in [108] showed improvement in the robot's social skills during greeting exchanges in a controlled setting. Because SHARE-C has a face, its greeting depends on its facial expressions, and this choice of proper facial expressions could make people feel more comfortable during the interaction [110]. Furthermore, as greetings include a spoken interaction, it becomes important to discern the choice of greeting phrases with respect to dialect, intention, and cultural significance.

The chosen greeting phrase was derived by elimination from the options presented by Germanos et al. [111]. The first options to be eliminated were those relevant to a particular subgroup only (e.g., Islamic greetings, Armenian greetings, and region-specific greetings); the next set of eliminated options were those from other languages (French and English), because their use in Lebanon varied depending on location, religious association, birth place, and gender. Additionally, if the robot begins using expressions that are not part of the Lebanese Arabic dialect, it could cause momentary confusion about which language the robot is speaking, which could have adverse effects on the patients. The most widely used greetings [111] that do not violate our criteria were "Marhaba" (hello), "Sabah El Kheir" (Good Morning), and "Masa El Kheir" (Good Evening). All three greetings were incorporated and SHARE-C alternated between them based on the time of the day. Note that "Marhaba" was used at times outside of the morning and evening hours, or if the robot needs to have subsequent visits to the same patient in a given time window. The three options are ubiquitous and fully understood by all members of the Lebanese society, regardless of their subcultures [111].

Telepresence Features. In terms of telepresence features, the robot was already equipped with speakers and a tablet with a front-facing camera. A microphone was added to allow full video conference capabilities. However, it was determined that testing this feature in the context of Phase-2 interviews, which were after a regular checkup, would be futile as it would provide unrepresentative results. That is mainly because the patients would not be able to provide realistic assessments about the efficacy of this system, as they had already interacted with their loved ones and medical staff in a face-to-face fashion on that same day. Therefore, testing and further developments on this system were postponed to following iterations of the robot. With SHARE-C, the tablet is located in its face area, thus starting a telepresence instance would force the replacement of its facial features with the remote person's image and muting its verbal features to enable uninterrupted human-to-human communication, unlike other social telepresence robots (e.g., Pepper and Ari in Table 1) where the screen is embedded in the torso area. Exploring the effect of the screen change on SHARE-C's perceived social identity and mitigation approaches and offer a promising direction for future HRI studies on SHARE-C.

Full HRI Procedure. Given all of the above, the next step was to utilize the social features and capabilities of SHARE-C in creating full HRI keeping all the contexts in mind. We present the following as the primary HRI template used, it is the exact procedure of the live demonstration for the patients and medical staff that participated in Phase-2 interviews. The procedure was followed to develop a patient-staff interaction by synthesizing the responses of Phase-1 interviews and the findings from the literature. The sample procedure below represents a first-time interaction, which takes place in the morning (for example), and the task is to deliver breakfast to the patient (for example):

- At first, the robot is parked outside the patient's room with the door closed. When the door is opened, the robot enters the room. The robot and the patient see one another when they are within the public zone of less than 1.3 m [108], with the robot directly facing the patient to "maintain eye contact."

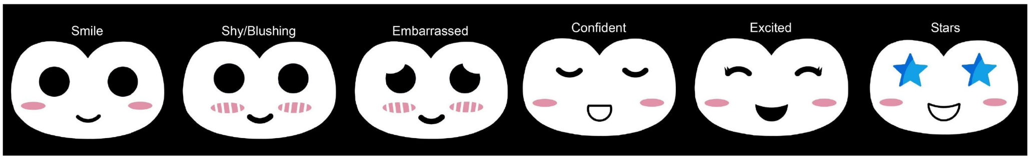


Fig. 11. Facial expressions and labeled emotions used in the final robot design.

