Responsible Service Robots

Navigating Ethical and Legal Challenges in Cities

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Deploying robots for public interest missions in a dynamic complex environment, such as a city, is technically and logistically challenging. Due to intended autonomy and coexistence with humans, the implementation also raises ethical and legal challenges. Although decisive for successful application and adoption, the ethical and legal challenges have yet to receive sufficient attention in the scientific and policy literature. It is also critical to assess the ramifications and overall impacts of service robots on sustainability, due to their production, use phase, and end of life. In this article, we set out to identify ethical, legal, and sustainability challenges when deploying service robots in and for cities. Our research is centered around the project "Robots and the City," which took place in the city of Brussels, Belgium, and investigated how these service robots can aid in satisfying future potential needs in the delivery of public missions. We first describe key challenges identified along with research and stakeholders as well as measures to navigate them. We then emphasize the importance of integrating user perspectives to comply with ethical and legal standards. As a conclusion, we present an overview of the challenges of urban service robots and set up a list of recommendations for designers and developers. Finally, we discuss the impacts and feasibility of such measures.

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INTRODUCTION

Cities and local governments like Brussels have a goal of becoming smart cities to improve quality of life while reducing their environmental impact, with a growing interest in exploring how robots could serve public missions. This refers to professional service robots that already operate in transport and logistics, hospitality, health care, professional cleaning, and maintenance and inspection (e.g., last-mile delivery robots, robotaxis, service desk robots, or street cleaning robots). The International Federation of Robotics (IFR) counts 921 service robot producers globally and registered more than 205,000 units sold in 2023, which accounts for growth of 30%. This shows how service robots are growing in numbers and populating various new domains [1].

The IFR defines a robot as a programmed actuated system to perform locomotion, manipulation, or positioning with a degree of autonomy. Further, "professional service robots" are robots that can move within their environment and perform useful tasks for humans or equipment [1]. Thus, they extend the field of operation, as they are no longer confined to an industrial setting. This can be a professional environment like a warehouse but also locations that are publicly accessible and hence involve a more diverse range of people. This means that interaction is not only happening between the robot and the operator but can occur between the robot and anyone present in this public space. The robot also ceases to be solely a tool but has behavior of its own, which means that without an operator present, the robot executes actions based on its design that in turn reflect the designer's or corporation's principles. This raises new ethical and legal concerns that must be addressed in responsible research and design of such service robots, as development seems to advance more rapidly than the creation of collective and standardized frameworks [2]. The discrepancy demands proactive approaches relying on social experiments or methods like technology assessment to mitigate social risks [3], [4]. The most recent example was in San Francisco, CA, USA, where a protest against robotaxis echoed a larger trend of municipalities struggling with technology integration without proper societal discourse and consent.[1]

There are design methods considering sustainability and touching on ethical implications in the early design stage of robots (e.g., [5]), but they do not focus on concrete on-site operational challenges from legal and ethical perspectives (e.g., permissions, safety, liability, surveillance, or data protection). To the extent of our research and knowledge, no such framework for this specific case exists. Therefore, our article aims to uncover these operational challenges and therefore draws from a research project, "Robots and the City," taking place over a period of four months. With 40 participants from Brussels (50% civil servants, 35% industry, and 15% academia) and the help of a professional service designer, we explored the impact of deploying robots in local contexts, investigating the acceptance, trust, and relevance of service robots.

[1] https://www.theguardian.com/technology/2023/jul/07/san-francisco-autonomous-cars-protest-cone

To address ethical, legal, and sustainability challenges, we adopted a two-step approach: an ethical and legal literature analysis followed by a participatory design approach centered on stakeholder engagement. The aim was to offer a comprehensive approach encompassing ethical discussions, legal boundaries, and sustainability concerns, which are crucial for robot deployment and human–robot interaction (HRI).

Three participatory workshops were organized in October 2024, following the double-diamond design method. The goal was to help define local use cases and accommodate fast-track development. The first workshop, "Citizen Needs in the Smart City," covered the discovery and definition by gathering and specifying problems in five domains: environment, well-being, mobility, infrastructure, and governance. The second, "How Do You Like Your Robot?," broadened the idea development and solution space. The final workshop, "Shaping a Service Robot for Brussels," involved rapid prototyping and testing refined solutions. These cocreation workshops revealed the participants' priorities, valued robot features, and concerns, shaping our research and challenges overview (the "Ethical Challenges" and "Legal Challenges" sections). Given the overlap among ethics, law, and sustainability, we include sustainability where relevant rather than in a separate section. The "Outcomes" section graphically presents challenges at the domain intersections, and the "Discussion" and "Conclusion" sections discuss the proposed framework's feasibility and conclude the article.

