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STAKEHOLDER SELECTION FRAMEWORK FOR PARTICIPATORY DESIGN OF SOCIAL ROBOTS

THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
ATILIM UNIVERSITY

EBRU YALÇIN

A MASTER OF SCIENCE THESIS
IN
THE DEPARTMENT OF MECHATRONICS ENGINERIING

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Approval of the Graduate School of Natural and Applied Sciences, Atılım University.

Prof. Dr. Ender Keskinkılıç
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I certify that this thesis satisfies all the requirements as a thesis for the degree of **Master of Science in Mechatronics Engineering, Atılım University**.

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This is to certify that we have read the thesis STAKEHOLDER SELECTION FRAMEWORK FOR PARTICIPATORY DESIGN OF SOCIAL ROBOTS submitted by Ebru Yalçın and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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ABSTRACT

STAKEHOLDER SELECTION FRAMEWORK FOR PARTICIPATORY DESIGN OF SOCIAL ROBOTS

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Social robots increasingly interact with humans in diverse contexts. This study addresses the gap in systematic methodologies for matching user needs with stakeholder expertise in participatory design. By creating a context-independent framework, it facilitates structured stakeholder selection through design and expertise spaces.

Using Quality Function Deployment (QFD) adapted to this study, the relationships between dimensions characterizing social robots and stakeholder expertise were analyzed resulting in a systematic stakeholder selection process. The developed framework also allows designers to check compatibility of stakeholders using the Design Structure Matrix (DSM) methodology. Validation conducted through case studies selected from the publications related to the participatory design of social robots, demonstrated the framework's applicability.

This research fills a critical gap in the literature by providing a systematic approach for the participatory design of social robots that are tailored and personalized to user needs.

Keywords: Social Robot, Participatory Design, Stakeholder Selection, Quality Function Deployment, Design Structure Matrix.

ÖZET

SOSYAL ROBOTLARIN KATILIMCI TASARIMI IÇIN PAYDAŞ SEÇİM ÇERÇEVESİ

Yalçın, Ebru
Yüksek Lisans, Mekatronik Mühendisliği Bölümü
Tez Yöneticisi: Doç.Dr.Zühal Erden

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Sosyal robotlar, insanlarla etkileşimde giderek daha yaygın hale gelmektedir. Bu çalışma, kullanıcı ihtiyaçlarını paydaş uzmanlıklarıyla eşleştirmeye yönelik sistematik bir metodoloji eksikliğini ele almıştır. Tasarlanacak sosyal robotun kullanım alanından bağımsız bir çerçeve ile tasarım ve uzmanlık alanları oluşturularak yapılandırılmış bir paydaş seçimi hedeflenmiştir.

Bu çalışmaya uyarlanmış Kalite Fonksiyon Dağıtımı (QFD) kullanılarak, sosyal robotları karakterize eden boyutlar ile paydaş uzmanlıkları arasındaki ilişkiler analiz edilmiş ve sistematik bir paydaş seçim süreci geliştirilmiştir. Geliştirilen çerçeve ayrıca tasarımcıların Tasarım Yapı Matrisi (DSM) metodolojisini kullanarak paydaşların uyumluluğunu kontrol etmelerine olanak sağlamaktadır. Sosyal robotların katılımcı tasarımıyla ilgili yayınlardan seçilen vaka çalışmaları aracılığıyla yürütülen doğrulama, çerçevenin uygulanabilirliğini göstermiştir.

Bu araştırma, literatürdeki kritik bir boşluğu doldurarak, kullanıcı ihtiyaçlarına göre uyarlanmış ve kişiselleştirilmiş sosyal robotların katılımcı tasarımı için sistematik bir yaklaşım sunmaktadır.

Anahtar Kelimeler: Sosyal Robot, Katılımcı Tasarım, Paydaş Seçimi, Kalite Fonksiyon Dağılımı, Tasarım Yapı Matrisi.

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CHAPTER 1

INTRODUCTION

The increasing penetration of automated technology into our daily lives has shifted the use of robots from structured tasks in controlled environments, such as factories or research laboratories, to more complex environments, such as homes and public places (hospitals, parks, museums, shopping malls, etc.). In such environments, fully or partially automated social robots appear as technological entities with social functionality that operate for and alongside humans. Social robots are designed to perform complex human interactions potentially involving multiple users and stakeholders [1] [2]. The usage areas of social robots are quite diverse, and they are starting to be used almost wherever interaction with humans is necessary. The most common of these areas are services, health, education, entertainment, and research [3]. Since social robots interact with people in different operational environments within daily life [4], they should be designed to meet the demands and needs of individual users and/or user groups for various settings. Therefore, methodologically speaking, a customized design approach based on the needs of different users is required for social robots, as opposed to a mass production-oriented design [5]. To this end, in order to develop a product family with customized - even personalized - social robots, it is essential to involve potential and/or real users in the design process.

1.1 User/Stakeholder Participation in Social Robot Design

There are various methods for user participation in design, such as participatory design, co-design, and user/human-centered design. Participatory design (PD) gives researchers and designers a chance to involve all stakeholders in a variety of design-related phases, such as the preliminary requirements and needs analysis or evaluation of the product prototype [6] [7] [8]. The co-design approach is intriguing since it promotes the idea that users can create the answer on their own while the designer takes on a support role. The ‘co’ is, thus, a reference to ‘collaborative’, which shows that the traditional role of the designer as the sole creator of new things is changing rapidly [9]. Lastly, user-centered design (UCD) is a philosophy that puts the user (human) at the center of the experience; the method focuses on determining the user's wants, preferences, and intent in order to create systems and services that are beneficial to them [10]. Persons from many disciplines, particularly psychologists, sociologists, and anthropologists, whose job is to understand users' needs and express them to the technical developers on the team, benefit from being included in user-centered design teams. Adding input to the design with the information received from the user is a common feature for all design methods with user participation. However, participatory design also addresses the social position of the participants in the research process and determines how to give them the power to make decisions for themselves and take action on issues that matter [11]. Nevertheless, there are some differences between participatory design and user-centered design; in the former, the user participates in all design and test processes; whereas, in the latter, she or he is included in the pre-design process and testing.

Generally speaking, a user is involved in the design process in various ways such as surveys, interviews, workshops, etc. These methods have been used in some studies at the very beginning of the design, in some to test the design, and in some to improve the design according to the feedback. User involvement in design processes has both advantages and disadvantages. The most important advantages are improving product efficiency, effectiveness, safety, and assisting in the management of users' expectations, and improving the levels of product satisfaction. In addition, this involvement develops a sense of ownership among users, while the collaborative techniques also result in more innovative problem-solving solutions. As the disadvantages are considered, some forms of data may be challenging to translate into design and the product may be too specific for general use, making it difficult to transfer to new clients due to complexity on top of expenses. A social robot is developed to reduce loneliness among elderly individuals, with active participation from a specific group during its design. Based on feedback, the robot is customized to be gentle, speak slowly, play 1960s music, and remind users of teatime. This example highlights the trade-off between user participation and generalizability, showing that while the robot meets the needs of a specific group, it may not appeal to younger or culturally diverse elderly individuals, emphasizing the challenge of balancing customization with broader appeal. However, although this is a disadvantage for many products, it is a requirement for social robots that focus on interaction with users and their diverse needs. Other disadvantages include higher costs and durations, requiring additional design team members and a diverse spectrum of stakeholders. Some of these disadvantages can be overcome through the formalization of the user/stakeholder participation process.

1.2 Motivation, Objective, and Research Questions

Participatory design of social robots aims to create technology that better adapt to the expectations and requirements of target users by considering their needs, perspectives, and desires. Thus, the active participation of potential users is critical. Beyond end users, other stakeholders who may have an interest or influence on the design process are also identified and included in the process. In the case of social robot design, stakeholders are various professionals/experts selected based on the application area, required functions, and features of the robot. These may include caregivers, healthcare professionals, policymakers, and others, depending on the context. The participatory design process is further elaborated via workshops, collaborative sessions, interviews, prototyping, and iterative feedback loops such that designers, end users, and stakeholders can work together to generate ideas, define requirements, and outline design concepts. Current studies in the literature on the participatory design of social robots focus on the development of a specific robot. As a result, end users and other stakeholders who participate in the process are selected by the research/design team, based on the specific context and application area. A holistic, systematic, and context-independent approach to these steps has not been found in the literature. Context-independence means that a method, framework, or design is not tied to a specific environment, user group, or application scenario. Instead, it can be applied flexibly across different contexts without needing major modifications.

The objective of this thesis is to develop a systematic and context-independent framework to determine specific users, professionals, and experts as potential stakeholders who can be consulted throughout the participatory design process for social robots. For this purpose, the following research questions are addressed;

RQ1: What are the dimensions characterizing a social robot?

RQ2: What is the design space of social robots based on these dimensions?

RQ3: Can we define a stakeholder space for various domains?

RQ4: How can we match the design space of social robots and stakeholder space to systematically select stakeholders for the participatory design of social robots?

1.3 Methodology and Scope

In order to answer these research questions, we use the following methodology which is elaborated in Chapter 3 of this thesis:

1. A context-independent **'D**esign Space for **So**cial Ro**bot**s (D-SoBOT)' is defined and formally presented based on a conceptual framework for characterizing social robots along 10-dimensions.

2. A 'Domain (**F**ield) Space for **Stakeholder**s **(F-Stakeholder)**' is defined for various domains using the information gathered from the related literature and further elaborated.

3. The relationships between D-SoBOT and F-Stakeholder are defined such that stakeholders can be associated with the user requirements resulting in a systematic selection of stakeholders for participatory social robot design.

1.4 Structure of the Thesis

The remaining sections of this thesis are organized as follows: Chapter 2 includes a review of the literature on the user-involvement methods in social robot design leading to the research questions of this study. Chapter 3 explains the methodology to develop the proposed framework. Chapter 4 presents the practical use of the proposed framework through design case studies selected from the literature. Finally, discussion, conclusions, and future research directions are provided in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 User Participation in Engineering Design

User participation is an important strategy in engineering design towards the goal of customization to ensure that the final product satisfies user needs and, therefore, is usable/useful/acceptable. According to recent research, designers produce more original concepts and ideas when working in a co-design setting with others than when doing it alone [12]. In order to create products, systems, and environments that are more responsive and appropriate to their inhabitants' and users' cultural, emotional, spiritual, and practical needs, user participation is utilized in a variety of fields, including product design, software design, urban design, architecture, landscape architecture, sustainability, graphic design, planning, and even medicine.

Several methodologies such as user-centered design, human-centered design, participatory design, co-design, and co-creation describe user participation in designing products, with some similarities and differences among their guiding principles.

User-centered design (UCD) is an approach to design focused on understanding the needs, preferences, and limitations of the end-users throughout all stages of the design process [13]. In other words, UCD is a philosophy that puts the user (human) at the center of the experience in order to create systems and services that are beneficial to them [10]. While the demands of the business are sometimes taken into consideration, most design choices are made with the wants and expectations of the user in mind. Key principles in UCD include user involvement, iterative design, and usability testing to refine solutions.

Human-centered design (HCD) is a broader approach that includes not only the users but also other stakeholders and the context in which the system or product will operate. Similar to UCD but broader, HCD focuses on creating solutions that cater to human needs, including emotional, social, and cultural factors, not just usability. It also emphasizes empathy, inclusivity, and sustainability [10].

Participatory Design (PD) is a well-known design methodology that aims to actively involve all important stakeholders (especially end-users) in the design process to ensure the result meets their needs [6] [7] [8] [14]. This method is focused on collaboration and is often used in public or community-driven projects. The expertise of various people and/or groups, such as factory workers, management, and external engineers, who all have different sets of skills, competencies, and backgrounds, can equally contribute to the design results and assess the final solutions, ensuring the result meets the specified and actual needs and is effectively usable. It is stated that PD allows designers to produce more inventive thoughts than they do when working alone [15]. In participatory design (PD), the objective is to create cooperative and collaborative design relationships that can empower users and enhance people's lives on a practical or political level rather than simply understanding people and their expertise to construct systems for them. The emerging design is always iteratively constructed, and this emerging design simultaneously comprises and elicits the research findings as co-interpreted by the designer-researchers and the participants who will use the design [16].

Co-Design is a subset or a specific form of participatory design where designers, users, and other stakeholders collaborate as equal partners to generate ideas and make decisions during the design process generally through workshops or collaborative sessions [17]. It emphasizes shared power and ownership over design decisions.

The co-design approach is intriguing since it promotes the idea that users can create the answer on their own while the designer takes on a support role. This strategy is undoubtedly inspiring because it encourages individuals to express their design actions. It is a rather new, though very popular, term that refers to a process in which different designers and/or other actors engage in jointly designing a product or a service. The 'co' is, thus, a reference to 'collaborative', which shows that the traditional role of the designer as the sole creator of new things is changing rapidly [9].

Co-creation is a collaborative process involving users, stakeholders, and sometimes customers in generating value or ideas. Co-creation is a broader term that encompasses co-design but also includes stakeholders collaborating on the entire value creation process beyond design, extending towards marketing and strategy development. It focuses on joint problem-solving and creativity with users and other contributors for business innovation [18].

There are similarities and differences among the above-mentioned methodologies. The similarities can be summarized as follows, whereas the differences are provided in Table *2.1*;

- **User/Stakeholder Involvement:** All of these approaches involve end-users and/or stakeholders to varying degrees.
- **Collaboration:** All approaches rely on collaborative efforts to ensure the final outcome aligns with user needs or shared goals. Each method emphasizes collaborative problem-solving and knowledge sharing.
- **Iterative Nature:** These approaches typically involve multiple iterations based on feedback in refining designs or solutions.
- **Goal Orientation:** All methods aim to improve the relevance, usability, or impact of the final product or solution.

Table 2.1: Differences between the design types

Aspect	**UCD**	**HCD**	**PD**	**Co-Design**	**Co-Creation**
Scope	Focused on end-users, primarily for product or system design	Includes broader context with societal factors	Involves wider stakeholders Focuses more on workplace/system design	Shared ownership among all, narrower focus on specific design tasks	Beyond design, covers the entire value creation process
Power Dynamics	Designers lead	Designers lead	Collaborative but led by experts	Equal footing for stakeholders	Equal, with a focus on value
Focus Area	Usability, functional needs and user experience	Broader human experiences and contexts	Collaborative input, stakeholder participation in design	Shared decision-making, equal collaboration in design process	Collaborative innovation beyond design
Outcome Ownership	Primarily the design team	Primarily the design team	Shared, but designer-driven	Shared ownership	Shared ownership
Level of User Role	Consultative, feedback-driven	Empathetic and inclusive	Active engagement in decisions	Equal partnership in ideation	Active engagement throughout lifecycle

Aspect	UCD	HCD	PD	Co-Design	Co-Creation
Origin	Ergonomics and usability practices	Design thinking and inclusivity	Scandinavian workplace movements	Design and innovation workshops	Business and innovation practices
Emphasis	Efficiency and effectiveness	Empathy, inclusivity, and sustainability	Shared decision-making	Equal design input	Value creation beyond product design

In summary, all of these strategies ultimately center on people, their needs, and how to address those needs. They share the notion that integrating people into the design process would result in products that are more useful [19]. UCD and HCD focus on understanding and designing for users, but HCD incorporates a broader perspective. PD, Co-Design, and Co-Creation are more collaborative, with participatory design ensuring stakeholders' voices are heard, co-design involving equal collaboration in the design phase, and co-creation extending the collaboration beyond design to the entire value creation process. User participation techniques are important approaches for developing social robots since they can accelerate the creation of contextually savvy robotics applications that take into account users' interpretations as contextual experts and the appropriate social infrastructures to integrate robots into daily life [20].