- Greeting occurs as follows: starts with a distance salutation (a smile and phrase) as the robot approaches the patient's social zone of 0.75 − 1.3 m [68]. In this step, the "Smile" face of SHARE-C (Figure 11) is shown on the screen as it greets the patient with the chosen phrase: "Sabah El Kheir" (Good morning).
- The robot then moves toward the patient's personal zone of 0.20 − 0.75 m in the approach phase [108]. We note that Takayama et al. [112] found that participants felt comfortable with an interpersonal distance of 0.40 − 0.60 m when approaching or being approached by a 1.35 m tall robot. Since SHARE-C is 1.5 m tall, those recommendations were used to set the personal zone. In this step, the "Smile" expression is changed to "Shy," which offers the most deference to patients. Here, the robot asks about the patient's well-being in the Lebanese dialect: "Keefna elyoum? Insha'Allah kello tamem?" (How are you today? God willing (positive hope), is everything fine?). This is a formulaic extension of the greeting where the intention is to express concern about the condition of the patient. Although the word "Insha'Allah" has a religious connotation, it is commonly used by people of all faiths in Lebanon to express positive hope, among other meanings [113]. Because of its widespread use and the formulaic nature of Lebanese dialect, using a different word without religious connotations would seem intentional and out of place [114].
- The robot would move into the intimate space of the patient (<0.2 m) to deliver a food item after performing a close salutation [108] as follows: first, the facial expression is changed back to the "Smile" face. The robot introduces itself as it approaches to deliver a food item placed on the tray saying: "Ana robot SHARE-C, jeet aateek l akel! Sahtein w nhar saiid!" (I am robot SHARE-C, and I am here to deliver your food! Enjoy your meal and have a nice day!). Another formulaic extension to the greeting stage during which the robot introduces its name and purpose, ending on a positive note of well wishes.
- After the patient takes the food item from the robot, SHARE-C moves back into the personal zone where the "Shy" face is displayed again. The robot then says goodbye to the patient by saying: "ilal-likaa! Bshoofkn areeban!" (Goodbye! See you soon!) turns around breaking eye contact and leaves the room. The phrase "ilal-likaa!" is closer to MSA with a stronger connotation of "good bye," but the literal translation is "until next time," while "Bshoofkn areeban!" is the Lebanese dialect way of saying "good bye," but with a stronger connotation and literal translation of "see you soon." The use of both of these is to allow the robot to convey both meanings as the insertion of certain words that maintain their MSA roots is still fairly common in the Lebanese dialect.

2.3.7 Manufacturing and Assembly Process. The robot's manufacturing was composed of four processes for the different body parts: the wooden mold for the body was made from interlocking wooden slices that were cut using a CNC router; the body was molded over the mold using a fiberglass resin composite; the arms, head, and tray supports were FDM 3D printed with PLA filament; and the internal brackets were cut and folded from steel sheets. Figure 12 shows images of the main steps of the robot's manufacturing and assembly process. The workflow included:

Fig. 12. Sequence of pictures showing the manufacturing and assembly of the robot.

cutting interlocking wooden slices that are assembled to produce the main body contours, filling the gaps in the wooden mold with polystyrene foam, and then layering fiberglass and resin onto the surface of the mold. After the mold was produced, a hole for the neck was made and a metal reinforcement ring was installed on the bottom for caster wheel attachment. An aluminum pipe was used for the spine connecting the neck to the internal scaffolding, and steel brackets were used to secure the body to the Kobuki mobile platform. An access panel was cut in the back of the body to enable reaching the internal cavity that houses the main electronics, embedded system, and self-disinfection system components. After painting the body in light blue, the 3D-printed head and arms were assembled into the body. Finally, the face screen and speakers were added to their respective slots in the head. The self-disinfecting system was not installed in this version of the prototype, as explained before, only its placeholders were put.

2.4 Prototype Testing and Validation

Based on the iterative nature of the SRCC framework, the designed robot was tested to validate its various aspects and collect feedback for future improvements. Therefore, a second phase of interviews was conducted with a different focus group of end users (patients and medical staff), after obtaining a second ethical approval of the protocol from the IRB at AUB. Similarly to what was done in the first stage, in-person interviews with current and former BMT patients and medical staff members from different units at the AUMBC were conducted. During the interviews, the prototype was first shown to end users, and then an explanation of the robot's role was provided, along with a live demonstration of certain aspects like motion, facial expressions, and audible phrases. Afterward, a specific set of questions was asked and feedback was recorded for later analysis.