The ethical analysis combined literature review with participatory workshop insights. The themes were distinguished based on recurring participant concerns, such as distrust or surveillance, enriching HRI literature narratives. Literature triangulation helped differentiate well-established concerns from novel user-informed insights, ensuring theoretical and contextual relevance.

The legal research involved analyzing existing legislation to provide a holistic overview of the current legal landscape and its gaps. Robots were considered autonomous entities capable of independent operation and data storage, though inherently linked to human oversight during malfunction or development.

To address the multifaceted nature of deploying service robots in public spaces, a combined methodology of literature review and participatory workshops was adopted. This approach enabled a critical synthesis of existing knowledge with grounded context-specific insights from stakeholders directly affected by service robots.

ETHICAL CHALLENGES

In the context of HRI, ethics can provide a critical framework for understanding the implications of robot deployment in human spaces. Specifically, robot ethics is concerned with the behavior of robots, the people who design and use robots, and how people treat robots [6]. Here, we focus on the question of how to design robots to conform to key concerns, such as trust, safety, surveillance, job displacement, and sustainability, in correspondence to norms and ethical principles. Considering

IEEE standard 7007-2021, we see a robot's behavior tied to its design and hence tied to the ethics of the human as a moral agent acting through the robot as an entity that executes actions bound to prescribed ethical or legal norms [7]. The standard establishes ontological subdomains that are reflected in our description of ethical challenges, one being accountability, as any entity that wields moral responsibility must engage ethically with the communities it serves [8].

Accountability in ethics extends beyond mere operational function. This ethical foundation emphasizes an entity's accountability to the community, aligning with Shearer [9], who points out that meaningful accountability requires a reevaluation of traditional ethical frameworks. This article applies ethical accountability to the context of service robots in public spaces, an area that is both innovative and laden with complex socioethical implications.

This section represents a synthesis of the challenges discussed during the workshops and highlighted in the literature review. The workshop discussions are summarized in Figure 1. The challenges identified during the workshops are based on observations and their thematic coding. This constructive approach is a multistakeholder perspective that involves citizens, interested parties, and researchers of different academic dimensions.

TRUST AND ACCEPTANCE IN HRI

According to Obrenovic et al., [10] trust is an essential component of successful HRI. It enables humans to engage confidently with robots, knowing that their interactions will be secure and reliable. Trust in HRI is influenced by several factors, categorized into human-related factors, robot-related factors, and situational factors.

First, human-related factors are based on personal needs, comfort, and past experiences with technology that shape trust levels. Some participants also related their attitude toward robots to fictional stories like *The Terminator* or *Wall-E*. Second, robot-related factors like reliability, behavior, and design play a significant role in building trust. Demonstrating prototypes at our workshops revealed quick movements of robots to be perceived as unpredictable, leading to mistrust. Also, the participants questioned the mimicking of humans or animals without adding any functional benefit, like a guide dog robot or bipedal robots for logistics. In their view, simple and functional design contributes to acceptance, which caters to the statement that the ethicalness of a robot seems to depend on its behavior, not its shape [11]. Nonetheless, the participants mentioned anthropomorphic design as fostering trust since they could relate more, even developing friendly feelings. Interestingly, this is limited to a certain degree that is described by the "uncanny valley" [12]. Another critique of anthropomorphic design involves the idea that such design is not neutral but, rather, shapes how we interpret and relate to robots, often assigning them moral significance and expectations. This factor is ethically questionable, as it has a direct and almost unconscious impact on the user [13]. Third, situational factors represent the cultural and environmental context of HRI. For instance, cultural attitudes toward technology can vary significantly, and robots that align with local norms and expectations are more likely to be trusted [10].