2.2 User Participation in Social Robot Design

In general, a robot is defined as a physical system that can perceive its environment, make plans in response to these sensory inputs, and act according to its environment [21]. While service robots usually focus on providing physical support and interaction, social robots aim to provide cognitive support through social interaction [22]. There are many definitions of social robots; for example, a social robot is defined as an independent physical operator, scanning for social behaviors and related rules [23]. A social robot is defined as an autonomous or semi-autonomous robot that interacts with humans by adhering to the behavioral standards anticipated by the people with whom the robot is designed to engage, according to the design-centered approach [24]. Social robots are also defined as physically structured autonomous agents that can communicate and interact with people in behavioral and emotional dimensions by following certain social cues and rules [4] [25]. Although there are some differences between these definitions, the basic characteristic that turns a robot into a social robot is that the social robot can interact with people by following social signals and rules while performing its tasks. Social robots are designed to assist target user groups such as children, patients, or elderly individuals in education, healthcare, service, and similar fields [26], to interact with people in a natural way, and to work in environments where people are present [27].

These autonomous, embodied entities interact, cooperate, and communicate with humans by acting in accordance with social standards. For fields where robots need social skills to create and maintain social relationships, including education or healthcare, social robots offer valuable answers (even if their domain is dominated by non-social activities). Robots must be built with acceptance, trust, and a tailored engagement with their users in mind if they are to be capable of forming social relationships [22] [26].

Since social robots are intertwined with humans, it is important to work with the user in the design and development processes. Thus, various user-oriented methods are applied in social robot designs to ensure that users are willing to accept them [28]. Persons from many disciplines, particularly psychologists, sociologists, and anthropologists, whose job it is to understand users' needs and express them to the technical developers on the team, benefit from being included in user-centered design teams. Similar to user-centered design, participatory design relies on user comments to determine appropriate designs and uses for social robots. Adding input to the design with the information received from the user is a common feature for all user-oriented design methods. However, participatory design also addresses the social position of the participants in the research process and determines how to give them the power to make decisions for themselves and take action on issues that matter [11].

Obviously, user involvement in the social robot design processes has both advantages and disadvantages. The most important advantages are improving product efficiency, effectiveness, safety, and assisting in the management of users' expectations, and improving the levels of product satisfaction. In addition, this involvement develops a sense of ownership among users, while the collaborative techniques also result in more innovative problem-solving solutions. As for the disadvantages, they include higher costs and durations, requiring additional design team members (such as ethnographers, and usability experts), and a diverse spectrum of stakeholders; moreover, some forms of data may be challenging to translate into design and the product may be too specific for general use, making it difficult to transfer to new clients due to complexity on top of expenses. However, although this is a disadvantage for many products, it is a requirement for social robots that focus on interaction with users and their diverse needs. The key point here is to construct a social robot product family that includes customized robots instead of designing a single product, and this approach needs to be realized during the highest level of abstraction at the conceptual design level.

User participation methods have been used in various studies in the literature as summarized below:

Marti and Giusti [29] applied the user-centered design method to create a robot called ‘Iromec’, which was capable of meaningfully interacting with several types of disabled children, including those who are autistic, somewhat mentally retarded, and severely motor impaired. They organized a number of workshops, panels, interviews, and observations of playing children to develop the user requirements. Different users/informants actively participated to assist the designers in shaping the design at various stages; at the beginning, to determine the problem in the domain; in the middle, to test assumptions; and, in the end, to test the robot in real-life settings. In a different work, user requirements were collected through focus groups and interviews for a robot named ‘TOOMAS’ developed to help clients in home improvement shops [28]. The user participation in that study also involved social scientists who assessed the findings from each stage of the data collection, spoke with robot developers, and were included in the usability engineering process for the user interface and the installed search engine. The usability criteria were also assessed via oral interviews and overt observations with various customers as participants who were also supposed to utilize the robot for the first time. The impacts of users' gender, age, educational background, and level of computer proficiency on robot usability were also examined.

The human-centered design was used in the ‘HOBBIT-The Mutual Care Robot’ project, which examined the use of robots to encourage senior adults to live independently [30]. The specific aim was preventing and detecting falls among the elderly. The user requirements for a social assistance robot were gathered through workshops, interviews, and a questionnaire. Two robot prototypes were designed, built, and tested by senior persons themselves who also found the robot to be friendly and happy. McGinn [31] applied user-centered design techniques to create a prototype socially assistive robot (SAR). This realization supports the critical requirement that designers use "design thinking" techniques that make it easier to create empathy with target consumers and actively involve them in the design process through interviews, focus groups, and surveys to obtain feedback. The Human-Centered Design and Participatory Design method was used in the EMAR project, where the goal was to develop a social robot that would help teenagers with mental health issues by detecting external signs of stress and mood changes and providing a micro-intervention in school settings [16]. The data collection was conducted through many interviews with teenagers, as well as by using the prototypes they had made at school. Afterward, the final prototype was designed and tested with virtual reality developed in accordance with this feedback. Despite some limitations, the use of participatory methodologies, particularly with vulnerable groups, proved to be important given the breadth of possible human-robot interaction studies available to date.

Giuliani [32] conducted another study to develop a robot that would allow physicians to remotely perform auscultation and echocardiography on patients. The user-centered design method was used and user requirements were collected from doctors. The first ‘ReMeDi’ prototype was developed after the feedback was delivered to doctors to use and test on dummy patients. The ReMeDi robot was successfully used by all of the doctors, even when it was still in the prototype stage. The doctors' input and observations were extremely helpful, leading to improvements in ReMeDi’s second prototype system design. Their findings are important for researchers who use the user-centered design method in the context of medical robotics, as well as for developers of medical robot systems. The Participatory Design method was used in designing a socially assistive robot (SAR) for education that was developed with the participation of stakeholders in different phases of the methodology [33]. They chose the social role of the robot which is a decisive factor for the combination of the features incorporated into the robot, taking into account the demands and requirements of the stakeholders. Quizzes and surveys were conducted and data were collected. A social robot design for teaching mathematics to children was made in the iCETA project, which uses the participatory design method [34]. According to the research, this method is effective at bringing together children and other stakeholders to come up with a plan that addresses their needs and ensures educational effectiveness. Another study aims to comprehend how people in a public setting perceive robot interactions and behavior [35]. The participants in this project study developed robot behaviors for applications in public spaces, later evaluating the designs in an actual robot and a simulator using the participatory design method.

Another project aims to make physical activities accessible to children with upper limb issues that they would not otherwise be able to do on their own. The 'MyJay' robot can pick up balls and shoot them into a goal. The user-centered design method was used, and the children were also involved in the design process after meeting with therapists and developing a high-fidelity prototype of the robot that can play a ball game. The studies were done online with the help of videos and pictures. After some testing with the prototypes, some interviews were done. According to the findings, the age factor was reported to have possibly had an impact on how engaged the children became with the robot. Future research can examine whether this can be verified for face-to-face communication and [26] [36] research aims to examine the social structure of facilities that house dependent older individuals, as well as the potential effects of social robot introduction. It was decided to use the co-design method in that project, but due to the COVID-19 crisis, it was combined with "cultural probes" and interviews instead of co-design.

The literature shows that user participation methods have been used in various social robot designs. Yet, these studies only apply one or more of the user-involvement methods in the design of one specific social robot alone in each case. It is realized that there is a lack of a generic and systematic methodology for user participation in designing social robots. As a contribution to fill in this gap, the present research focuses on developing a framework for the systematic selection of users and other stakeholders who need to be involved in the participatory design of social robots. Towards this purpose, the following research questions are addressed in this thesis;

RQ1: What are the dimensions characterizing a social robot?

RQ2: What is the design space of social robots based on these dimensions?

RQ3: Can we define a stakeholder space for various domains?

RQ4: How can we match the design space of social robots and stakeholder space to systematically select stakeholders for the participatory design of social robots?

Chapter 3 explains the methodology to answer these questions and presents the conceptual/theoretical framework developed in this research.

CHAPTER 3

METHODOLOGY

3.1 Systematic Framework for Stakeholder Selection: An Overview

The process flow for the participatory design of social robots is depicted in Figure *3.1*. In this research, a systematic and context-independent framework is developed to select stakeholders for consultation throughout the participatory design process. The framework uses systematic matching between **'Social Robot Dimensions (D-SoBOT)'** and the '**Stakeholder Fields (F-Stakeholder)**' using formal representations.

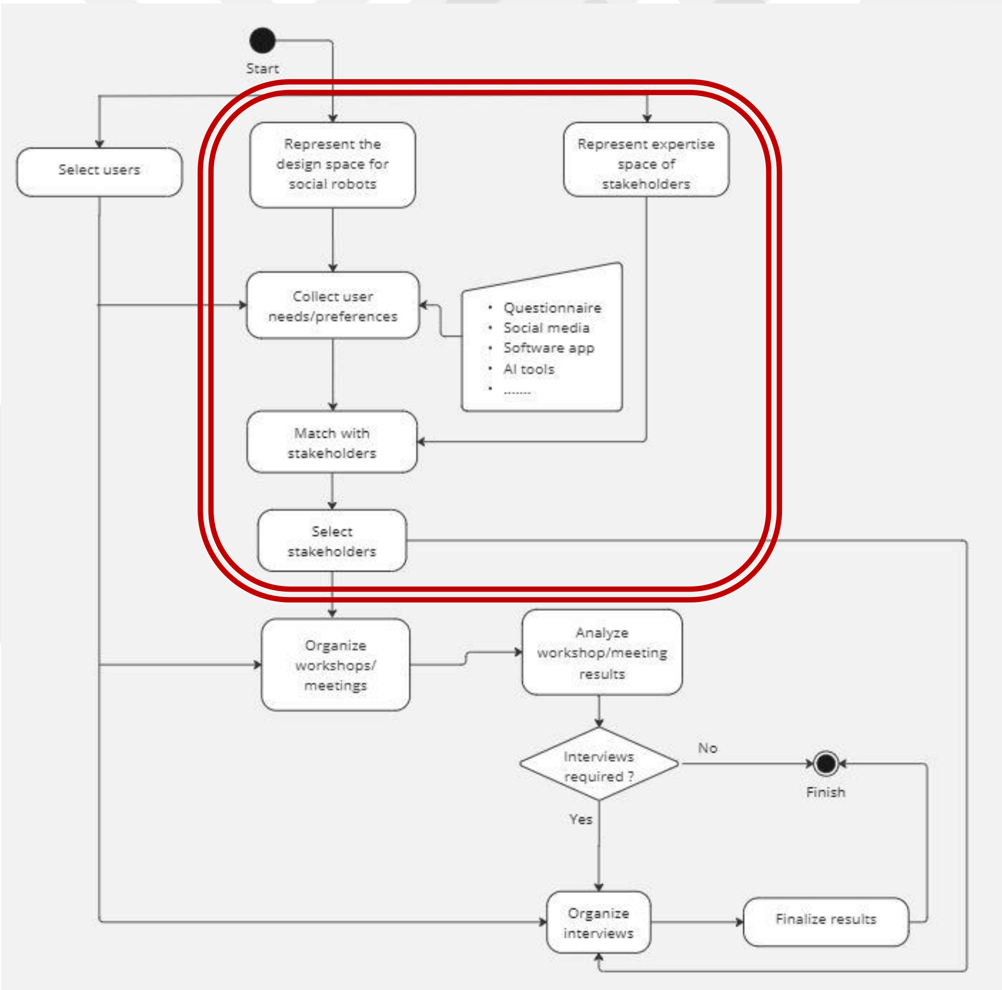


Figure 3.1: Systematic methodology for participatory design of social robots

In the present study, **D-SoBOT** is defined based on a conceptual framework for characterizing social robots along 10 dimensions which are adopted and extended [37]. **F-Stakeholder** is defined for various domains using the information gathered from the related literature and further elaborated. Detailed information and taxonomy for DS-SoBOT and F-Stakeholder are explained in Section 3.2 and Section 3.3, respectively. The process flow for the developed framework is composed of the following 4 steps which are explained in Section 3.4.

- *STEP 1: Definition and formal representation of D-SoBOT*
- *STEP 2: Definition and formal representation of F-Stakeholder*
- *STEP 3: Matching D-SoBOT and F-Stakeholder*
- *STEP 4: Selecting stakeholders*

3.2 Social Robots Dimensions

Social robot dimensions are important design considerations along which social robots and their interactions with humans are described [42]. In this thesis, 10 dimensions are selected based on the related literature and they are arranged into axes or categories that frame potential design options in order to define a design space for social robots. Depending on their intended function, environment, and interactions with people, the many sorts of social robots would be developed using this design space as a conceptual map. The sections 3.2.1 to 3.2.10 explain each dimension for which the axis, range, and example points (instances) are presented in Table A.1 in Appendix A.

3.2.1 Embodiment (Appearance):

This dimension is based on the robot's physical embodiment, as distinct from any type of robot behavior. In order to differentiate social robots from abstract or virtual entities, embodiment refers to their physical form and appearance. It describes how people view a robot's physical attributes and effects for interaction with people. Additionally, embodiment includes a robot's ability to become a part of a user's subjective experience, increasing the user's sense of presence and engagement in the encounter [38] [39] [40]. Designers can produce social robots that not only carry out practical tasks but also improve user experience through meaningful and natural interactions by comprehending and utilizing the embodiment dimension. Embodiment is a crucial component that influences how robots fit into human surroundings and carry out their social tasks, not just design decisions [38] [40].

Design Considerations: What is the physical form that best suits the social context and function? Is a humanoid form necessary, or is an abstract form sufficient?

- The intended social connection: should be reflected in the physical form. In nursing situations, for instance, a humanoid appearance may promote empathy and trust, but in industrial applications, an abstract form might be adequate.
- Functionality versus Aesthetics: To guarantee usability and acceptance, designers must strike a balance between technical efficiency and a user-centric look.

3.2.2 Interactivity (Social Capability):

Robot’s capabilities to engage in and maintain social interactions of varying complexities. The ability of a robot to engage and sustain conversations with humans, from simple exchanges to more intricate, emotionally sensitive discussions, is known as interactivity or social capability. It involves the robot's ability to identify, decipher, and react to a variety of social cues, including speech, gestures, facial expressions, and emotional states. The user experience can be improved by customizing robots' social interactions to suit personal tastes as they grow more skilled at comprehending and responding to human behavior [41] [42] [43].

Design Considerations: What forms of communication (verbal, non-verbal) are necessary for effective interaction? How natural should the communication be?

- Verbal and Non-Verbal Communication: The forms of communication required for effective interaction depend on the context. In healthcare, for instance, robots may need to use verbal communication and non-verbal cues (like facial expressions) to provide emotional support. In industrial or service settings, simpler interactions may suffice.
- Naturalness of Communication**:** The degree to which the user feels a natural robot communication, is critical in determining how engaging and effective the interaction will be. The ability to simulate human-like exchanges can improve trust and user satisfaction [41] [44].

3.2.3 Autonomy (Self-determination)

The amount of control the robot has over performing the task(s) and the ability to determine behavior that will maximize the likelihood of goal satisfaction. Autonomy refers to the extent to which a robot is capable of independently performing tasks and making decisions without human intervention. It includes the robot's ability to determine the best course of action to achieve a goal, based on its own assessment of the environment and its mission. In the context of social robots, autonomy involves the robot's capacity to operate without constant guidance, while still ensuring the quality and relevance of its actions [45] [46].

Design Considerations: How much decision-making power should the robot have? Should it work autonomously, assist humans, or rely on operator guidance?

- Decision-Making Power which is the degree to which a robot should be able to make independent decisions is a critical consideration. Some robots may function better with human assistance (e.g., collaborative robots), while others may require a high level of autonomy to achieve tasks more efficiently (e.g., autonomous vehicles or healthcare robots).
- Assistance vs. Autonomy: Determining the balance between assisting humans and fully relying on robotic decision-making is important for both safety and functionality, especially in environments like healthcare and service industries [45] [46].