2.4.1 *Phase-2 Interview Analysis.*

Patient's Data Analysis. In this phase, 11 patients who had been admitted as BMT patients into the isolation room and checked out prior were interviewed after a routine check up with their doctor. They were seven males and four females ranging between 32 and 71 years old. Two out of 11 patients were from Iraq, and the other nine were from Lebanon. Of those from Lebanon, two had participated in Phase-1 interviews but stated only vaguely remembering "something about a robot." After getting the patient's consent, the procedure described prior in Section 2.3.6 was followed. The room in which the interviews were conducted had an interior similar to the standard isolation room at AUBMC, while noting that certain isolation rooms were different in area and layout depending on which wing of the hospital they were in.

After the robot exited the room, the interviews were conducted with the interviewers being the researchers conducting this study. The patients were asked the following questions, which are related to those formulated in Phase-1 for validation purposes. The language for the interview was Lebanese dialect, and the results were translated to English by the researchers. The same

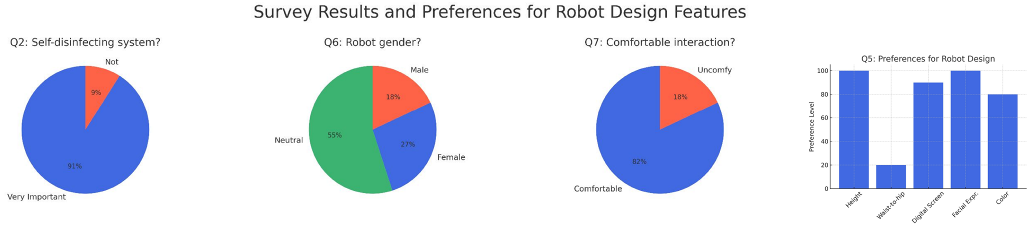


Fig. 13. Post-demonstration patient interview results.

thematic content analysis method from Phase-1 was used. The duration of Phase-2 was one and a half months.

Q1: What are your (the patient's) impressions/feelings after seeing the robot?

The most commonly used words to answer this question were: comfortable (9 patients), cute (11 patients), friendly (11 patients), and big (9 patients). All of the patients liked how the robot looked in general and had positive feelings after seeing it for the first time. The main negative comment was that the shoulders were wider than desired.

Q2: Would you (the patient) feel safer if the robot has a self-disinfecting system?

About 91% of the patients asserted that a self-disinfecting system would be very important for a robot entering their isolation rooms. "When BMT patients are isolated, all that they think about is their weak immunity system and the imposed risks on their health each time someone enters their room. This system will make me more comfortable for sure," said one patient.

Q3: In your (the patient's) opinion, will such a robot reduce the risk of disease transmission during isolation?

Patients considered that a robot like SHARE-C would protect them and reduce the risk of infection during isolation periods. These fears have been exacerbated among immunocompromised patients since the spread of COVID-19, a highly transmissible virus that is very risky to such patients. As remarked in Phase-1, the biggest fear of patients came from staff members delivering food to isolation rooms and custodial services that clean the rooms, whom they perceive as not abiding by the necessary precautions at all times. Given that the robot, if properly operated and accidents are avoided, will not have the risk of entering a room without sterilization, implementing it will make them feel more comfortable and safer.

Q4: Based on the physical appearance of the robot, what did you (the patient) like and dislike the most?

Patients liked the facial expressions of the robot because they made it seem friendly and more acceptable. They did not like the large size of the upper part of the body (chest-to-shoulders ratio) and postulated that even if the arms carry the tray, the shoulder area's width can be reduced by around 50% while keeping the height as-is.

Q5: Did you (the patient) like the following features: height, waist-to-hip ratio, use of a digital screen for the face design, facial expressions, color, and overall body shape?

Patients liked the different features of the robot's physical appearance (see Figure 13 for each feature), except for the shoulders' width that was mentioned in Q4.

Q6: Do you (the patient) think that the robot belongs to a specific gender or is it gender neutral?

About 27% considered that the robot is a female because of the shaped body or the pink cheeks, 18% considered that it is a male because of the blue color, and 55% thought that it is gender neutral.

Q7: Did you (the patient) feel comfortable while interacting with the robot?

About 82% of the patients felt comfortable when the robot interacted with them (changed its facial expressions and greeted them). They believe that these features have a positive impact during isolation and they could serve an entertaining role as well.

Q8: Did you (the patient) like the Lebanese dialect? Would you prefer other languages?