SAFETY IN ROBOT ETHICS

The discussion of safety is an all-encompassing debate that represents a multidisciplinary approach. This section aims to discuss safety in terms of the ethical safety of HRI, encompassing emotional factors. At the same time, safety in terms of human physical integrity is a crucial legal discussion that is addressed in the "Legal Challenges" section.

Robots must be designed to avoid harming humans. This is particularly crucial in fields like health care or eldercare, where service robots directly interact with vulnerable populations. The growing role of robots in spheres like eldercare includes tasks such as companionship, health monitoring, and assisting with daily activities. These interactions provide a unique lens to explore ethical implications. Accordingly, robots should be designed to prevent emotional distress that could stem from diminished privacy, treating older adults in a patronizing manner, unclear accountability, decreased human interaction, and misleading emotional responses/formation of emotional dependency/attachments [14]. Similarly, anthropomorphic designs, while fostering trust, can also lead to emotional attachment that risks psychological harm if not managed responsibly [15].

SURVEILLANCE AND DATA PRIVACY

As robots become more prevalent in public spaces, concerns around data protection and surveillance intensify. Service robots, particularly those with advanced sensory capabilities, such as cameras, may collect and store personal data, inadvertently creating surveillance systems. Robots that mimic human social behaviors may encourage people to

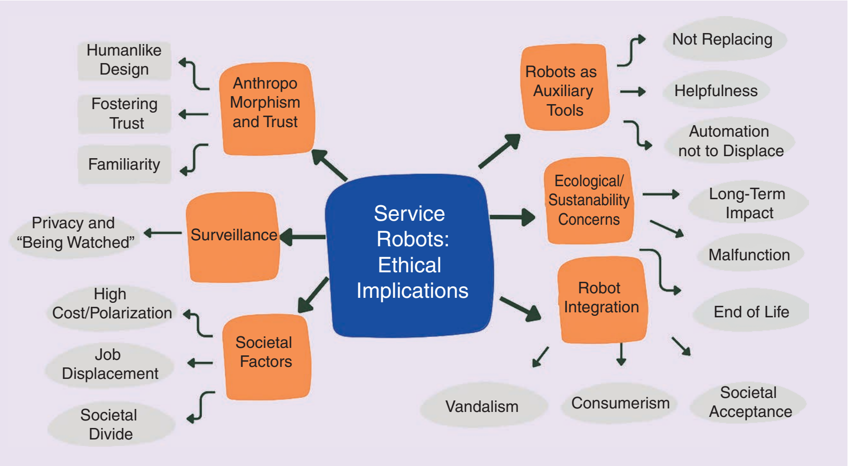

FIGURE 1. The topics collected during the workshops.

share personal information, which can then be stored or analyzed without their full understanding [16].

This is highly relevant for robots processing personal data by design, e.g., robot assistants at municipal service desks that interact with citizens. As conceptualized during the workshops, these robots translate, help fill out forms, or give instructions based on personal requests, hence processing personal data of citizens. In that regard, IEEE 7007-2021 sets up a "data privacy and protection ontology" focusing primarily on ethical aspects and defining processes and agents involved to understand core concepts and relationships [7]. Similarly, ethical and legal guidelines ought to specify who is accountable for errors, misuse, or data breaches involving robots. Clear accountability structures are essential for maintaining trust and protecting individual rights [16]. The "transparency and accountability ontology" (7007-2021) proposes such a structure to define which data must be communicated to whom to mitigate transparency concerns [7].

> "SERVICE ROBOTS, PARTICULARLY THOSE WITH ADVANCED SENSORY CAPABILITIES, SUCH AS CAMERAS, MAY COLLECT AND STORE PERSONAL DATA, INADVERTENTLY CREATING SURVEILLANCE SYSTEMS."

JOB DISPLACEMENT

The ethical challenge of job displacement remains central to discussions about the adoption of service robots. In the workshops, the participants consistently highlighted concerns about how robots and automation could impact the job market, with a key focus on job reduction versus creation. They questioned whether the integration of robots might significantly reduce human jobs and how vulnerable groups might adapt. While automation could eliminate roles, such as repetitive tasks, it also offers potential for new opportunities [17].

Fear of job displacement is often driven by public anxieties and cognitive biases, as discussed during the workshops. These concerns are particularly prevalent among vulnerable groups, such as low-skilled workers and older adults. Individuals in repetitive and easily automated jobs or nearing retirement may feel heightened anxiety due to limited educational backgrounds or difficulty acquiring new skills. This fear stems from both a lack of exposure to potential benefits and the psychological stress of uncertain job stability [18].