3.2.4 Social Intelligence (Social Interaction):

Social intelligence in robots refers to their ability to understand and respond appropriately to social contexts, including recognizing and interpreting human emotions, communication styles, and social norms. This encompasses a robot's capacity to take another person's perspective, understand social cues, and engage in meaningful, context-aware interactions. Social intelligence allows robots to adapt their behavior based on the social environment, whether that involves following basic etiquette or interpreting complex group dynamics [47] [48] [49].

Social intelligence in robots can range from minimal or no social understanding, where robots follow only basic engagement protocols, to advanced awareness, where robots can interpret and adjust their behavior based on the complexity of social norms, group dynamics, or cultural cues.

Design Considerations: What level of social awareness is necessary for the robot to be effective in its role? Does it need to understand intricate social cues?

- Level of Social Awareness: Robots should be equipped with the appropriate level of social understanding to fulfill their intended role. For example, a robot in a healthcare setting may need to be more attuned to emotional cues, while one in a service setting may only need basic awareness of customer service norms.

- Complexity of Social Cues: Determining how finely a robot should interpret and respond to social cues is essential for its integration into various social environments, especially those involving complex interpersonal dynamics or sensitive situations [47] [48] [49].

3.2.5 Emotional Intelligence

Emotional intelligence in robots refers to their ability to recognize and appropriately respond to human emotions. This involves detecting emotional cues, such as facial expressions, body language, and tone of voice, and then reacting in a way that aligns with the emotional context. Emotional intelligence can range from basic recognition of emotions to more complex responses, including empathy and emotional support. In essence, emotionally intelligent robots can understand not only the visible signs of emotion but also the nuances behind them, allowing them to engage in emotionally attuned interactions [50] [51] [52] [53].

Design Considerations: Should the robot recognize and respond to emotions? To what extent should it mimic or express emotions?

- Emotional Recognition: Should robots only detect and respond to emotions, or should they also be capable of mimicking emotions?
- Emotional Expression**:** To what extent should robots express emotions? Should they simply reflect human emotions, or should they also convey emotional states to make the interaction more engaging and empathetic?

3.2.6 Purpose, Role, and Application Area

Types of goals the robot achieves and benefiting application areas. The purpose, role, and application area of a robot refers to the specific goals the robot is designed to achieve and the functions it serves in different environments or contexts. These roles are integral in determining how a robot interacts with users and other systems, and they shape the design and capabilities of the robot. Depending on the context, robots can serve in a variety of roles, such as being companions, assistants, caregivers, or tools for specific tasks like delivery or medical assistance [54] [55].

Design Considerations: What is the primary role of the robot? How does that role influence its design and social capabilities?

- Primary Role: What is the core function of the robot, and how does it influence its design and interaction style?
- Social Role: How does the robot's intended role affect its social capabilities? For instance, robots designed for caregiving may need to interact in more empathetic and responsive ways compared to robots used for more straightforward tasks.
- Application Areas**:** The role of the robot may vary greatly across different sectors such as healthcare, entertainment, hospitality, or industrial settings.

3.2.7 Adaptability

Adaptability in social robots refers to their ability to learn from interactions and adjust their behavior over time to better suit individual users or changing contexts. This capability is essential for creating more personalized, context-aware interactions that improve the robot's utility and engagement with humans. The adaptability dimension involves the robot's capacity to modify its responses and actions based on user feedback or environmental changes [56] [40].

Design Considerations: How should the robot adapt to different users or contexts? Should it learn over time or stick to predefined behavior?

- Learning Capabilities: How should the robot learn over time? Should the robot's behavior be based solely on predefined algorithms, or should it evolve based on user interactions?
- Contextual Flexibility: How adaptable should the robot be to varying environments or tasks? For instance, a robot may need to switch between more formal and informal behavior depending on the user's context or cultural background.
- User Experience: Ensuring that the robot's learning process enhances rather than frustrates the user experience is crucial. How can robots adapt to both new and returning users effectively without overwhelming them with constant changes?

Recent studies have explored the importance of adaptability in robot design, especially in dynamic environments. Some robots, such as those designed for medical or care purposes, benefit from high adaptability, as they learn to interact more effectively with users over time based on feedback and context [56] [57].

3.2.8 Ethical and Cultural Awareness

Ethical and cultural awareness in robots refers to their ability to understand and act in accordance with ethical guidelines and cultural norms. This includes considering societal impacts, and ethical dilemmas, and being sensitive to diverse cultural backgrounds. Robots with this awareness are expected to make decisions that respect privacy, safety, and cultural differences. They are also programmed to handle situations where they must adapt to various ethical standards or cultural contexts to ensure appropriate interactions [58] [59].

Design Considerations: How should the robot be programmed to handle ethical dilemmas or cultural differences? What safeguards need to be in place?

- **Ethical Protocols:** What ethical rules or guidelines should robots follow in various situations? How should they handle complex ethical dilemmas, such as those involving privacy, consent, or safety?
- **Cultural Sensitivity:** How should robots adapt to different cultural contexts? Should they learn to adjust based on the cultural background of the user, and how should they handle potential conflicts arising from cultural differences?

Robots with high ethical and cultural awareness can ensure respectful interactions with users from diverse backgrounds, and prevent potential conflicts related to cultural misunderstandings or unethical actions.

3.2.9 Proximity

Spatial features are related to the physical distance between the robot and the human during interaction. Proximity refers to the spatial features related to the physical distance between a robot and a human during interaction. This dimension is crucial in determining how a robot should position itself to ensure effective interaction while maintaining comfort and safety for the user. Proximity can influence the robot's responsiveness, the nature of its interaction with humans, and its ability to perform tasks in close or remote settings [60] [61].

Design Considerations: How should the robot be programmed to distance in front of the people?

- Distance Programming: How should robots be programmed to maintain an optimal distance from humans during interaction? What factors, such as cultural preferences or specific tasks, should influence the robot's positioning?

- Human Comfort and Safety: Ensuring that the robot's proximity does not invade personal space, while still enabling effective assistance or interaction.

3.2.10 Temporal profile (Period)

Time-related aspects (timespan, duration, and frequency) of interactions with a social robot. The temporal profile of a social robot refers to the time-related aspects of its interactions with humans, including the timespan, duration, and frequency of these interactions. This dimension addresses how often and for how long a robot engages with humans, considering various factors like the needs of the user and the context of the interaction [62].

Design Considerations: What should be the exact period of action?

- Action Timing: What should be the ideal period between robot actions, and how should this timing be adapted based on user needs or the robot's role?
- Frequency of Interactions: Should the robot's interactions be constant, or should they follow specific time intervals, for instance, in healthcare or service contexts?
- User Comfort and Efficiency: How does the timing of these interactions affect the user experience, and how can robots optimize interaction periods for different contexts?

3.3 Stakeholders for Social Robot Dimensions

In this thesis, the following domains for stakeholders are considered. These domains are defined using the information from the literature given in Section 2.2.

3.3.1 Technical Domain:

The technical domain includes experts and professionals involved in the embodiment, autonomy, and other technical dimensions of social robots. Mechanical structures, sensor integration, control, and durability are universal requirements across all social robot types. ***Engineers*** play a pivotal role in the physical design and functional implementation of robots [63] [64]. Specific experts on developing artificial intelligence systems (***AI Developers***) for social robots are also essential to improving robot interactivity, autonomy, adaptability, social intelligence, and emotional intelligence dimensions [65] [66]. ***Assistive technology designers*** concentrate on developing interfaces that are easy to use and accessible for people, particularly for older users or those with disabilities. For instance, Jibo and other robots are made to assist those who are visually or physically unable by providing voice-based communication [67].

Compared to static learning tools, personalization and progress tracking provide a distinct benefit. Designing social robots that are user-friendly, secure, and pleasant requires the involvement of ***ergonomists*** or ***human factors specialists***. In order to minimize cognitive and physical strain during use, these experts make sure that the robot's physical design, interface, and interactions match human capabilities and limits [68] [69].

3.3.2 Science-Mathematics Domain:

By offering fundamental information and creative solutions, the science and mathematics sector significantly contributes to the advancement of social robot design and functionality. ***Physicists*** contribute significantly to the development of social robots by offering insights into energy systems, sensor technologies, and material properties. Their expertise ensures the effective operation of robots, optimal energy utilization, and the integration of cutting-edge technologies, such as advanced optics or quantum computing, to enhance robot performance. ***Mathematicians*** are equally essential, as they develop algorithms and models that underpin robot behavior, learning processes, and interaction strategies. Their work is vital for improving computational efficiency and optimizing machine learning systems within robots. ***Zoologists*** bring a unique perspective to social robotics by applying their understanding of animal behaviors to create bio-mimetic robots. These robots replicate naturalistic movements and social cues, making them particularly effective in applications such as entertainment, education, or therapy settings [70]. By creating novel materials for safety and durability, such as non-toxic coatings and sensors that react to chemical stimuli, ***chemists*** help create social robots. In the healthcare industry, where biocompatible materials are essential for patient engagement, their work is especially significant for robotics. ***Biologists*** inform the design of bio-inspired robots by studying living organisms’ structures, movements, and behaviors. This expertise is critical for developing adaptive algorithms and ensuring robots interact seamlessly with humans in natural environments [69]. The science-mathematics domain guarantees that social robots are not only technologically sophisticated but also safe, effective, and able to engage with humans in an intuitive manner by incorporating ideas from various scientific fields.

3.3.3 Healthcare Domain:

Health professionals such as doctors and nurses provide guidance for healthcare robots' interactive features to satisfy diagnostic and therapeutic requirements or patient involvement. For instance, ReWalk and other robots use ***physiotherapists'*** insights to help patients through activities during stroke recovery [71]. Social robots' use and perception in healthcare settings are influenced by patient preferences and feedback. Robots such as Paro, for example, employ emotional cues to help individuals with dementia feel more at ease; however, their interactions are modified according to the patient's comfort level [72]. Robots that can identify emotional cues, adjust to user demands, and use efficient communication techniques are designed with assistance from ***psychologists***. This is especially crucial in fields where knowledge of human psychology improves user acceptance and involvement, such as therapy, eldercare, and education [73] [69]. Therefore, ***patients*** are considered as one of the most influential stakeholders in the healthcare domain. In order to manage the availability of robots for various shifts, emergency readiness, and real-time operations, ***hospital managers*** concentrate on the temporal profile of robots within hospitals. Their participation guarantees that robots adhere to the hospital's operating and patient care schedules [74] [75]. Experts in ***human anatomy*** are crucial to the design and development of social robots, especially those that closely resemble or interact with people. Their knowledge guarantees that the physical interfaces, postures, and motions of robots conform to human anatomical principles, enhancing user comfort, ergonomics, and safety. This knowledge is particularly important when it comes to healthcare robots and assistive technology, as the precise design has a direct impact on how well the robot helps patients or supports medical personnel [76].

3.3.4 Social Domain:

In order to ensure that social robots' interactions, behaviors, and functions conform to social norms and expectations, the social domain focuses on integrating them into society. ***Sociologists*** play a key role in analyzing how robots influence society and defining their appropriate functions in daily life. Their expertise is particularly important in settings such as social, educational, or medical environments, where cultural norms and expectations significantly impact user acceptance and the efficacy of robotic solutions [77] [78]. ***Social service professionals*** work with engineers and designers to mold the robot's capabilities so that they improve care quality and uphold a high degree of empathy and sensitivity to the demands of the users. Experts in social services also assist in integrating robots into current care systems, guaranteeing their efficacy and usefulness in actual social service environments [79] [80]. In order to ensure that ethical issues are ingrained in the development process, ***ethicists*** are essential to the design and implementation of social robots. They assess possible hazards, make sure moral standards are followed, and deal with privacy, autonomy, and justice concerns. Ethicists assist in defining the parameters of robot-human interactions in fields such as healthcare, elder care, and social services, making sure that robots enhance and complement human empathy and compassion rather than take their place [81] [82]. ***Social workers*** provide valuable insights into the challenges faced by vulnerable populations, ensuring that robots are designed to address both practical and emotional needs. They contribute to the creation of robots that offer companionship, assistance with daily activities, and support without substituting essential human interactions. By bridging the gap between technology and the human experience, social workers advocate for the ethical deployment of social robots, ensuring they deliver genuine societal benefits and uphold human dignity [83]. The social domain guarantees that robots are developed and implemented in ways that align with societal values, improve user well-being and promote moral and compassionate interactions by integrating the knowledge of sociologists, social service professionals, ethicists, and social workers.

3.3.5 Educational Domain:

In order to accommodate a range of educational needs, encourage student engagement, and improve learning experiences, the educational sector places a strong emphasis on integrating social robots into learning environments. ***Educational professionals*** contribute to the creation of robots that engage students, encourage teamwork, and facilitate tailored learning by offering insights into how students learn best. Additionally, they make sure that robots adhere to moral principles and educational norms, which makes the technology a useful instrument in a variety of learning settings. Their feedback is essential to ensuring that educational robots support social and cognitive development while meeting a range of learning demands, from STEM education to special education [84]. By making sure the robot's communication style, emotional intelligence, and adaptability accommodate different learning contexts and individual needs, ***Educational Guidance Specialists*** help ensure that social robots are an effective teaching tool. This professional knowledge aids in directing the adaptation of the robot's interactions and reactions to conform to accepted educational frameworks [47]. ***Teachers*** and ***students*** are integral to the development and implementation of social robots in education. Teachers provide critical insights into classroom dynamics, how robots can support diverse learning needs, and ways to complement traditional teaching methods. Students, on the other hand, offer valuable feedback on how robots engage, interact, and contribute to their educational journeys. Together, these groups shape the robots' emotional intelligence, adaptability, and interactivity, ensuring that they enhance both the teaching and learning processes [85]. To create learning objectives that robots can support, ***curriculum developers*** collaborate closely with educational experts. They make sure that the robots offer interactions and information that improve the learning process. Robots can help with skill development, individualized learning, and making learning more interesting and accessible by being incorporated into the curriculum [86] [87].

3.3.6 Service Domain:

The robot's interaction promotes both mental and physical health, meeting needs like task assistance or companionship. ***Elder Care Specialists*** make sure that Care-O-bot and other robots engage with senior citizens in a way that fosters safety, companionship, and well-being. To keep users' minds engaged, they provide features like interactive games or medicine reminders [88]. With an emphasis on qualities like empathy and reactivity under pressure, ***Caregivers*** assist in the design of robots that support human care. They ensure that the robot supports human care rather than takes its place by directing its responsive and sympathetic behavior. Additionally, caregivers shed light on how robots can support both physical and emotional requirements [89] [90]. For individuals with disabilities, proximity behaviors of assistive robots must be finely calibrated to ensure accessibility without hindering mobility or independence. ***Disability Support Workers*** provide valuable insights into designing robots that foster supportive and empowering relationships with users [91] [92]. Special care robots that help with everyday tasks need to be able to comprehend the time components of daily tasks. Similarly, ***daily assistants*** help ensure that robots can manage time-sensitive tasks, aiding elderly or disabled individuals with mobility, meal preparation, or medication at appropriate times during daily routines [93] [94]. Cleaning robots have to maneuver through confined areas and stay clear of objects like humans and furniture. ***Cleaning specialists*** make sure robots can adjust to a variety of settings, increasing productivity and security [75] [95]. In emergency and disaster response scenarios, the role of robots becomes critical. ***Emergency responders*** provide essential feedback to develop and implement robots capable of performing life-saving tasks such as search and rescue, medical assistance, and evacuation. These robots are designed to effectively support human responders during high-pressure situations [96]. The service domain guarantees that social robots are safe, dependable, and compassionate tools that can satisfy a range of user demands by combining the knowledge of elder care specialists, caregivers, disability support workers, daily assistants, cleaning specialists, and emergency responders.