Patients preferred the Lebanese dialect, citing its familiarity and ease of understanding, which made them feel more comfortable and better relate to the robot. Notably, two non-Lebanese (Iraqi) patients also preferred the Lebanese dialect stating that they expect a robot in Lebanon to speak the Lebanese dialect. Three patients suggested offering multiple language options, including French and English, to accommodate those who might not understand Arabic or the Lebanese dialect easily.

Q9: What future improvements can be made to the design?

The patients' answers to Q9 can be categorized into two bins:

- *Physical Appearance*: (a) reduce the shoulders' width and b) use another material for the body (some suggested plastic) because the casted/painted body made the robot look rudimentary. Here, it was explained to the patients that the robot designed and manufactured in this work is a low-resolution prototype for POC only and that more advanced manufacturing processes would be followed for the final product.
- *Functionality*: Patients preferred to limit the functionality of the robot to basic tasks only. It was explained to them that the robot's tasks include delivering food items and other supplies (e.g., tissues), in addition to providing telepresence. Two patients suggested adding entertainment features to the robot like playing music, and another patient suggested adding a feature where the robot could also clean the isolation room.

Medical Staff's Data Analysis. Seven medical staff were interviewed in Phase-2: two doctors and five nurses, all female and Lebanese from the Pediatric (with prior BMT experience) and BMT units, with ages ranging between 25 and 50 years old. Two of the nurses and one of the doctors had participated in the Phase-1 interviews. The focus of the questionnaire was on the robot's functionality and the staff's ability to adapt to it, more so than its physical appearance.

Q1: What are your (the medical staff's) impressions/feelings after seeing the robot?

Similarly, a positive attitude toward the robot was observed, which is consistent with the feedback of the patients.

Q2: Are you (the medical staff) able to adapt to its presence as part of your job?

The medical staff ensured that it would not be hard for them to adapt to it, especially since they use technological devices and electronic gadgets in their daily lives that are not too dissimilar to the ones used to control the robot.

Q3: Should the robot be remotely controlled or autonomous?

The interviewed medical staff members stated that three main objectives to be achieved by the robot's control method are: time-saving, decreasing the risk of infection, and decreasing the usage of PPE. Medical staff consider that having a manually controlled system will achieve the two latter points, but would consume their time. Therefore, many of them suggested implementing a semi-autonomous system (84% for semi-autonomous, 16% for fully autonomous) that works as follows: all of the commands are to be issued by the medical staff whenever they need the robot to execute a certain mission, but the robot will complete them on its own (autonomously).

Q4: What future improvements can be made to the design?

The medical staff responses to Q4 can be categorized into two bins:

- *Physical Appearance*: (a) decrease the shoulders' width and (b) change the color to a neutral one (olive skin or silver) for younger patients and colorful for children.

- *Functionality*: While the doctors suggested having the robot take vital signs for patients, the nurses indicated that the robot should not perform any tasks related to the patient's health, and it is sufficient to provide telepresence and delivery functionality.

3 Discussion

This research applied the SRCC framework to produce SHARE-C, a social-service robot for healthcare use. The framework provided clear guidance to craft a robot with features that are socially accepted by the human subjects who would interact with it. Suiting the needs of both the robotics industry and research institutions, SRCC provided an overarching framework that can accommodate paths to both research and market, and represents an advancement in how design thinking is approached. Consequently, one of the notable advantages of employing the SRCC framework in this study was the ability to reach a viable prototype stage in a relatively quick fashion, which was desirable given that the ultimate goal of this research study was investigating SHARE-C's social acceptance, and not necessarily creating a market-ready product.