Workshop discussions also noted that service robots are frequently designed to complement human labor rather than replace it, often taking on dangerous or undesirable tasks. The participants debated whether multifunctional robots could make humans irrelevant, with the conclusion that such effects depend heavily on context. For example, robots excel at assembly line tasks but cannot replace human empathy and judgment in areas like health care. Efforts to create robots with humanlike consciousness also face paradoxes, as machines cannot replicate subjective human experiences, a crucial aspect of many human capabilities [19].

SUSTAINABILITY

For us, ethical implications of sustainability stem from impacts during all lifecycle stages of an urban service robot and lead back to ethical principles, like human dignity, autonomy, justice, or physical and mental integrity (among others), suggested by the European Group on Ethics in Science and New Technologies [2]. Here, we want to add to the discussion the processes that come before or after the use phase, as their impacts are prone to violate ethical standards. An extensive collection of possible risks during all lifecycle stages is described in the lifecycle assessment (LCA) and social LCA (SLCA), which can be applied to any urban service robots [20], [21]. For the LCA, the ReCiPe method describes impact categories, their damage pathways, and the according area of protection. The areas include damage to human health caused by increases in respiratory, carcinogenic, and noncarcinogenic diseases or malnutrition; damage to the ecosystem caused by damage to terrestrial, freshwater, or marine species; and damage to resource availability caused by increased extraction costs [22]. Robots are prone to have a high impact on all three areas, as the production of batteries and electric motors requires resources that have detrimental process of mining, refining, and production [3]. The impact categories of the SLCA include human rights, working conditions, health and safety, cultural heritage, governance, and socioeconomic repercussions [21]. Any robot serving public missions must be held accountable for possible negative consequences in those categories, which is why we see this as an ethical challenge related to sustainability.

LEGAL CHALLENGES

The deployment of an urban service robot requires careful consideration of both national and European laws. Challenges arising from national law are mostly centered around road traffic regulations, as they currently do not accommodate service robots within the city. Additionally, gaining permission for testing and operation too often depends on individual decisions, making it a cumbersome process with uncertain outcomes [23].

In the Brussels region, adherence to the national road code is essential. Initially, the law required all vehicles or convoys in motion to have a driver, thereby excluding autonomous vehicles. Nonetheless, the royal decree of 18 March 2018 introduced article 59/1, which allows the minister for road traffic, or their delegate, to grant temporary regulatory exemptions for experiments or pilot projects under specific conditions. The Federal Public Service Mobility and Transport agency clarifies that this provision enables the testing of new traffic signs, markings, and technologies within pilot projects, thereby offering the opportunity to trial public service robots as well as fostering the enhancement of robotics. This has particularly been used for trials of automated vehicles.[2]

However, national laws differ, and a complete listing would require too much space. Thus, in the following, we focus on European legislation to explore the categories of operational safety, data protection, liability, and sustainability and how they affect the deployment of a service robot for public missions, as intended by some administrative organizations in the Brussels region. We present an overview of the relevant legal frameworks in Table 1.

OPERATIONAL SAFETY

The legal challenge in ensuring overall safety is primarily related to hazards emerging from the complex and dynamic environment posed by public spaces and interaction with humans. As of now, the European Union (EU) Machinery Directive, which will be replaced by the EU Machinery Regulation (MR) on 20 January 2027, covers operational safety that also applies to the deployment of urban service robots. The legislation on machinery safety is complemented by International Organization for Standardization (ISO) safety standards mostly related to industrial robots but also by ISO 13482:2014, which introduces a set of safety standards concerning HRI for personal care robots, mobile servant robots, physical assistance robots, or person carrier robots.

However, both the MR and the supplementary ISO standards remain somewhat vague. Although ISO 13482:2014 specifies what to do when there are objects and barriers present or physical characteristics such as snow, dust, water, slopes, steps, and uneven ground, it does not touch upon factors related to public spaces like crowd density, unspoken social norms, and misbehavior, caused by a lack of understanding of the basic science behind HRIs at the time of its publication [24]. Those factors have ethical implications and play an important role not only for the functionality of the robot but also for acceptance by citizens. Operational difficulties due to crowds and vandalism were mentioned several times during our workshops.