3.3.7 Design-Art Domain:

In the Design-Art Domain**,** ***industrial designers*** prioritize both functional and aesthetic elements. For instance, industrial cleaning robots are designed to be compact for accessibility, ensuring they can navigate tight spaces effectively, whereas hospitality robots are crafted to appear friendly and approachable, which is crucial for gaining clients' trust and providing a welcoming presence [97]. The design and development of social robots involve various stakeholders, including music experts, painters, sculptors, architects, landscape architects, and interior designers. Their input is essential when the robot's creative functions, aesthetic attributes, and interactions with its surroundings are crucial. Whether for amusement, private settings, or public areas, these specialists ensure that robots meet artistic, architectural, and spatial requirements. ***Music experts***, for instance, can advise on equipping robots with musical talents, enabling them to play instruments or create harmonious sounds that enhance user experiences. ***Architects*** and ***interior designers*** can help integrate robots into environments, ensuring they complement the existing décor and contribute to the overall design and decoration tasks. Additionally, ***sculptors*** and ***landscape architects*** influence how robots enhance artistic or outdoor spaces, integrating seamlessly while promoting artistic experiences and creativity [98]. This multidisciplinary approach ensures that social robots are not only functional but also aesthetically pleasing and culturally relevant, making them more effective and accepted in various social settings.

3.3.8 Entertainment-Fantasy Domain:

Futurists aid in foreseeing potential problems that robots may encounter in the ensuing decades, including moral conundrums, society integration, and the requirement for robotic systems to be flexible. They guarantee that robots are created with a long-term perspective in mind, which will enable them to remain applicable and efficient in future situations, particularly when societal standards and technological advancements continue to advance [99]. In the context of interactive storytelling, games, or live events, stakeholders like ***entertainment professionals*** and game creators focus on customizing robots to assume roles such as performers or companions. They influence the robot's capacity to evoke emotions and sustain interest by integrating dynamic and captivating interactions, such as interactive narratives or gaming elements [100] [95]. Some expertise creates dynamic and captivating interactions that enthrall audiences, like interactive narrative or gaming elements. The creation of captivating interactive experiences is the main goal of ***game creators***. Robots used in live performances or video games, like Sony's Aibo, must, for example, have dynamic behavior that changes in response to audience participation [101]. Proximity between robots and human actors must facilitate coordinated motions and prevent collisions. ***Performers*** direct the seamless integration of robots into routines [102] [103]. To ensure inclusivity and respect audience diversity, ***media professionals*** instruct entertainment robots to steer clear of abusive or culturally insensitive content [100] [95]. Robots are frequently included in performances, games, and exhibitions in the entertainment industry. The robot's performance timeframes are controlled by ***content creators***, who also coordinate its movements with the rest of the production. For audience interaction, they must make sure that robots execute their tasks precisely and at the appropriate times [103] [102]. In entertainment venues, robots frequently engage with sizable crowds. To guarantee that robots operate efficiently without endangering audience experiences or compromising safety, ***event organizers*** have an impact on spatial design [104] [105]. ***Audience Analysts*** ensure the robot's interactions appeal to target demographics by adapting them based on user trends and preferences. For example, robots in interactive exhibits are often customized using data from visitor behavior to enhance engagement [106]. ***Media Psychologists*** study how robots can emotionally connect with users through cues like voice modulation and facial expressions. They investigate the impact of robots' visual and emotional signals on user engagement, such as how theme park robots use exaggerated facial expressions or modulated speech to enhance immersion [107].

3.3.9 Economy-Business Domain:

In this domain, ***business teams*** play a crucial role in identifying target markets, potential applications, and the economic feasibility of deploying robots. Their strategic planning helps align the robot's features with market demands, business goals, and customer expectations, contributing to pricing, branding, and commercial success. This ensures that robots are accessible and relevant across diverse industries. ***Economists*** are essential in assessing the economic viability, market potential, and long-term impacts of social robots on enterprises and societies. Their responsibilities include evaluating the cost-benefit aspects of robot manufacturing, distribution, and maintenance, ensuring affordability and accessibility for the intended users [108]. ***Service Industry Professionals'*** knowledge aids in customizing interaction for particular jobs, including cleaning, customer service, or check-ins. They assist in identifying tasks that are context-specific and require engagement. Robots like Pepper, for example, help customers in retail by responding to their inquiries and making tailored buying suggestions [109]. ***Long-term care managers*** bridge the gap between technology and human-centered care by ensuring social robots are used ethically, culturally relevant, and operationally efficient. This approach enhances the quality of life for those receiving care [110]. In sectors like logistics, service robots are required to follow rigorous timetables, including delivery windows or transport duties within a specified time frame. ***Logistics planners*** ensure robots follow these schedules efficiently, impacting overall operations and workflow [111] [112].

3.3.10 Government Domain:

In the adoption and application of social robots in urban settings and public services, ***municipalities*** play a crucial role. They oversee the integration of this technology to meet societal demands, improve service delivery, and enhance urban living. For example, social robots can assist residents with administrative tasks, guide tourists, or help with community events in public areas [113]. In the context of disaster management and emergency response, ***firefighting authorities*** are essential players. Social robots designed for firefighting can help in dangerous situations by detecting fires, locating trapped individuals, and navigating through smoke-filled environments. These robots enhance the safety and effectiveness of firefighting operations by reducing risks to human responders [114]. ***Security authorities*** collaborate with engineers, AI developers, and ethicists to address issues such as data privacy, situational awareness, and unbiased decision-making. Robots in this field can perform tasks like population surveillance, intrusion detection, and quick response to security breaches. This collaboration ensures that social robots meet the stringent requirements for public safety and trust [115]. The development, application, and regulation of social robots in a variety of fields are significantly influenced by ***parliamentary*** authorities. As legislative entities, they oversee the ethical, legal, and societal ramifications of robot integration, making sure that it is in line with national policy goals and the public interest. Lawmakers have the power to shape regulations pertaining to data privacy, safety requirements, labor consequences, and social robot accessibility [116]. ***Tax authorities*** play a crucial role in integrating and regulating social robots in public services and industry. They maintain appropriate fiscal control by developing tax policies specific to robotic technologies. These policies may include applying relevant tax codes to robot-related enterprises or offering tax credits or deductions to encourage the adoption of socially beneficial robots. Additionally, tax offices help address labor market shifts by using robots to manage business taxes while ensuring economic sustainability [117].

3.4 Stakeholder Selection Framework

In order to develop a systematic framework for stakeholder selection in the participatory design of social robots, the following 4-step methodology is used.

STEP 1: Definition and formal representation of D-SoBOT

A context-independent '**D**esign Space for **So**cial Ro**bot**s (D-SoBOT)' is defined based on the social robot dimensions explained in Section 3.2. D-SoBOT is fully represented in Table B.1 in Appendix B and a partial view can be seen in Figure *3.2*. D-SoBOT is formally defined as a set of 10 elements;

$$\text{D-SoBOT} = \{D_1, D_2, D_3, D_4, D_5, D_6, D_7, D_8, D_9, D_{10}\} \quad (1)$$

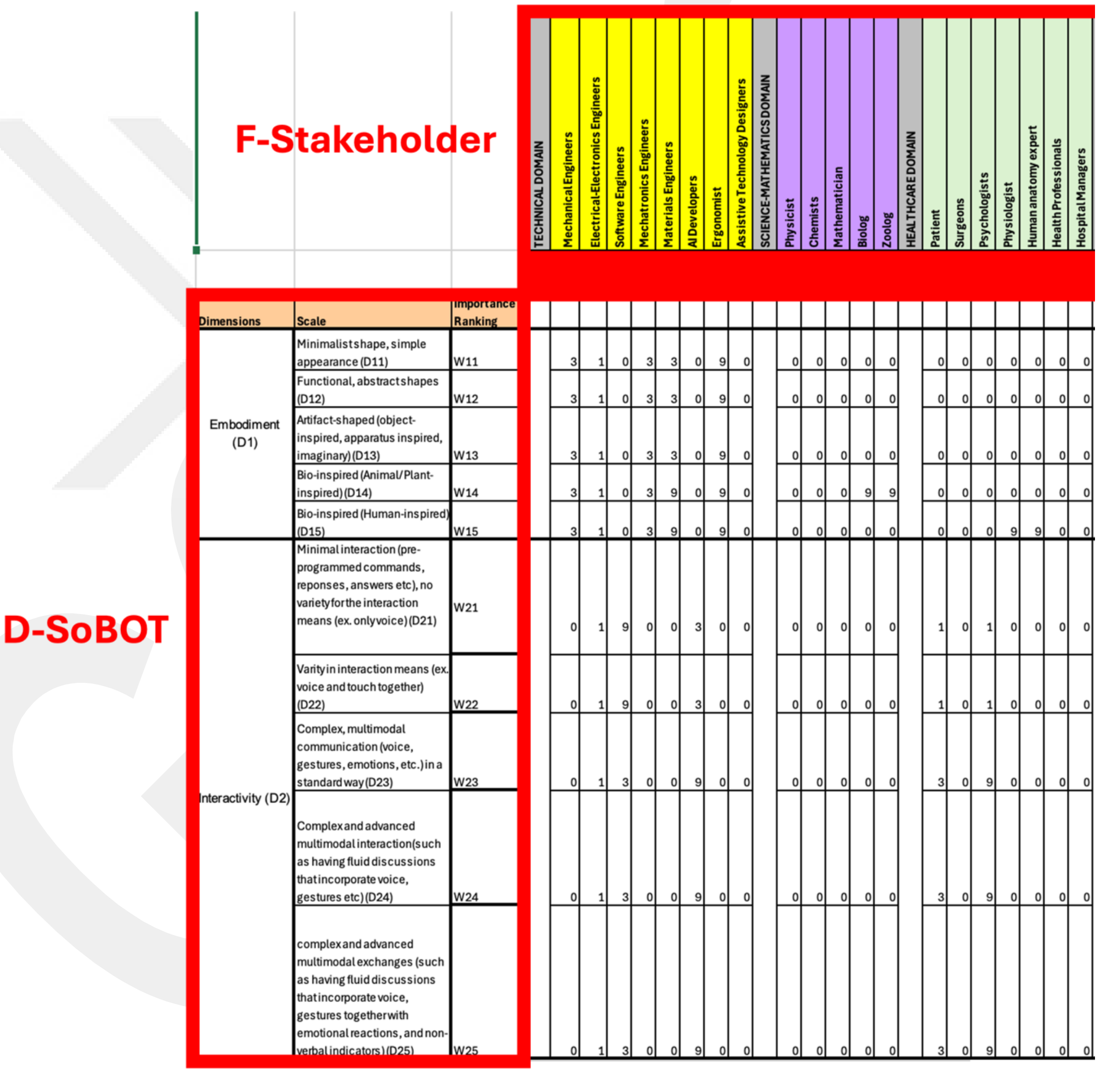
where D_i ($1 \leq i \leq 10$) is a dimension characterizing a social robot as explained in Section 3.2. D_i is represented as a (k x 2) array;

$$D_i = (D_{ij}, W_{ij}) \mid (1 \leq j \leq k) \quad (2)$$

where,

D_{ij}: j^{th} symbolic value for the i^{th} dimension
W_{ij}: Importance ranking for D_{ij} ($1 \leq W_{ij} \leq k$)

In this study, symbolic values for each dimension are defined using a 5-point scale and, therefore, *k* is constant (k=5). However, *k* can also be selected as different for each dimension. At the beginning of the design process, the user is required to select a *"j"*th symbolic value for each dimension *"i"* and a corresponding importance ranking (W_{ij}). The other elements of the array will be *"null"*. The user defines a required "state", which includes a "symbolic value" with its "importance ranking" for each SoBOT dimension. Therefore, the designer gathers initial information from users about their needs/preferences based on the valuation of social robot dimensions.



Dimensions	Scale	Importance Ranking	TECHNICAL DOMAIN	Mechanical Engineers	Electrical-Electronics Engineers	Software Engineers	Mechatronics Engineers	Materials Engineers	AI Developers	Ergonomist	Assistive Technology Designers	SCIENCE-MATHEMATICS DOMAIN	Physicist	Chemists	Mathematician	Biolog	Zoolog	HEALTHCARE DOMAIN	Patient	Surgeons	Psychologists	Physiologist	Human anatomy expert	Health Professionals	Hospital Managers
Embodiment (D1)	Minimalist shape, simple appearance (D11)	W11		3	1	0	3	3	0	9	0		0	0	0	0	0		0	0	0	0	0	0	0
	Functional, abstract shapes (D12)	W12		3	1	0	3	3	0	9	0		0	0	0	0	0		0	0	0	0	0	0	0
	Artifact-shaped (object-inspired, apparatus inspired, imaginary) (D13)	W13		3	1	0	3	3	0	9	0		0	0	0	0	0		0	0	0	0	0	0	0
	Bio-inspired (Animal/Plant-inspired) (D14)	W14		3	1	0	3	9	0	9	0		0	0	0	9	9		0	0	0	0	0	0	0
	Bio-inspired (Human-inspired) (D15)	W15		3	1	0	3	9	0	9	0		0	0	0	0	0		0	0	0	9	9	0	0
Interactivity (D2)	Minimal interaction (pre-programmed commands, reponses, answers etc), no variety for the interaction means (ex. only voice) (D21)	W21		0	1	9	0	0	3	0	0		0	0	0	0	0		1	0	1	0	0	0	0
	Varity in interaction means (ex. voice and touch together) (D22)	W22		0	1	9	0	0	3	0	0		0	0	0	0	0		1	0	1	0	0	0	0
	Complex, multimodal communication (voice, gestures, emotions, etc.) in a standard way (D23)	W23		0	1	3	0	0	9	0	0		0	0	0	0	0		3	0	9	0	0	0	0
	Complex and advanced multimodal interaction(such as having fluid discussions that incorporate voice, gestures etc) (D24)	W24		0	1	3	0	0	9	0	0		0	0	0	0	0		3	0	9	0	0	0	0
	complex and advanced multimodal exchanges (such as having fluid discussions that incorporate voice, gestures together with emotional reactions, and non-verbal indicators) (D25)	W25		0	1	3	0	0	9	0	0		0	0	0	0	0		3	0	9	0	0	0	0

Figure 3.2: Algorithmic representation for stakeholder selection

STEP 2: Definition and formal representation of F-Stakeholder

The 'Domain (**F**ield) Space for **Stakeholders (F-Stakeholder)**' is a set of different application domains (fields) for stakeholders who can be involved in the design process of social robots. F-Stakeholder is presented in Table B.1 in Appendix B and part of F-Stakeholder can be seen in Figure *3.2*. F-Stakeholder is formally defined as follows;

$$\text{F-Stakeholder} = \{F_1, F_2, F_3, \ldots\ldots\ldots\ldots, F_m\} \quad (3)$$

where *m* is the number of stakeholder domains.

In this thesis, 10 stakeholder domains are considered (m=10) and they are explained in Section 3.3. Each element F_z ($1 \leq z \leq m$) of F-Stakeholder represents a stakeholder domain, and, also defined as a set of corresponding stakeholders;

$$F_z = \{S_{z1}, S_{z2}, S_{z3}, \ldots\ldots\ldots\ldots, S_{zn}\} \quad (4)$$

where ($S_{zt} \mid 1 \leq t \leq n$) represents a stakeholder in F_z and n is the number of stakeholders for the F_z domain.