By comparing the findings of Phase-1 and Phase-2, it was noticed that there was consistency in the opinions of the surveyed patients and medical staff toward implementing SHARE-C in hospitals (90% in Phase-1 and 100% in Phase-2). A generally positive attitude toward the devised robotic system design was observed, where the robot's overall shape was acceptable, the end users liked it, and they asserted that they feel comfortable with it being around them. The main change to implement in the next design iteration was reducing the size of the upper part to obtain a robot with narrower shoulders while keeping the same height. It must be noted that the design and size of the hospital rooms differ based on their location in the building, where some rooms have a more narrow entrance strip followed by a larger area near the patient's bed, while others are narrower near the patient's bed. The room for this study was the one with a larger area near the bed and some patients mentioned that their BMT isolation rooms had narrower sections than the demonstration room when discussing the size of the robot (not all isolation rooms at AUMBC have the same area and layout). With that said, the suggestion to make the shoulder and torso areas narrower (up to 50%) would make the shape of the body closer to an A-shape, which is considered more massive and than an hourglass figure, but similarly friendly according to Liberman-Pincu et al. [69]. However, it is possible to maintain a shape closer to the hourglass by keeping the waist area noticeably narrower than the torso, and keeping the form of the shoulders after decreasing their size.

In terms of functionality and tasks, the self-disinfecting system was considered important and highly appreciated by the patients and medical staff. However, as the interviewed patients are recovering, i.e., they have checked out of their isolation rooms, it is possible that patients who are still in isolation might harbor more skepticism. In that case, it becomes more pertinent to demonstrate the self-disinfection system to them, possibly even before their surgery as part the pre-surgery information package, to gain a clearer understanding of their perceptions of safety and trust, and to prevent any surprises when dealing with post-surgery negative emotions and stress later on. Furthermore, it would be advisable to have the self-disinfection demonstration incorporated into the robot's routine during first contact with the patients to increase trust, as they would not be able to see it during normal operation because the robot performs disinfection outside the door upon entry (and exit).

As for the robot's operation, the medical staff members who were interviewed in Phase-1 preferred to have manual control over the robot's functions; however, in Phase-2 and after observing how they would be required to manually control all of its actions, they felt that it would not be very time efficient. As a result, they suggested having a semi-autonomous system, where the robot receives top-level commands from the staff to go to a specific room at a particular time, and the robot would autonomously navigate to the room. The previous choice was understandable as patients are their priority, and trusting unfamiliar technology can be difficult when lives are at stake. However, this was a surprising and significant shift in medical staff preference regarding robot control, as an overwhelming majority (84%) in Phase-2 suggested a semi-autonomous system, even without viewing a demonstration of autonomous capabilities. The growing trust among the medical staff may be attributed to the increasing documentation of robotics' success in healthcare at AUBMC and across the region [115, 116]. This shift also indicates that while the social features of the robot could influence trust among patients, for the medical staff, this trust was mostly derived from efficient functionality. However, this is not to say that the staff members do not value the robot's social aspect; on the contrary, they care about it for the sake of their patients' mood and mental health, but they do not interact with the robot as much as patients do. Social aspects of the robot are more important to those who socially interact with the robot, and it was understood from the first step of the design process when needs were assessed, that not all stakeholders care equally about the robot's social aspects.

Preliminary results supported the acceptance of SHARE-C by patients in Lebanon and the effect of using the Lebanese dialect on its acceptance. Another factor that was investigated was whether patients were able to observe any explicit or implicit cultural aspects in the robot, and what those aspects were. The main culturally relevant element pointed out by the patients was the robot's Lebanese dialect, making it, as anticipated, SHARE-C's most significant cultural component from the patients' perspective. In fact, none of the patients indicated noticing any bias toward a particular subculture or the exclusion of others. This supports the effectiveness of the culturally aware framework that was implemented, particularly in preventing issues that might conflict with the Lebanese cultural context. In summary, using social robots in the healthcare domain is encouraged, as long as the robots do not completely replace the staff members or perform medically related tasks. Self-disinfection was deemed as important and needs to be demonstrated. Finally, the Lebanese dialect made patients feel more comfortable and eager to interact with the robot.

4 Future Work

After gathering data from stakeholders, it is possible to improve the design as per the elements of the HCD and SRCC frameworks. Future work concerns three main aspects: the physical appearance of the robot, its functionality, and its identity.

Regarding appearance, conclusions from interviews suggest reducing shoulder width and achieving a smoother body finish, while maintaining proportionality between all parts when these changes are introduced.