The MR offers more support by recognizing the category of autonomous mobile machinery. It demands the assessment and prevention of hazards due to close contact, namely, human–machine interaction and human–machine coexistence in a shared space without direct collaboration [25]. Furthermore, it mandates a conformity assessment to make sure autonomous mobile machinery is compliant with the regulation's health and safety requirements. Yet, certain aspects remain ambiguous. For instance, while both the MR and the EU Artificial Intelligence (AI) Act (AIA) mandate human oversight, the MR lacks specificity regarding when and how the oversight should be conducted [25]. This is a concern in use cases where no technical personnel are present, like welcoming/guiding robots in city centers, rendering a design and deployment concept more complex.

Finally, we want to mention two additional factors regarding operational safety. The software of safety components deemed high-risk AI by the AIA triggers a third-party conformity assessment under the MR. This refers to testing, certification, and inspection done by a designated body on behalf of the national notifying authority, precluding any "in-house" conformance assessments [26]. Second, there is a required cybersecurity certification. This implies that urban service robots must have a certificate of conformity from a relevant cybersecurity certification scheme following EU regulation 2019/881. This safeguards against potential threats like distributed denial-of-service attacks and command manipulation, ensuring safe operation in urban environments [25], [27].

DATA PROTECTION

It is evident that the use of cameras by service robots for navigation in public spaces introduces legal challenges relating to privacy, specifically, the collection of data and compliance with the stringent General Data Protection Regulation (GDPR). The regulation is applicable if a service robot processes personal information that directly or indirectly identifies a particular person, even if the data are pseudonymized or encrypted. If the GDPR is applicable, the following data

TABLE 1. Relevant legal frameworks by the European Union.

LEGISLATION	REFERENCE
Machinery Regulation	Regulation 2023/1230 of the European Parliament and of the European Council of 14 June 2023 on machinery
Artificial Intelligence Act	Regulation 2024/1689 of the European Parliament and of the European Council of 13 June 2024 laying down harmonized rules on artificial intelligence
General Data Protection Regulation	Regulation 2016/679 of the European Parliament and of the European Council of 27 April 2016 on the protection of natural persons regarding the processing of personal data and on the free movement of such data
Proposed product liability directive	European Parliament legislative initiative on liability for defective products, 2022/0302 (codecision)
Ecodesign for Sustainable Products Regulation	Regulation 2024/1781 of the European Parliament and of the European Council of 13 June 2024 establishing a framework for the setting of ecodesign requirements for sustainable products
Corporate Sustainability Reporting Directive	Directive 2022/2464 of the European Parliament and of the EropeanCouncil of 14 December 2022 amending regulation 537/2014, directive 2004/109/EC, directive 2006/43/EC, and directive 2013/34/EU as regards corporate sustainability reporting
Corporate Sustainability Due Diligence Directive	Directive 2024/1760 of the European Parliament and of the European Council of 13 June 2024 on corporate sustainability due diligence and amending directive 2019/1937 and regulation 2023/2859

[2]https://www.code-de-la-route.be/fr/regulation/amendment/download/hilr2ujaa1

processing principles need to be adhered to by the data controller: lawfulness, fairness and transparency, purpose limitation, data minimization, accuracy, storage limitation, integrity and confidentiality, and accountability.

The data controller, presumably the robot manufacturer, as well as potential processors the controller may work with, must justify their processing on one of the legal bases listed in article 6 of the GDPR to be considered lawful. This can be based on consent, legal obligation, performance of a contract, public interest, legitimate interest, or vital interest. For urban service robots, this is likely to be on the grounds of "public interest" or "legitimate interests." The public interest ground applies if the processing is necessary for a task carried out in the public interest or in the exercise of official authority entrusted to the controller. So, if deployed by the City of Brussels with the goal of becoming a smart city, it could be considered in the public interest [28]. On the other hand, under legitimate interest, the processing of camera images can be deemed lawful only if the interest is considered legitimate and necessary and does not override the fundamental rights of individuals. Consequently, the difficulty for the data controller will be the need to prove that the purpose of the robot's cameras pursues a legitimate interest that overrides the right to privacy.