STEP 3: Matching D-SoBOT and F-Stakeholder

A systematic method is developed for matching D-SoBOT with F-Stakeholder by adapting and merging two well-known techniques used in product design, namely Quality Function Deployment (QFD) and Design Structure Matrix (DSM). Quality Function Deployment (QFD) is a systematic methodology used to translate customer needs into engineering characteristics. QFD is especially beneficial in aligning product design with the expectations of customers or stakeholders. QFD is basically a method of conversion from qualitative user requirements into quantitative parameters to define design specifications so as to assure product quality for user acceptance [118]. The House of Quality (HoQ) is the basic design tool of QFD [119] [120]. It identifies and classifies customer desires (WHATs), identifies the importance of those desires, identifies engineering characteristics that may be relevant to those desires (HOWs), correlates the two, allows for verification of those correlations, and then assigns objectives and priorities for the system requirements. The output of the HoQ is a matrix with customer desires on one dimension and correlated non-functional requirements on the other dimension. In this thesis, the QFD methodology and the HoQ are used to map user requirements formulated within 10 social robot dimensions explained in Section 3.2, with the potential stakeholders to be involved in the participatory design process. Design Structure Matrix (DSM) is another tool used to model and analyze the dependencies and interactions among various elements in a system [121] [122] [123] [124]. It is particularly useful for understanding how components within a product or design influence each other, to help in managing complexity during the design process. In this thesis, DSM is adapted to identify the dependencies and relationships between different stakeholders. Merging QFD and DSM methods to match D-SoBOT with F-Stakeholder provides a robust method for aligning user requirements given in terms of social robot dimensions, with relevant stakeholders who must be included in the participatory design process.

Below is a detailed explanation of how these two methodologies are adapted and used in this thesis for matching social robot dimensions with relevant stakeholders. The process in STEP 3 unfolds in the following 2 phases:

Phase I: Matching and Ranking Stakeholders for Social Robot Dimensions Using QFD an HoQ

The original QFD methodology helps gather and translate customer requirements into technical specifications using a matrix called House of Quality (HoQ). The modified and adapted use of OFD and HoQ process begins with identifying the requirements, each of which is stated as a symbolic value ($D_{ij)}$ of a social robot dimension with a user-defined importance ranking (W_{ij}). Then, these values (WHATs) are mapped onto stakeholders (S_{zt}, as WHOs instead of HOWs) to be involved in the participatory design of a social robot to satisfy these requirements. During this mapping, the conformity of social robot dimensions on stakeholders is assessed by designers using the “Stakeholder Relationship Value (SRV)” based on the rating scheme given in Table 3.1. The resulting modified HoQ matrix is called the “D-S Matching Table” and it is presented in Table B.1 in Appendix B.

Table 3.1: The Stakeholder Relationship Value (SRV) used for relational rating

Relationship	**SRV**
NO	0
WEAK	1
MODERATE	3
STRONG	9

Phase II: Identifying the Stakeholder Interdependencies Using DSM

Once relevant stakeholders and their impact for the requirements of social robot dimensions are determined, the next challenge is performing a compatibility check to further investigate interdependencies between stakeholders. This is where Design Structure Matrix (DSM) becomes useful, since it helps identify the dependencies and relationships between different design elements. These elements are considered as the stakeholders, while adapting the method in this thesis. It is crucial because including one stakeholder could affect others, and these dependencies may have a profound impact on the overall participation of stakeholders in the design process. A modified DSM - called as the "Stakeholder Compatibility Table (SCT)" - is constructed by listing all stakeholders categorized in various domains along both axes of a square matrix. In each cell of the SCT, dependencies are marked to indicate how stakeholders affect each other, based on the compatibility relationships listed in Table 3.2. The SCT thus provides a clear view of which stakeholders interact and how they influence one another.

Table 3.2: Compatibility relationships between any two stakeholders A and B

Notation	***Compatibility relationships between A and B***	***Explanation***
+2	Strong positive compatibility	If A is selected B must be selected
+1	Weak positive compatibility	If A is selected B may be selected
0	No compatibility relationship	A and B are independent
-1	Weak negative compatibility	If A is selected B may not be selected
-2	Strong negative compatibility	If A is selected B must not be selected

By adapting and merging Quality Function Deployment (QFD) with Design Structure Matrix (DSM), a systematic method is developed to match social robot dimensions with stakeholders in a participatory design process. QFD ensures that user requirements are associated with the relevant stakeholders, while DSM provides a clear understanding and representation of the interdependencies and interactions between different stakeholders. This combined approach enables design teams to include as many and diverse stakeholders as necessary and sufficient, in order to conduct participatory design of social robots.

STEP 4: Selecting stakeholders

In the developed formalism, stakeholders are selected in two stages;

In the first stage, the "D-S Matching Table" is used to identify the stakeholders based on the Total Stakeholder Relationship Value $(SRV)_T$ for all stakeholders calculated as follows:

$$(SRV)_T = \sum_{i=1}^{10} W_{ij} \times SRV \text{ , } \forall W_{ij} \neq \text{"}null\text{"} \quad (5)$$

If $(SRV)_T$ is greater than a threshold value, the associated stakeholder is selected. In this thesis, the threshold value is specified as 50.

In the second stage, the "Stakeholder Compatibility Table (SCT)" is used to check the stakeholders' compatibility for participatory design. As a result of the compatibility check, some of the selected stakeholders may be excluded, and/or some other stakeholders with SRV values less than the threshold may also be included in the stakeholders list.

The justification for selecting the threshold value for $(SRV)_T$ as 50 in the first stage is explained below:

The Quality Function Deployment (QFD) methodology employed assigns scores based on stakeholder influence and relevance across various dimensions; with evaluations of 0, 1, 3, or 9, and weights ranging from 0 to 5. The cumulative score for each stakeholder is calculated by summing the products of these evaluations and their respective weights. This scoring mechanism ensures that stakeholders who have a substantial impact across multiple critical dimensions receive higher scores.

In applying QFD to stakeholder selection, establishing an appropriate threshold is crucial for effectively identifying and prioritizing key stakeholders. The use of threshold values in QFD and related decision-making methodologies is well-documented. For instance, in the context of supplier selection, thresholds are set to ensure comparability and measure the comprehensive effect of each option [125]. Similarly, in project prioritization, thresholds help in systematically assessing and ranking projects based on their scores. Setting a threshold value acts as a filter to focus resources and attention on stakeholders most likely to significantly impact project outcomes. This is particularly important in complex projects where equal inclusion of all potential stakeholders is neither feasible nor efficient [126].

In this study, a threshold value of 50 was utilized, meaning stakeholders with a cumulative score exceeding this value were selected for inclusion. This decision is supported by several methodological considerations. In this study, ten dimensions were considered, providing a comprehensive analysis of stakeholder impact. With ten dimensions, the maximum possible score for a stakeholder is 450 (i.e., 9 points per dimension multiplied by 10 dimensions, each weighted by 5). The threshold of 50 represents a value over 10% of this maximum score and ensures that stakeholders with significant influence across all dimensions are not overlooked.

Another rationale supporting the threshold value of 50 in the stakeholder selection process stems from a numerical analysis of typical scoring scenarios in the QFD matrix. The methodology uses the standard QFD relationship scale of 0-1-3-9 and customer-defined importance weights on a 0–5 scale. In a representative case, if a stakeholder has an average relationship value of 3 across selected dimensions, and the corresponding customer-defined weights average between 3 and 4, the weighted score per dimension would range between 9 and 12. For example, if a stakeholder is associated with only four dimensions—two with a weight of 3 and two with a weight of 4—the cumulative weighted score becomes (3×3)+(3×3)+(3×4)+(3×4)=42. This indicates that even with partial dimension inclusion and moderate relationship values, the resulting total approaches the 50-point threshold. Hence, setting the cut-off at 50 is a balanced and reasonable decision. It ensures that stakeholders with substantial relevance across fewer but critical dimensions are not omitted, while also maintaining a high standard of selectivity. Furthermore, this approach reflects a conservative but inclusive strategy, especially valuable in contexts where not all dimensions may be equally applicable to each stakeholder. It supports the goal of preventing under-representation of potentially important contributors, aligning with best practices in stakeholder analysis in participatory design.

The developed formalism is given below and presented by an algorithm in Figure *3.3*:

1. The user will select a symbolic value for each SoBOT dimension – *return* D_{ij}
2. The user will determine the importance ranking for each D_{ij} – *returns* W_{ij}
3. Calculate “Stakeholder Relationship Value - SRV”: Add all values obtained by multiplying W_{ij} and the relational rating value (RV) for each stakeholder S_{zt} - *returns* Total Stakeholder Relationship Value (SRV) for all stakeholders.

4. Select S_{zt} with SRV ≥ 50 and add to the "list of stakeholders" to be consulted for the participatory design of the SoBOT.
5. Check S_{zt} with SRV < 50 for compatibility using Stakeholder Compatibility Table and determine if they need to be included in the "list of stakeholders". If yes, add to the list.
6. Check S_{zt} with SRV ≥ 50 for compatibility using Stakeholder Compatibility Table and determine if they need to be excluded from the "list of stakeholders". If yes, remove it from the list.
7. Return the final version of the "list of stakeholders".

```
BEGIN

  Initialize FinalStakeholderList ← empty
  Initialize PreliminaryList ← empty

  FOR each stakeholder Szt DO
    SRV ← 0

    FOR each dimension Dij DO
      Get symbolic relationship value RVij,zt (possible values: 0, 1, 3, 9)
      Get importance weight Wij (range: 0-5)
      SRV ← SRV + (Wij × RVij,zt)
    END

    IF SRV ≥ 50 THEN
      Add Szt to PreliminaryList
    END
  END

  // Compatibility check for stakeholders with SRV < 50
  FOR each stakeholder Szt NOT in PreliminaryList DO
    Check compatibility from Stakeholder Compatibility Table

    IF compatible THEN
      Add Szt to FinalStakeholderList
    END
  END

  // Compatibility check for stakeholders with SRV ≥ 50
  FOR each stakeholder Szt IN PreliminaryList DO
    Check compatibility from Stakeholder Compatibility Table

    IF compatible THEN
      Add Szt to FinalStakeholderList
    ELSE
      Skip or remove Szt from list
    END
  END

  RETURN FinalStakeholderList

END
```

Figure 3.3: Complete Algorithm of the Process

3.5 Answers to the Research Questions

This thesis systematically addressed the research questions outlined in Section 1.2 by employing the methodology explained in this chapter. This section provides a summary of answers to these questions.

The first question, which focused on **“the dimensions characterizing a social robot”**, was explored through literature survey. As a result, 10 dimensions characterizing these robots were extracted and compiled with their design considerations as explained in Section 3.2.

The second research question, concerning **“the design space of social robots”**, was analysed based on these dimensions, identifying symbolic values for each dimension as explained in Section 3.4 and represented in Table B.1 in Appendix B.

The third research question, concentrates on **“a stakeholder space for various domains”,** and answered by literature survey on the participatory design of social robots extracting 10 domains each of which include key stakeholders in the related publications, as provided in Section 3.3 and as formally presented in Section 3.4.

The fourth question, is about **“matching the design space of social robots and stakeholder space to systematically select stakeholders for the participatory design of social robots”**. The answer is given as adaptation of QFD-HoQ and DSM methodologies, resulting in a systematic framework for selection of stakeholders in participatory design of social robots as explained in Section 3.4.

Overall, the study offers comprehensive answers to the proposed questions, contributing valuable knowledge to the field of **“participatory design of social robots”** and setting the stage for future research on **“automated selection of stakeholders in participatory design of social robots”**.

In order to show the usage of the developed framework, four case studies were conducted and presented in Chapter 4.

CHAPTER 4

CASE STUDIES

This chapter presents four case studies to explain how to use the systematic stakeholder selection framework developed in this thesis for the participatory design of social robots. For this purpose, the participatory design of four different social robots are selected from the literature. In each case study, the required stakeholders are selected using the developed framework. Then, the results are compared with the stakeholders already involved in the corresponding published study.

Publications for case studies are selected from four distinct robot categories which are **service robots, healthcare robots, educational robots, and special care robots**, considering the explanation of detailed design processes, the availability of information related to stakeholders and design requirements concerning the robot.

For consistency, each case study is conducted and presented in the same style explained below:

General information: This section introduces the selected publication providing information about the social robot, explains the purpose and scope of the participatory design study.

Stakeholders involved: In this section, a list of stakeholders already involved in the selected publication is given and their roles are explained briefly.

User requirements for social robot dimensions: In this section, a symbolic value (D_{ij}) and importance rankings (W_{ij}) are assigned for each social robot dimension based on the information in the selected publication. They are presented using a table titled as "User requirements for social robot dimensions in Case Study X". The rankings are specified based on a detailed literature review about the "Importance Rankings for

Social Robot Categories” compiled and presented in Appendix C. That review provides information on the importance rankings (as symbolic values) regarding 10

social robot dimensions, for 5 social robot categories as educational robots, healthcare robots, service robots, entertainment robots, and special care robots. Based on the requirements outlined in each case study, Quality Function Deployment (QFD) and Design Structure Matrix (DSM) tables are completed. First, the SRV values are calculated for all stakeholders, and those exceeding the threshold value of 50 are identified and highlighted within the QFD tables. As a secondary validation, stakeholders are further assessed using DSM tables to ensure compatibility and consistency within the stakeholder network, resulting in the final selection of stakeholders for the case study. The combined QFD-DSM tables for each case study is depicted as a separate sheet in the Excel file given in Appendix B.

Comparison of stakeholders: In this section, stakeholders selected by using the developed framework and those already involved in the published study are listed in a table titled as “Comparison of the stakeholders for Case Study X”. The roles of new stakeholders selected by the developed framework are explained. In cases of differences, a justification is provided for each additional stakeholder identified by our method, including reasoning as to why they could be considered relevant or even critical for that specific robot type. These justifications are organized according to relevant professional domains or stakeholder roles.

This structured and repeatable method strengthens the validity of the stakeholder selection framework and supports its applicability across four different types of social robots in participatory design contexts.

4.1 Case Study 1: Service Robot

General information: The selected study describes the user-centered design and evaluation process of a humanoid mobile shopping robot named TOOMAS that assists customers in home improvement stores by providing product information, navigation support, and recommendations. The study involved three empirical field studies with a total of 343 participants, focusing on the robot's usability and acceptability [127].

Stakeholders involved: TOOMAS is considered as a service robot and, in the published work, the following stakeholders are involved in the design process:

- **Engineers & Designers:** Responsible for developing the robot's hardware and user interface, focusing on durability, navigation capabilities, and interactive features.
- **Long-term Care Managers & Business Teams:** Ensured the robot aligned with store goals, such as improving customer experience and increasing sales.
- **Ergonomist & Assistive Technology Designers:** Evaluated usability and interaction design to enhance accessibility for diverse user groups.
- **Customers:** The primary users who interacted with the shopping robot, TOOMAS, in a real store environment.
- **Store Employees:** Provided insights into the robot's functionality and its integration into the store's operations.

User requirements for social robot dimensions: In the case study, valuation and importance rankings are assigned for each social robot dimension as presented in Table 4.1. Since TOOMAS is categorized as a service robot, rankings for service robots are used.

Table 4.1: User requirements for social robot dimensions in Case Study 1

Dimensions	**Selected Requirement**	**Importance Ranking**
Embodiment (D_1)	Artifact-shaped (object-inspired, apparatus inspired, imaginary) (D_{13})	($W_{13} = 3$)
Interactivity (D_2)	Complex, multimodal communication (voice, gestures, emotions, etc.) in a standard way (D_{23})	($W_{23} = 5$)
Autonomy (D_3)	Semi-autonomous with context-aware decision-making. (D_{33})	($W_{33} = 5$)
Social Intelligence (D_4)	Limited ability to detect and react to simple social norms. (D_{42})	($W_{42} = 4$)
Emotional Intelligence (D_5)	Assisting with defined tasks (e.g., basic caregiving). (D_{52})	($W_{52} = 4$)
Purpose, Role and Application Area (D_6)	Companion roles, offering user engagement. (D_{62})	($W_{62} = 4$)
Adaptability (D_7)	Intermediate learning capabilities, adapting to preferences. (D_{73})	($W_{73} = 3$)

Dimensions	Selected Requirement	Importance Ranking
Ethical and Cultural Awareness (D_8)	Moderate sensitivity to ethical issues. (D_{83})	($W_{83} = 4$)
Proximity (D_9)	Physical proximity with restricted interaction. (D_{93})	($W_{93} = 4$)
Temporal Profile (D_{10})	Continuous engagement in a structured context. (D_{103})	($W_{103} = 4$)

Comparison of stakeholders: The Total Stakeholder Relationship Value $(SRV)_T$ for all stakeholders is calculated and stakeholders with a $(SRV)_T$ greater than 50 (as a threshold value) are selected. These are **engineers (Mechatronics Engineers, Software Engineers)**, **AI developers**, **ergonomists**, **industrial designers**, **psychologists**, **ethicists**, **daily assistants**, and **entertainment professionals**. However, to avoid potential omissions, stakeholders whose $(SRV)_T$ value is below 50 are cross-checked for compatibility to ensure no relevant groups were excluded. This comprehensive approach minimized the risk of overlooking key contributors and ensured that a broad range of stakeholders participated in the user-centered design of the robot. As a result of the compatibility check, identified professions deemed necessary for collaboration appeared as **assistive technology designers** and **business teams**, which were subsequently added to the list. However, while business teams were considered significant, **long-term care managers** were assessed to have no substantial influence and were therefore excluded. Table *4.2* depicts a comparative list of stakeholders selected by the developed formalism and those involved in the published study.