Regarding functionality, implementing the semi-autonomous control method can be achieved via SLAM algorithms, line-tracking with colored paths for each room, or a combination of both for increased reliability. The robot should receive commands from medical staff and autonomously navigate to specified rooms, with collision avoidance. An augmented display feed for staff to monitor and correct navigation is recommended. A new drive system can be installed to increase speed and operating time and include components for autonomous navigation like stereo cameras and other sensors. A major remaining challenge is enabling the robot to open BMT patient room doors, which are harder to open due to negative pressure. Regarding identity, another study should be conducted to assert the positive effects of associating SHARE-C with the Lebanese cultural context and its acceptance by patients in all of Lebanon, some of whom might not be native Lebanese or Arabic speakers. This can be achieved by giving the robot another identity, testing the two identities with the targeted populations, and making comparisons.

Limitations of this study stem from the small number of participants, as even with AUBMC's scale, Lebanon's small population limits the number of BMT patients available. This was further noticed, as even with the length of time separating Phase-1 and Phase-2 (almost one year), the turnover of patients was lower than expected, as there was an anticipation of zero repeat patients since they would have completed the treatment and the monitoring period, after that transitioning to less frequent visits. Repeats among medical staff were more anticipated, as doctors would stay in their department of specialty for long stretches of their careers and nurses changed department once every 3 years, on average. This does not devalue the conclusions, but suggests the need for larger-scale studies involving multiple hospitals in Lebanon. Another limitation is the social class and location of interviewees, as AUBMC, located in Beirut, generally serves higher-income individuals. Future work should expand to remote areas and include lower-income brackets for broader input. Limitations also arise from the robot itself due to the lack of advanced manufacturing techniques in the low-resolution prototype, which affected its appearance and initial perceptions. The prototype also did not include a functional self-disinfection system, which prevented studies on sterilization efficacy, focusing on perceptions instead. Future research should allocate more resources to develop a more functional robot to evaluate performance comprehensively. Given the challenges of placing mobile robots in hospital settings, researchers should explore and establish more practical and quantitative methods for assessing factors such as safety and sterility, which might differ from those established for other medical equipment.

5 Conclusion

In this research, a self-disinfecting social healthcare robot was designed by following the HCD-based SRCC framework, shaping the robot's design from the early stages. Findings from interviews and literature were incorporated into the robot's appearance and interaction features. After producing a low-resolution prototype, it was tested with end users to validate its design and identify future improvements in functionality, appearance, and identity. The study showed the proposed design could reduce the perceived risk of infection among patients and provided a faster delivery method, making patients and healthcare workers feel safer. Further design iterations are needed to achieve a prototype capable of clinical trials to determine efficacy in reducing the actual risk of infection, not just the perceptions.

The designed robot was accepted by end users, though improvements are needed in the second iteration. Preliminary results from interviews showed that social robots are accepted in healthcare in Lebanon, with people appreciating their benefits if properly implemented. Positioning the robot within the Lebanese cultural context mainly through its dialect was widely accepted and preferred by end users, aligning with studies in other countries with different cultural identities. The next design iteration will include new features to enhance its capabilities, acceptance, and adoption, as well as expand the study on social robot acceptance and the impact of its Lebanese cultural context association on the Lebanese people.

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Declarations

- *Conflict of Interest/Competing Interests*: N. Daher received a research grant from the Maroun Semaan Faculty of Engineering and Architecture (MSFEA) Crisis Research Catalyst (CRC) Initiative. The remaining authors assert that they have no conflict of interest.

- *Ethics Approval and Consent to Participate*: Ethical approval for the protocol of this study was provided by the Human Research Protection Program (HRPP) and the Institutional Review Board (IRB) at the American University of Beirut (AUB). Phase-1: SBS-2020-0409, Phase-2: SBS-2021-0392. Informed consent was obtained from all individual participants included in the study.
- *Data Availability*: Data collected during the current study, which includes the anonymized responses of interviewees in Phase-1 and Phase-2, are available from the corresponding author upon reasonable request.
- *Video*: A short (1-minute) video, which summarizes this article and shows the robot in action, is made publicly available via the following link.
- *Author Contribution*: Nijad Al Dubayssi, Marwa Ismail, Myriam Ebrekgi, Yves Daoud, and Naseem Daher contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by Marwa Ismail, Nijad Al Dubayssi, Myriam Ebrekgi, and Yves Daoud. The first draft of the manuscript was written by Nijad Al Dubayssi, Marwa Ismail, Myriam Ebrekgi. All authors read and approved the final manuscript.

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