The balance between privacy rights and legitimate interests should be determined through a balancing test, which considers whether individuals would reasonably expect their data to be processed in a certain way, the nature of the personal data, and the likely impact of the processing [29]. The processing is more likely to be justified if it aligns with this expectation and does not cause significant harm or discomfort [29]. Cultural and societal expectations can also support the controller's case. Generally, if the controller can show that its interest benefits society, it strengthens the controller's grounds for processing personal data [30]. For instance, a service robot using cameras to empty garbage bins is likely justified, as it serves the public interest.

Along with the requirement of a legal basis, camera images may be retained only for the duration required to fulfill the purpose of data processing. Individuals need to be aware of data collection and granted access to the data. Robot manufacturers must ensure that these data protection rules are thoroughly considered during design and deployment. This has proved to be a difficulty in other public robots, for example, in delivery robots [31].

LIABILITY

The deployment of an urban service robot introduces several challenges regarding its autonomy and responsibility. An overall question, also raised in the workshops, is, What happens if the robot causes harm to a human, and who is held liable in this scenario? National and union liability frameworks, due to their human-centered nature, are challenged by this question and the characteristics of robotics. Certain features complicate linking harm to human behavior, which can allow for a fault-based claim under national laws. This implies that victims might miss out on adequate compensation if proving responsibility claims is difficult or prohibitively expensive [32].

The new EU product liability directive, set to be transposed into domestic legislation by the end of 2026, shows progress regarding the liability question of new technologies' autonomous decisions. It creates a framework to accommodate compensation for injured people and alleviates their burden of proof. Liability will fall on the "economic operator," which can be the manufacturer, distributor, importer, authorized representative of the manufacturer, and provider of remote order processing services. Ultimately, these increased efforts toward addressing liability and new technologies, with the introduction of a more accommodating framework, could positively impact the deployment of urban robotics.

SUSTAINABILITY

The EU developed several laws concerning the sustainability of a product or company that will also apply to any type of robotics. This relates first to the recent Ecodesign for Sustainable Products Regulation that came into force on 18 July 2024. It applies directly since a regulation needs no transposition into national law and affects any product with a high environmental impact as well as information and communication technology or other electronics, which includes robotics or necessary intermediates. Second, the Corporate Sustainability Reporting Directive, from 1 January 2023, was initially aimed at the 500 biggest publicly listed companies but gradually extended to small and medium enterprises with a capital market orientation from 1 January 2026. It directs companies to report on their concepts, risks, and results regarding social and ecological sustainability. Finally, the Corporate Sustainability Due Diligence Directive regulates actions and reporting on how companies determine their impacts on social and ecological sustainability and take countermeasures to avoid jeopardizing the Paris agreement or violating human rights. The directive came into force on 25 July 2024 and must be transposed until 26 July 2026. It also aimed at bigger companies at first (>5,000 employees) but gradually extended to smaller ones (>1,000 employees). The last two frameworks might not be legally binding, as certain conditions have to be met by the producer. Nonetheless, we recommend complying with and understanding them as guidelines for corporate responsibility and sustainability.

OVERVIEW

Complying up with the many regulations is a challenge of its own, and we therefore list the ones we identified as relevant and used in the preceding sections in Table 1.

OUTCOMES

Our research and the stakeholder involvement also offered insights on how to address the challenges and develop an understanding of them. To give an overview of the key challenges, we created the diagram in Figure 2. It sets urban service robots at the intersection of ethics, legislation, and sustainability and sorts the challenges accordingly. A lot of the aspects coming up in our research and during group discussions are multifaceted and can hardly be appointed to one category only. Therefore, we tried to split some of the terms into fragments that fit more easily into the three domains. For example, environmental impacts of robots include impacts on human health through, e.g., toxicity and impacts on the natural environment, as in resource extraction, and are the subject of legislation, e.g., the Corporate Sustainability Reporting Directive. The same is true for subjects of the GDPR. For instance, surveillance can trigger the feeling of being watched, whereas privacy and transparency also have an ethical connotation but are subjects of existing regulation. Finally, data protection refers only to the legal domain, as the discomfort of surveillance, the basic human need for privacy, and the moral issue of transparency are already accounted for in the diagram.

This can by no means be an exhaustive representation of challenges faced by urban service robotics but, rather, a first approach to support an understanding of the intricacies posed by this complex task.