Table 4.2: Comparison of the stakeholders for Case Study 1

Stakeholders in the published study	Stakeholders selected by the developed framework
Engineers	Engineers (Mechatronics Engineers, Software Engineers)
Customers	N/A
Ergonomists	Ergonomists
Assistive Technology Designers	Assistive Technology Designers
Industrial Designers	Industrial Designers

Stakeholders in the published study	Stakeholders selected by the developed framework
Business Teams	Business Teams
Long-term Care Managers	N/A
N/A	AI Developers
N/A	Psychologists
N/A	Ethicists
N/A	Daily Assistants
N/A	Entertainment Professionals

Certain professions, such as **psychologists**, **ethicists**, **daily assistants**, and **entertainment professionals**, were also deemed critical for the participatory design process of service robots. Including experts from these fields enhances the robot's ability to meet diverse user needs while ensuring that ethical considerations, emotional engagement, and practical usability are seamlessly integrated into the design. The following contributions from these professions highlight their relevance to service robots:

Ethicists:

Ethicists play a vital role in guiding the development and deployment of service robots to ensure adherence to moral and cultural standards. Their contributions include:

- Addressing societal and individual impacts by ensuring robots operate within acceptable ethical boundaries.
- Establishing guidelines to protect human dignity, justice, and privacy in robot operations [128] [129].
- Resolving ethical dilemmas such as consent in human-robot interactions, bias in AI decision-making, and safeguarding against potential misuse [130] [128].
- Promoting transparency and accountability frameworks, fostering trust in service robots [131] [74].
- Ensuring public acceptance by aligning robot design with universal ethical standards and mitigating societal resistance [130] [74].

Entertainment Professionals:

These experts customize service robots to engage users through interactive storytelling, games, or live events, enhancing their role as companions or performers. By designing emotionally engaging and entertaining experiences, they improve the robot's capacity to sustain user interest, particularly in environments like elder care facilities, hospitality, or educational institutions [100] [95].

Daily assistant:

Daily assistants contribute by focusing on the practical usability of service robots in everyday routines. For instance:

- They ensure that robots effectively assist with time-sensitive tasks such as medication reminders, meal assistance, or mobility support, particularly for elderly or disabled users.
- By incorporating their input, service robots can reliably support users in managing their daily schedules, reducing stress, and improving quality of life [93] [94].

Psychologists:

Psychologists provide crucial insights into user behavior, cognitive development, and emotional well-being. For service robots, their role includes:

- Ensuring that interactions are age-appropriate and cognitively stimulating, particularly for educational or caregiving purposes.
- Designing feedback mechanisms that reinforce learning and engagement constructively without causing frustration or overstimulation.
- Supporting the development of adaptive systems that respond to user needs, promoting meaningful and productive interactions [132].

The inclusion of **psychologists, ethicists, daily assistants, and entertainment professionals** enriches the participatory design process, ensuring that service robots are designed to cater to practical, emotional, and ethical dimensions of user experiences. By incorporating diverse expertise, the outcome is a more comprehensive, user-centered design that aligns with the complex needs of modern service environments.

4.2 Case Study 2: Special Care Robot

General information: The selected publication investigates how assistive robots can decrease the strain on caregivers while improving older adults' independence, safety, and quality of life [133]. For four weeks, researchers used an immersive participatory design approach to install a mobile manipulator called “Stretch” in the home of an elderly person with mobility limitations and his care partner. A robotics engineer and an occupational therapist lived with the participants during this period, modifying the robot's features in response to user input. The published study illustrated how co-designing with end users produced solutions that decreased caregiver workload while enhancing the care recipient's autonomy in everyday tasks (e.g., self-feeding, light switch control, and social involvement). According to that study, developing helpful robots that are both socially acceptable and easy to use requires participatory design.

Stakeholders involved: The stakeholders and their designated roles as identified in the published article are as follows:

- **End users,** or **older adults**, gave input on the robot's comfort, autonomy, and usability.
- **Caregivers** discussed how the robot could lessen their effort and enhance patient treatment.
- **Occupational Therapists:** helped design features that facilitate everyday tasks, mobility, and self-feeding.
- **Robotics engineers** optimized robotic capabilities by implementing technical changes depending on customer needs.
- **Human Factors / Ergonomics Experts** focused on optimizing the interaction between users and the robot by improving interface design, reachability, and task accessibility. Their contributions ensured that the robot accommodated users' physical and cognitive limitations, enhancing safety and ease of use.

User requirements for social robot dimensions: The immersion study found that older individuals and their caregivers had several important demands and expectations about helpful robots. The D_{ij} values are assigned and presented in Table 4.3, in accordance with the dimensional characteristics identified in the article and summarized below:

- Physical Assistance: The robot should help with meal preparation, self-feeding, flicking switches, keeping comfortable (e.g., wearing a percussion vest), and housekeeping chores.
- Autonomy: Users wanted semi-autonomous features like movement recording and replay in addition to direct teleoperation.
- Usability: The robot's interface has to be simple to use, compatible with voice instructions, and reachable via head-tracking sensors.
- Social Engagement: Robots ought to make it easier for people to engage in social activities like card games.
- Customization: Creating or altering tools (such as button pushers or adaptable spoons) was essential to user happiness.

Table 4.3: User requirements for social robot dimensions in Case Study 2

Dimensions	**Selected Requirement**	**Importance Ranking**
Embodiment (D_1)	Functional, abstract shapes (D_{12})	($W_{12} = 3$)
Interactivity (D_2)	Minimal interaction to multimodal (D_{21})	($W_{21} = 4$)
Autonomy (D_3)	Semi-autonomous with context-aware decision-making. (D_{33})	($W_{33} = 4$)
Social Intelligence (D_4)	Limited ability to detect and react to simple social norms. (D_{42})	($W_{42} = 3$)
Emotional Intelligence (D_5)	Limited detection and response to user emotions. (D_{51})	($W_{51} = 3$)
Purpose, Role and Application Area (D_6)	Assisting with defined tasks (e.g., basic caregiving). (D_{62})	($W_{62} = 5$)
Adaptability (D_7)	Basic customization options. (D_{72})	($W_{72} = 5$)
Ethical and Cultural Awareness (D_8)	Moderate sensitivity to ethical issues. (D_{83})	($W_{83} = 4$)
Proximity (D_9)	Close interaction with natural movement (D_{94})	($W_{94} = 5$)
Temporal Profile (D_{10})	Regular but limited interactions (D_{102})	($W_{102} = 4$)

<u>Comparison of stakeholders:</u>

The stakeholders identified through the QFD analysis in the developed method are **engineers (Mechatronics Engineer, Software Engineers), AI developers, ergonomists, patients, psychologists, physiotherapist, health professionals,**

ethicists, caregivers, disability support workers, and daily assistants. However, when the DSM is used for a re-evaluation, it is determined that the roles of Disability Support Workers and Daily Assistants are redundant, given that Caregivers already fulfill similar responsibilities. As a result, it is considered appropriate to exclude these two stakeholders from the final list. A comparison of the stakeholders chosen using the created formalism and those participating in the published study is shown in Table 4.4.

Table 4.4: Comparison of the stakeholders for Case Study 2

Stakeholders in the published study	**Stakeholders selected by the developed framework**
Engineers (Robotic Engineers)	Engineers (Mechatronics Engineer, Software Engineers)
Human Factors/Ergonomists	Ergonomists
Older Adults/End Users	Patients
Occupational Therapists	N/A
Caregivers	Caregivers
N/A	Ethicists
N/A	AI Developers
N/A	Psychologists
N/A	Physiotherapist
N/A	Health Professionals

Certain professions, such as psychologists, physiotherapists, caregivers, ethicists, AI developers and health professionals are essential for the participatory design process of Special Care Robots. Including these experts enhances the robot’s ability to provide effective support in various care settings, particularly for patients with specific needs. Here's a brief explanation of their roles:

- **Physiotherapist**: These experts ensure that the robot can assist patients in rehabilitation exercises and physical therapy routines. Their involvement ensures that the robot's capabilities are designed to support mobility and physical recovery.

- **Psychologists:** These professionals are crucial in ensuring the emotional and psychological well-being of users, especially in healthcare environments. They help design interactions that foster trust and promote positive mental health outcomes for patients.
- **Ethicists**: These professionals ensure that ethical principles are respected in all aspects of human–robot interaction. Their role includes safeguarding user privacy, ensuring informed consent, and maintaining dignity in care settings. They also contribute to establishing ethical design frameworks that guide robot behavior in sensitive environments.
- **AI Developers**: These experts are responsible for designing intelligent systems that allow the robot to exhibit adaptive behavior, learn from user input, and personalize interactions. Their contributions are essential in enabling natural communication, context-aware decision-making, and responsive assistance in dynamic care scenarios.
- **Health Professionals**: Health professionals provide clinical expertise to ensure that the robot's functions align with medical standards and patient care needs. They help design features such as medication management, vital sign monitoring, and emergency alerts, ensuring the robot contributes to both safety and healthcare efficiency.

Including a diverse range of stakeholders, such as those in healthcare and ethical fields, allows for the creation of a more comprehensive and user-centered design, ensuring that the Special Care Robot can meet both the practical and emotional needs of patients while adhering to ethical standards.

4.3 Case Study 3: Healthcare Robot

General information: For this case study, the selected publication investigates how assistive robots can help older adults with their everyday care and medical requirements in hospital environments [134]. The published study focuses on how older persons engage with assistive health robots used to do activities including health monitoring, mobility aid, and prescription reminders. In order to evaluate user requirements and expectations, the study uses a participatory design method, taking into account input from healthcare experts, older persons, and caregivers.

This case study shows how important assistive health robots are to improving healthcare services for senior citizens. The study highlights the importance of high levels of usability, ethical issues, and interactivity in healthcare robots. To guarantee more integration into senior care settings, future advancements should concentrate on enhancing social intelligence, emotional flexibility, and increased autonomy.

Since Case Study 2 includes special care robot, the distinction between the special care robot and the healthcare robot is noted here: Healthcare robots are primarily designed to support medical tasks such as health monitoring, medication management, and mobility assistance within clinical or home healthcare environments. In contrast, special care robots focus more broadly on enhancing the quality of daily living for individuals with specific needs, including older adults or people with disabilities, by promoting autonomy, social engagement, and emotional well-being beyond strictly medical functions. Therefore, they have been categorized separately to reflect their distinct focus areas and user requirements.

Stakeholders involved: The stakeholders and their designated roles as identified in the published article are as follows:

- **Doctors, nurses,** and **therapists** were among the healthcare professionals who contributed their medical knowledge to guarantee that the robot could assist with healthcare duties like prescription reminders and vital sign monitoring.
- **End users,** or **older adults**, evaluated the robot in authentic healthcare settings and offered input on its usability and efficacy.
- **Caregivers:** Assessed how the robot affected their workload and made recommendations for enhancements.
- **Engineers** were responsible for the robot's mechanical design, sensor integration, and overall hardware functionality. Their expertise ensured the robot could perform physical tasks safely and reliably, while also meeting ergonomic and environmental constraints of healthcare settings.

User requirements for social robot dimensions: According to the published study, successful healthcare robots should promote mental wellness, ease independent living, and improve medical adherence. Researchers discovered that multimodal robots—which include voice, touch, and visual feedback—were more well-liked after conducting tests in real-world environments. Furthermore, the significance of trust-building, personalization, and ethical considerations in healthcare robots are underlined. Table 4.5 displays the D_{ij} values, which were assigned based on the dimensional properties mentioned in the article.

- Health Monitoring: The robot ought to monitor vital signs, identify falls, and send out alarms in case of an emergency.
- Medication management: reminding patients to take their prescription drugs on schedule and notifying caretakers when a dose is missed.
- Physical Assistance: Supporting users' movement by assisting them in standing up or directing them to various locations.
- Social and Emotional Support: Talking to others, providing company, and identifying emotional signs to improve wellbeing.
- Usability and Accessibility: An intuitive interface that can be used with voice and touch commands to suit varying degrees of cognitive and physical ability.
- Privacy and Ethical Considerations: Making sure that the robot respects the user's autonomy and preferences, and that personal data is handled safely.

Table 4.5: User requirements for social robot dimensions in Case Study 3

Dimensions	**Selected Requirement**	**Importance Ranking**
Embodiment (D_1)	Functional, abstract shapes (D_{12})	($W_{12} = 3$)
Interactivity (D_2)	Varity in interaction means (ex. voice and touch together) (D_{22})	($W_{22} = 5$)
Autonomy (D_3)	Semi-autonomous with context-aware decision-making. (D_{33})	($W_{33} = 4$)
Social Intelligence (D_4)	Limited ability to detect and react to simple social norms. (D_{42})	($W_{42} = 4$)
Emotional Intelligence (D_5)	Moderate ability to identify and react to common emotional expressions. (D_{52})	($W_{52} = 4$)

Dimensions	Selected Requirement	Importance Ranking
Purpose, Role and Application Area (D_6)	Companion roles, offering user engagement. (D_{63})	($W_{63} = 5$)
Adaptability (D_7)	Intermediate learning capabilities, adapting to preferences. (D_{73})	($W_{73} = 4$)
Ethical and Cultural Awareness (D_8)	Moderate sensitivity to ethical issues. (D_{83})	($W_{83} = 4$)
Proximity (D_9)	Close interaction with natural movement (D_{94})	($W_{94} = 5$)
Temporal Profile (D_{10})	Regular but limited interactions (D_{102})	($W_{102} = 5$)

<u>Comparison of stakeholders:</u>

The stakeholders identified through the QFD process include **engineers (Mechatronics Engineer, Software Engineer), AI developers, ergonomists, patients, psychologists, physiotherapists, health professionals, ethicists, and daily assistants**. However, when further control is conducted using the DSM, it is determined that roles such as Caregivers, Elder Care Specialists, and Disability Support Workers could be included, but since Daily Assistants already fulfill many of these responsibilities, the inclusion of these additional roles is deemed unnecessary. As a result, caregivers, elder care specialist and disability support workers are not included in the final table. Those who participated in the published study and those chosen using the created formalism are compared in Table 4.6.

Table 4.6: Comparison of the stakeholders for Case Study 3

Stakeholders in the published study	Stakeholders selected by the developed framework
Engineers (Computer Engineers)	Engineers (Mechatronics Engineer, Software Engineer)
Doctors, Nurse	Health Professionals
Older Adults/End users	Patients
Therapists	N/A

Stakeholders in the published study	Stakeholders selected by the developed framework
Caregivers	N/A
N/A	Psychologists
N/A	AI Developers
N/A	Physiotherapists
N/A	Ethicists
N/A	Daily Assistants

Certain professions, such as psychologists, physiotherapists, daily assistants, AI developers, ethicists and health professionals, are deemed critical for the participatory design process of Healthcare Robots. Including these experts ensures that the robot can effectively address the needs of patients and healthcare workers in a clinical setting. Here's a brief explanation of their roles:

- **Physiotherapists:** These professionals ensure that the robot can assist patients with rehabilitation and physical therapy routines. Their input ensures the robot's design supports mobility, strength, and overall recovery.
- **Health Professionals:** These experts provide valuable feedback on how the robot can best integrate into healthcare systems, focusing on patient care, safety, and medical procedures. Their involvement ensures that the robot enhances healthcare delivery while adhering to medical standards.
- **Psychologists:** These experts contribute to the robot's design by ensuring that the interactions are emotionally engaging and support the mental well-being of patients. Psychologists also help address any psychological concerns that may arise during robot interaction.
- **Daily Assistants:** These individuals contribute practical insights into the everyday tasks and routines that patients and healthcare providers face. By considering their feedback, the robot's design can include features that streamline daily healthcare tasks, improving efficiency and user satisfaction.
- **Ethicists**: Ensure that healthcare robots comply with ethical standards regarding privacy, autonomy, consent, and safe data handling.

- **AI Developers**: Implement algorithms for personalization, decision-making, and multimodal communication, enabling intelligent and responsive behavior.

Including these stakeholders ensures that the Healthcare Robot is not only effective in providing medical assistance but also tailored to address the emotional, social, and physical needs of patients and healthcare providers alike. This comprehensive approach guarantees a user-centered design that meets the multifaceted demands of modern healthcare environments.

4.4 Case Study 4: Educational Robot

General information: The publication selected for this case study explores the process of designing educational robots. According to the published study, integrating instructors, students, and education professionals enhances the use and efficacy of socially assistive robots (SARs) in classroom environments [135]. In order to get feedback on three important areas as follows, the study uses qualitative focus groups with 127 stakeholders from five different European nations:

- The SAR's function in schools.
- The SAR's physical attributes,
- The SAR's voice and communication skills

The results show that expectations for SARs vary throughout stakeholders. Instructors see the SAR as a tool to help with workload management, student monitoring, and lesson planning. Conversely, students anticipate that SARs will operate as tutors or learning partners, helping with information retrieval, study support, and interactive participation. The published paper offers a paradigm for using participatory design to create SARs that satisfy these various criteria.

Stakeholders involved: The stakeholders and their designated roles as identified in the published article are as follows:

- **Teachers:** Shared their thoughts on how the robot could help with classroom management, student engagement, and lesson planning.

- **Students:** submitted input on motivation, usability, and engagement after interacting with the robot as a learning partner.
- **Educational Professionals:** Contributed to the development of the robot's instructional strategy, guaranteeing conformity with curricular requirements.
- **Engineers**: Engineers were responsible for the development of the robot’s hardware and software systems, ensuring reliable functionality, user-friendly interfaces, and technical integration in the classroom environment.
- **Administrative Staff**: Administrative staff supported the deployment of the robot within the educational setting by managing logistical aspects, such as scheduling, resource allocation, and institutional alignment with the robot’s educational use.

User requirements for social robot dimensions: The D_{ij} values are assigned in accordance with the dimensional characteristics identified in the article and these values are presented in Table 4.7.

- Tutoring and Learning Support: Students anticipate that SARs will offer tutoring, respond to inquiries, and support learning through individualized help.
- Classroom Support: SARs are needed by teachers to keep an eye on student engagement, identify distractions, and assist in overseeing class activities.
- Personalization and Adaptability: SARs ought to be adaptable to the wants of students and the topic matter, including the capacity to change roles and communication approaches.
- Motivation and Engagement: Voice commands, gestures, and gamified learning strategies should all be used in the interactive SAR to keep students interested.
- Physical Design and Social Presence: According to stakeholders, the SAR should avoid overly anthropomorphic appearances and instead have a welcoming, non-threatening appearance.

Table 4.7: User requirements for social robot dimensions in Case Study 4

Dimensions	Selected Requirement	Importance Ranking
Embodiment (D_1)	Functional, abstract shapes (D_{12})	($W_{12} = 3$)
Interactivity (D_2)	Minimal interaction (pre-programmed commands, responses, answers etc.), no variety for the interaction means (ex. only voice) (D_{21})	($W_{21} = 4$)
Autonomy (D_3)	Semi-autonomous with context-aware decision-making. (D_{33})	($W_{33} = 3$)
Social Intelligence (D_4)	Limited ability to detect and react to simple social norms. (D_{42})	($W_{42} = 3$)
Emotional Intelligence (D_5)	Limited detection and response to user emotions. (D_{51})	($W_{51} = 3$)
Purpose, Role and Application Area (D_6)	Companion roles, offering user engagement. (D_{63})	($W_{63} = 5$)
Adaptability (D_7)	Basic customization options. (D_{72})	($W_{72} = 4$)
Ethical and Cultural Awareness (D_8)	Moderate sensitivity to ethical issues. (D_{83})	($W_{83} = 3$)
Proximity (D_9)	Close interaction with natural movement (D_{94})	($W_{94} = 5$)
Temporal Profile (D_{10})	Continuous engagement in a structured context. (D_{103})	($W_{103} = 4$)

Comparison of stakeholders:

The stakeholders identified through the QFD process method include **engineers (Mechatronics Engineer), AI developers, ergonomists, psychologists, ethicists, teachers, students, educational professionals, curriculum developers, and educational guidance specialists**. However, when further control is conducted using the DSM, it is determined that if Teachers and Students are already included, the role of Educational Professionals becomes necessary. Yet, since the Educational Professionals already covers many aspects of this role, the inclusion of Educational Guidance Specialist is deemed redundant. Additionally, it is concluded that if both Educational Professionals and Teachers are present, the role of Curriculum Developers is not needed, so this is also excluded from the final list. The stakeholders chosen by the created formalism and those participating in the published study are compared in Table 4.8.

Table 4.8: Comparison of the stakeholders for Case Study 4

Stakeholders in the published study	Stakeholders selected by the developed framework
Teachers	Teachers
Student	Student
Administrative Staff	N/A
Educational Professionals	Educational Professionals
N/A	Engineers (Mechatronics Engineer)
N/A	Ergonomist
N/A	Psychologists
N/A	Ethicists
N/A	AI Developers

Certain professions, such as, psychologist, ethicists, ergonomists and AI developers are essential for the participatory design process of Educational Robots. Including these experts ensures that the robot can effectively support both teaching and learning in educational settings. Here’s a brief explanation of their roles:

- **Psychologists and Ethicists:** Psychologists contribute to understanding the impact of the robot on student well-being, ensuring that interactions are age-appropriate and psychologically beneficial. Ethicists ensure that the robot respects ethical guidelines in its interactions with students, promoting fairness and addressing concerns about privacy, bias, and inclusivity.
- **Ergonomists**: Ergonomists play a crucial role in ensuring that the robot's design is user-friendly, safe, and physically accessible to students. They ensure that the robot’s interface and interaction mechanisms are comfortable for prolonged use, reducing strain and promoting effective engagement in the learning environment.
- **AI Developers**: Develop intelligent learning algorithms and adaptive feedback mechanisms to tailor educational experiences to individual learners.

Including these stakeholders ensures that the Educational Robot is designed to support effective learning, ethical considerations, and emotional well-being. Their collective input results in a comprehensive, user-centered design that aligns with the diverse needs of modern educational environments.

Ethicists are professionals who focus on evaluating and guiding ethical decision-making in various sectors, including healthcare, technology, and public policy. Typically, ethicists have academic backgrounds in Philosophy, Ethics, Law, or Theology. Some specialize further by obtaining advanced degrees in fields such as Applied Ethics, Biomedical Ethics, or Technology Ethics. Professionals with strong foundations in moral reasoning and critical analysis, such as philosophers, bioethicists, and legal scholars, are well-qualified to perform the role of an ethicist in participatory design processes for social robots. Although ethics is emphasized as a critical concern in the published studies, the specific stakeholder or professional responsible for ethical oversight is often not explicitly identified. As a result, ethical stakeholders are frequently absent from the stakeholder lists in the reviewed publications. However, ethical considerations remain essential, and the lack of formally designated ethical stakeholders highlights a significant gap. Future participatory design processes should explicitly include ethicists or ethical experts to ensure that social robot development aligns with moral standards, protects user rights, and addresses societal concerns in a systematic and accountable manner.

Comparing the stakeholders selected by using the developed framework and those included in the published studies shows a strong alignment with the objectives of the thesis. It not only validated the inclusion of relevant professions but also extended the collaborative framework by integrating experts from additional fields. This highlights the robustness of the approach and its ability to accommodate diverse expertise for participatory design of social robots.

CHAPTER 5

CONCLUSION

5.1 Conclusion

The participatory design of social robots plays a pivotal role in aligning technological innovations with the diverse needs and expectations of users and stakeholders. This thesis emphasizes the necessity of a systematic and context-independent framework to identify and integrate relevant users, professionals, and experts in the design process. The proposed framework introduces the concepts of the '**D**esign Space for **So**cial Ro**bot**s (D-SoBOT)' and 'Domain (**F**ield) Space for **Stakeholders (F-Stakeholder)**', providing a structured mechanism to match user needs with appropriate stakeholders through a formalized and replicable methodology. This approach bridges the gap between theoretical design principles and practical implementation by offering a comprehensive representation of user demands and stakeholder expertise independent of any specific context. The framework contributes a participatory design process, which enhances product adaptability and innovation through iterative feedback loops, prototyping, and collaborative sessions.

To validate the applicability and effectiveness of the developed framework, four comprehensive case studies were conducted based on different categories of social robots: service robots, healthcare robots, special care robots, and educational robots. In each case study, QFD and DSM methodologies were applied to systematically evaluate stakeholder involvement based on the robot type and user requirements identified in published studies. The results demonstrated a strong alignment between the stakeholders selected using the proposed methodology and those present in the actual participatory design projects.

Moreover, the analysis revealed that following a systematic stakeholder selection process not only validated the relevance of initially identified stakeholders but also uncovered additional expert groups whose inclusion could significantly enhance the participatory design process. For instance, stakeholders such as psychologists, physiotherapists, daily assistants, educational guidance specialists, and entertainment professionals emerged as critical contributors for ensuring a more holistic, inclusive, and participatory design outcome across different robot types.

Despite its strengths, the framework faces challenges, such as the complexity of stakeholder selection and the potential costs associated with implementing participatory approaches. However, its structured nature offers significant potential to streamline these processes and mitigate associated disadvantages, thus providing a repeatable and scalable pathway for the participatory design of social robots. The findings of this thesis not only contribute to the academic understanding of user participation in social robot design but also provide practical insights for developers aiming to create socially functional and user-centric robots. Future research could focus on the empirical validation of the framework across diverse application areas, further refining its scalability and robustness in dynamic and multifaceted operational settings.

This research highlights that the strategic and systematic involvement of a broad range of stakeholders, guided by a formalized selection framework, is critical to the success of participatory design in social robotics. Through structured stakeholder integration, the design of social robots can be made more inclusive, effective, and socially responsive, ensuring that these technologies meaningfully enrich the lives of their users.

5.2 Limitations

While the proposed framework offers a structured approach to integrating user and stakeholder input in the design of social robots, several limitations should be acknowledged:

- Although the framework is intended to be context-independent, the quality and relevance of the outcomes largely depend on the initial data collection phase. Gathering comprehensive and representative data from diverse user groups and application areas remains a significant challenge.
- The current implementation involves manual efforts to define relationships between the '**D**esign Space for **So**cial Ro**bot**s (D-SoBOT)' and 'Domain (**F**ield) Space for **Stakeholders (F-Stakeholder)**'. This process may be time-consuming and prone to human error, which could impact the accuracy of stakeholder selection.
- As the dimensions of social robots and the complexity of stakeholder expertise increase, the scalability of the framework might become a challenge. Managing large-scale data and maintaining efficiency while expanding the design and stakeholder spaces may require advanced computational resources.
- While the framework is conceptually robust, its practical applicability has yet to be validated extensively across diverse real-world scenarios. Initial case studies may not fully capture the complexities of different operational environments.
- The framework's focus on tailoring social robots to specific user needs and contexts may lead to designs that are too specialized, reducing their transferability or adaptability to other use cases.
- Involving users and stakeholders in the design process raises concerns about privacy and ethical data use. The framework currently does not address how sensitive data, such as user preferences and behavioral information, should be securely managed.

5.3 Future Work

The proposed framework provides a structured and systematic approach to integrating user and stakeholder input into the design process for social robots. However, there are several opportunities for future enhancements and development remain. One promising avenue is the automation of the '**D**esign Space for **So**cial Ro**bot**s (D-SoBOT)' and 'Domain (**F**ield) Space for **Stakeholders (F-Stakeholder)**' using software tools. By leveraging advancements in artificial intelligence (AI), these spaces could be dynamically generated and optimized to select stakeholders based on user needs with greater efficiency, precision, and accuracy.

Additionally, the framework can be expanded to include more dimensions and sub-dimensions of social robots, offering increased flexibility to accommodate diverse application areas. The existing ranges of parameters within each dimension could also be extended, allowing for more granular and tailored design specifications. Furthermore, integrating the framework with current technological advancements, such as machine learning models and real-time user feedback systems, could enable the inclusion of additional features that enhance the adaptability and functionality of social robots. These developments would further bridge the gap between conceptual design and practical implementation, making the framework even more robust and scalable.

An important future step is to extensively test the proposed framework across various sectors and real-world applications. Its applicability can be evaluated in designing social robots for diverse domains such as healthcare, education, and service industries to ensure its robustness and adaptability in dynamic operational environments.

Furthermore, the case studies conducted as part of this research revealed that ethicists and psychologists consistently emerged as critical stakeholders across all types of social robots, regardless of the specific application domain. This highlights the fundamental importance of **ethical** and **psychological** considerations in participatory design. Therefore, a dedicated stakeholder domain could be developed in future research specifically for ethicists and psychologists, ensuring their systematic and detailed integration into the design process. This extension would not only improve the ethical soundness and psychological adaptability of social robots but also enhance public acceptance and user satisfaction.

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APPENDIX

Appendix A: Dimensions, Axis, Range and Examples

Table A.1: Example points of dimensions

Dimension	Axis	Range	Example Points
Embodiment (Appearance)	Physical Form and Appearance	From minimalist or abstract designs (e.g., geometric shapes) to fully humanoid robots with anthropomorphic features, expressive faces, and lifelike movements	Simple devices like smart speakers vs. robots with expressive faces or human-like bodies
Interactivity (Social Capability)	Communication Complexity	From minimal and simple interaction (pre-programmed commands or responses) to complex, multimodal communication (such as having fluid discussions that incorporate voice, gestures, emotional reactions, and non-verbal indicators)	Minimal Interaction: Simple voice-activated robots like smart speakers or robots that only respond to specific commands. Complex Interaction: Robots like Pepper or Jibo, which can engage in open-ended conversations, recognize and interpret emotional expressions, and respond in ways that simulate empathy and understanding.
Autonomy (Self-determination)	Level of Autonomy	The range of autonomy varies from fully teleoperated robots (requiring human control for all actions) to fully autonomous robots (capable of self-directed actions and decisions using artificial intelligence).	A robot remotely controlled by a human operator vs. a robot that makes independent decisions using AI. Fully Teleoperated: Robots controlled remotely by a human, such as drones or robots in medical procedures requiring operator intervention for each movement.

Dimension	Axis	Range	Example Points
			Fully Autonomous: Robots that can make decisions independently based on real-time data using AI with minimal human oversight.
Social Intelligence (Social Interaction):	Understanding Social Context	From no social understanding to high-level context awareness (interpreting complex social norms and behaviors).	Minimal Understanding: A robot that follows basic social protocols, such as saying "hello" or responding to commands in a neutral manner. High-Level Awareness: A robot that can adapt to various social contexts, such as changing its tone or actions based on the user's emotional state or adjusting its behavior according to group dynamics or cultural norms (e.g., recognizing when to be formal or informal in conversation).
Emotional Intelligence	Recognition and Response to Emotions	Robots can have varying levels of emotional intelligence. At one end of the spectrum, they may only detect basic emotions (e.g., a smile or frown), while at the other end, they might provide emotional support by recognizing and responding to complex emotions such as sadness, joy, frustration, or anxiety.	Basic Recognition: A robot that detects simple facial expressions (e.g., smiling or frowning) and adjusts its behavior accordingly, such as smiling back or responding with neutral statements. Advanced Emotional Empathy**:** A robot that not only recognizes emotional cues but also understands deeper feelings. For example, a robot that detects sadness in a user's voice and responds with comforting words or offers actions designed

Dimension	Axis	Range	Example Points
			to improve the user’s mood.
Purpose, Role and Application Area	Functionality and Social Role	The role of a robot can range from being task-specific, such as a robot designed solely for delivering items, to a more complex, multi-functional role, such as a companion or assistant that provides social engagement, emotional support, and even medical care.	Task-Specific Role: A robot designed for delivering goods or acting as a self-checkout assistant in retail environments. Multi-Functional Role**:** A robot that serves as both a social companion for elderly individuals and an assistant for healthcare tasks like medication reminders.
Adaptability	Personalization and Learning	Adaptability can range from fixed, predetermined behaviors (where the robot does not alter its actions based on the user) to fully personalized interactions, where the robot learns from past interactions and adjusts its behavior accordingly.	No Personalization: A robot that repeats the same responses or actions regardless of the user's preferences or past interactions. Full Adaptability: A robot that learns user preferences over time and customizes its responses, for instance, adapting its communication style based on the user's emotional state or history of interaction.
Ethical and Cultural Awareness	Ethical Considerations and Cultural Sensitivity	The ethical and cultural awareness of robots can range from a lack of awareness, where robots perform actions without consideration for ethics or culture, to a high level of awareness, where they follow ethical protocols and adapt their behavior based	Minimal Awareness: A robot that performs tasks without considering cultural norms or ethical guidelines, such as ignoring the need for user consent or privacy. High-Level Awareness: A robot that follows ethical protocols, such as ensuring privacy in sensitive environments, or adjusts its behavior to respect cultural norms

Dimension	Axis	Range	Example Points
		on cultural norms or ethical standards.	(e.g., altering communication style depending on cultural expectations).
Proximity	Distance between human and robot	Proximity in robot interactions ranges from remote or indirect interaction, where the human and robot are spatially or temporally separated, to proximate interaction, where both are in the same location or environment.	Remote Interaction: A scenario where the robot interacts with a human from a distance or through mediated channels (e.g., virtual interaction or telepresence). Proximate Interaction: Situations where the robot operates closely with the human in shared physical spaces, such as robots in healthcare or domestic environments assisting in real-time.
Temporal profile (Period)	Period between the interactions with robot and human.	Temporal aspects of robot interactions can range from short, frequent interactions to longer, less frequent engagements.	Short Periods: A robot that interacts periodically with a user, such as asking a patient to confirm their condition at regular intervals during treatment. Longer Intervals: Robots designed to interact less frequently, such as those offering reminders or status updates at specific times during the day.

Appendix B: Matching Example and Case Studies

Table B.1 : Matching Dimensions and Expertise Space and Case Study Examples

Appendix C: Rating Scheme for SR Dimensions based on Robot Types

Rating Symbology: 1-5 (Low-Moderate-Moderate to High-High-Very High)

1. **Importance of Embodiment**

Educational Robot: (Moderate)

- Since educational robots frequently interact with kids or students, having a warm and interesting appearance might improve the educational process.
- To make the robot friendly, it must be simple and have a non-threatening appearance.
- Buttons and facial expressions are examples of visual cues that could support interactive learning.

Healthcare Robot: (High)

- Healthcare robots engage with patients, frequently in stressful or vulnerable circumstances.
- A calm, unthreatening appearance can ease tension and foster trust.
- To project dependability and expertise, one must appear tidy and professional.

Service Robot: (Moderate)

- Service robots frequently work in public areas where appearance affects brand perception, such as hotels, restaurants, and airports.
- A polished and professional design could improve the connection and lend credibility.
- Functional design and ergonomics also contribute to usability.

Entertainment Robot: (Very High)

- Since the purpose of entertainment robots is to enthrall and entertain, their appearance is crucial to their success.
- To emotionally engage users, they frequently feature imaginative or emotive designs.
- A dynamic or aesthetically pleasing design can greatly increase their entertainment value.

Special Care Robot: (High)

- People with impairments or the elderly are frequently helped by special care robots. A warm and sympathetic demeanor can promote friendship and trust.

- To accommodate people with different degrees of cognitive or physical ability, the design should be simple, intuitive, and non-threatening [136] [137] [138].

2. **Importance of Interactivity**

Educational Robot: (High)

- For pupils to participate in active learning, interaction is essential. Robots capable of sophisticated communication, such as multimodal inputs (speech, touch), can adjust to a variety of learning environments.
- Teachers can encourage interest by using robots that can have natural conversations.

Healthcare Robot: (High)

- Building patient trust can be achieved through effective interaction, particularly when replies are sympathetic. Interactive cues are used by robots in rehabilitation or elder care to engage patients.
- Effective caregiving is made possible by multimodal communication.

Service Robot: (Very High)

- In public areas, service robots must engage with a variety of clients. User happiness rises when communication is dynamic and clear.
- Hotel concierge robots that use voice and touchscreens for natural interactions are among the examples.

Entertainment Robot: (High)

- Interactivity is essential for maintaining user engagement with entertainment robots. Advanced reaction robots improve user experience by, for example, responding to audience emotions.

Special Care Robot: (Very High)

- For older or disabled users, interaction helps close communication gaps. Caregiving duties can be made simpler by robots with intuitive user interfaces [139] [104].

3. **Importance of Autonomy**

Educational Robot: (Moderate)

- Self-directed activities, such as quizzes or demonstrations, are made possible by moderate autonomy, but they still need teacher supervision.

Healthcare Robot: (High)

- For accuracy and dependability, key task-performing robots (such those assisting with surgery) require a high degree of autonomy. Self-governing rehabilitation robots improve the effectiveness of recovery.

Service Robot: (Very High)

- For logistics and hospitality, fully autonomous navigation is crucial since it enables robots to operate autonomously in dynamic environments like airports.

Entertainment Robot: (Moderate)

- Semi-autonomous robots can respond dynamically to inputs and follow pre-programmed patterns to keep users interested.

Special Care Robot: (High)

- When it comes to everyday chores like reminding people to take their medications, autonomous robots in caregiving lessen the workload for human caregivers [140].

4. **Importance of Social Intelligence**

Educational Robot: (High)

- Gaining insight into classroom dynamics improves the efficacy of instruction. Robots with social intelligence are able to recognize and react to students' emotions.

Healthcare Robot: (Very High)

- Social intelligence helps robots comprehend patients' emotional states, which is important for mental health and elder care.

Service Robot: (High)

- In order to provide courteous customer service, robots must be aware of cultural conventions and preferences.

Entertainment Robot: (High)

- By simulating genuine interactions, socially intelligent robots maintain user engagement. For more purposeful entertainment, they might decipher user preferences.

Special Care Robot: (Very High)

- Building trust with vulnerable people is facilitated by social intelligence, particularly in therapy or eldercare settings [141].

5. **Importance of Emotional Intelligence**

Educational Robot: (High)

- A positive learning environment is facilitated by acknowledging and addressing students' emotions.
- Adapting instructional methods to each student's needs can be made easier with emotional intelligence.
  For example, expressing frustration may lead to further clarifications or support.

Healthcare Robot: (Very High)

- In order to offer consolation and support in times of stress, emotional intelligence is essential in the healthcare industry. Particularly in palliative care, robots need to be able to sense patients' emotions and react sympathetically.
- Among the uses are mental health support and therapeutic robots.

Service Robot: (High)

- Positive client experiences in sectors like hospitality are guaranteed by emotional intelligence. Acknowledging client satisfaction or dissatisfaction can enhance the quality of services.

Entertainment Robot: (Very High)

- Engaging narrative, games, or performances require emotional intelligence. Immersion and user happiness are increased by robots that replicate human emotional reactions.

Special Care Robot: (Very High)

- To foster friendship and trust, robots helping vulnerable groups need to have great emotional intelligence. This is particularly crucial for people who have psychological or emotional requirements [142].

6. **Importance of Purpose, Role and Application Area**

Educational Robot: (Very High)

- Educational robots are designed to perform particular tasks, like teaching assistants or tutors. Effective implementation in a variety of educational contexts is ensured by a clear purpose.

Healthcare Robot: (Very High)

- To guarantee efficiency and safety, clearly defined duties are necessary, such as senior care, rehabilitation, or surgical help. Specialization improves patient outcomes.

Service Robot: (High)

- Robots do a variety of jobs in service industries, including cleaning and concierge services. Role clarity ensures operational efficiency and avoids work overlap.

Entertainment Robot: (High)

- For entertainment robots to live up to audience expectations, they must play specific roles, like actors or interactive storytellers. The design and engagement strategies are driven by their mission.

Special Care Robot: (Very High)

- Special care robots need to be able to perform specific duties, such helping with everyday chores or offering elderly or disabled people company [143] [144].

7. **Importance of Adaptability**

Educational Robot: (High)

- Educational robots must be able to adjust to different learning styles and speeds because they frequently engage with diverse student groups.
- Learning results are improved when content distribution is tailored based on real-time feedback.
- Robots that adapt their behavior or language complexity to the cognitive level of the user are among the examples.

Healthcare Robot: (Very High)

- Managing various patient demands, medical conditions, and settings requires flexibility.
- To address patients' unique emotional or physical conditions, robots may need to modify their engagement styles (e.g., moving from assistive to instructive modes).
- Adaptability in rehabilitation guarantees personalized treatment plans.

Service Robot: (Moderate to High)

- In dynamic locations, such as malls and airports, service robots frequently engage with a range of users.
- Interaction across languages, cultural settings, and work requirements is made easier by adaptability.
- For example, depending on the user's request, a concierge robot may go from providing information to serving as a navigation assistant.

Entertainment Robot: (Moderate)

- Since entertainment robots frequently interact with humans in casual situations, flexibility is less important but still helpful for sustaining engagement.
- The entertainment experience can be improved by catering to user preferences (e.g., joke genre, dance movements).

Special Care Robot: (Very High)

- Special care robots help people who are elderly or disabled, and they need to be highly adaptive to accommodate different physical and cognitive capacities.
- For instance, a robot might modify duties for people with limited mobility or change the level or tempo of its speech for those who are hard of hearing [145] [146] [147] [148] [149] [150].

8. Importance of Ethical and Cultural Awareness

Educational Robot: (High)

- Cultural awareness guarantees inclusivity, particularly in schools with a varied student body. Robots must follow moral standards when gathering data and protecting student privacy.

Healthcare Robot: (Very High)

- When interacting with patients, robots must adhere to ethical and cultural norms, particularly when handling sensitive health data.

Service Robot: (High)

- In order to provide seamless interactions, service robots in worldwide contexts must adjust to cultural variances in customer service.

Entertainment Robot: (Moderate)

- When creating content, entertainment robots should adhere to ethical standards to ensure that it is appropriate for a variety of audiences and free of offensive content.

Special Care Robot: (Very High)

- In caregiving settings, special care robots must exhibit ethical responsibility by protecting user privacy and cultural sensitivities [151].

9. Importance of Proximity

Educational Robot: (Moderate)

- During lessons, proximity guarantees efficient communication and interaction. However, students shouldn't feel overpowered by physical proximity.

Healthcare Robot: (Very High)

- In order to perform hands-on assistance (like surgery) or comfort patients during therapy, proximity is essential in the healthcare industry.

Service Robot: (High)

- Customer interactions are improved by proximity, particularly in the retail or hotel industries. Ergonomic design guarantees usability and accessibility.

Entertainment Robot: (High)

- Physical closeness increases participation by enabling intimate interaction between users during games or performances.

Special Care Robot: (Very High)

- For elderly or disabled people, close closeness guarantees efficient help with everyday duties or emotional support [152].

10. Importance of Temporal Profile

Educational Robot: (Moderate)

- Robots must adjust to long-term learning objectives, such as enhancing learning outcomes across semesters, while balancing response time during interactions.

Healthcare Robot: (Very High)

- While prolonged presence facilitates healing and rehabilitation, prompt response times are essential in emergency situations.

Service Robot: (High)

- Consistent timing is necessary for logistics and cleaning robots to maintain operations and ensure efficiency.

Entertainment Robot: (High)

- User immersion is ensured by temporal synchronization throughout performances. Entertainment experiences may be hampered by delays.

Special Care Robot: (Very High)

- For people who require special care, prompt reminders for activities or medications are essential. Regular scheduling fosters dependability and trust [153].

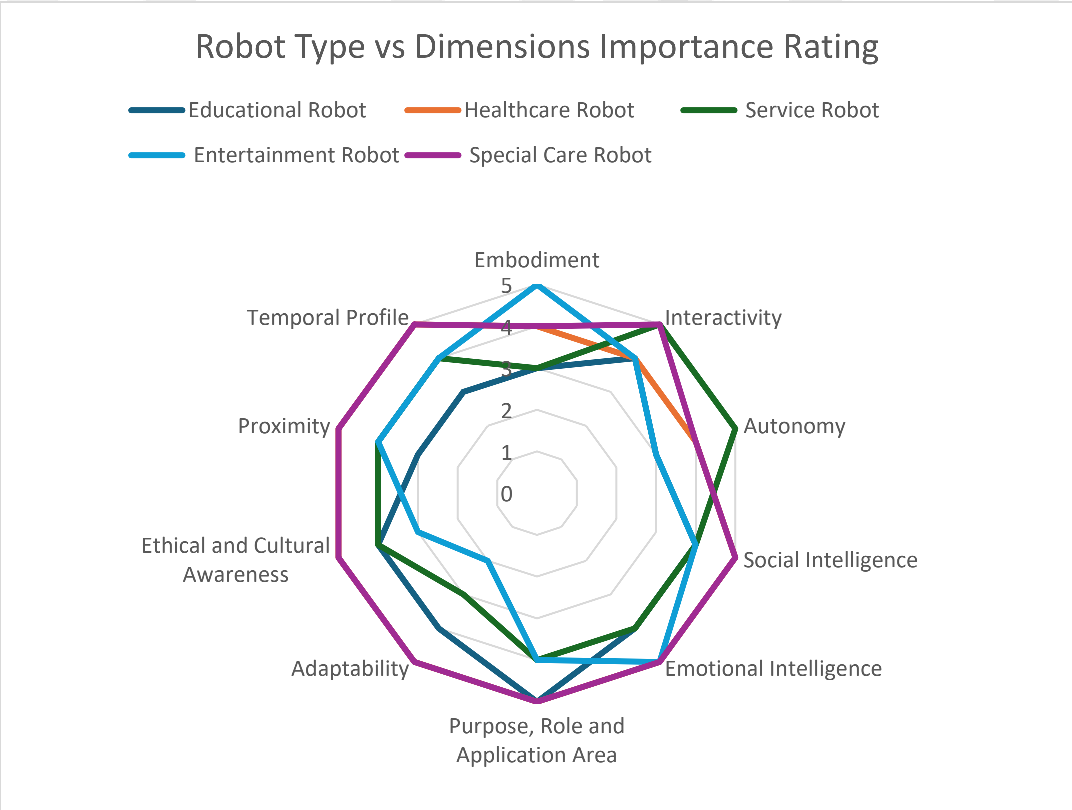

Figure C.1: Robot Type vs Dimensions Importance Rating