WORKSHOP CONCLUSIONS

Each workshop ended with a question trying to capture the participants' work and discussions. The participants' answers were documented and contributed to our findings. This also led to our lessons learned, as summarized in Table 2.

- *What makes Brussels smart?* "Digital tools should be easy to use by all," "democratize participation," "centralized data," "connectivity and interdependency of all domains," "access to information and education by all," "collaboration inside Brussels region," "increase digital maturity and confidence in health care," "a city that is adapted to its inhabitants' diversity and that understand their individual lived experiences"
- *What makes a robot relevant?* "It must be accessible to all and benefit the society as a whole," "when it reduces the CO_2 footprint," "a simple solution to problem," "one that considers the root cause and doesn't treat the symptoms," "a good understanding of the problem," "when all stages, especially the end of life, are thought through and sustainability standards are applied"
- *What makes a good prototype?* "It has to be useful and clearly show its functions," "giving an idea of the final product and how it can be useful," "it gets you forward in the process of developing an idea and helps to exchange feedback, criticism," "it furthers teamwork and gives a vision of how to reach the goals."

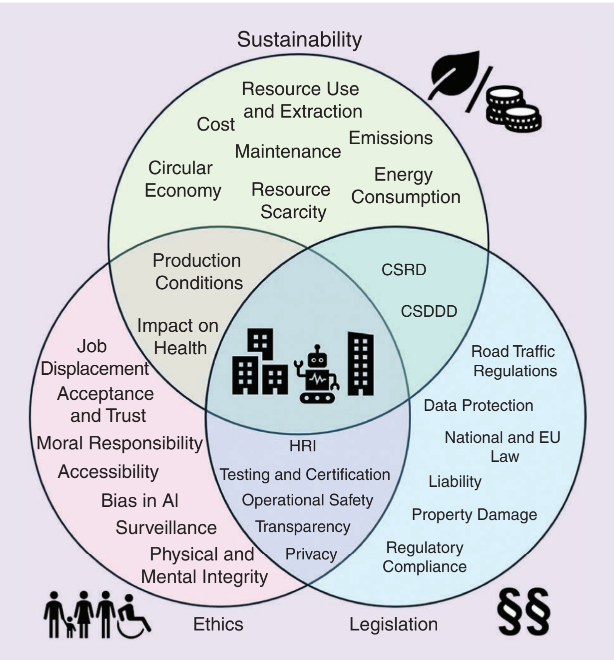

FIGURE 2. Urban service robots at the intersection of ethics, law, and sustainability. CSRD: Corporate Sustainability Reporting Directive; CSDDD: Corporate Sustainability Due Diligence Directive.

WORKSHOP CONCEPTS AND PROTOTYPES

The first workshop yielded a list of the three most relevant challenges within the five given domains of a smart city.

1) *Mobility*:
   - enable easy and seamless switches between transport modes (foot, bus, tram, metro, and car)
   - remove physical and digital barriers of public transport
   - protect pedestrians and foster bicycle safety and comfort
2) *Well-being*:
   - empower self-awareness of basic health and nutrition
   - detect and communicate early-stage illnesses efficiently

TABLE 2. Lessons learned from the stakeholder involvement.

ASPECT	EXPLANATION
Different perspective and focus	Observation of participants' designs gives insights on their perception of the problems and what they deem to be relevant. Although the concepts and prototypes may not make it as a final design, they will contain important functions and features.
Perks of participation	The event itself, with its educational and active sessions, increases the engagement of people with the whole subject. Listening to people's concerns and discussing and developing ideas together conveys a feeling of participation and being taken seriously. Involvement increases familiarity and, thus, acceptance.
Goal-dependent workshop structure	Depending on the goals or requirements for the outcome of such an event, the structure should be modified. Our approach was broad and explorative, for a first iteration. Tweaking the time and timing of workshops can help to steer outcomes and have a better connection/transmission of the topics of each session (double diamond).
Goal-dependent participant composition	In the same way, a variation on the homogeneity of participants can put a focus on solutions for a targeted domain or preidentified problem statement. Also, the addition of participants or guiding staff for design processes might increase the quality of the outcomes.

- improve physical and mental health for lower socioeconomic classes

3) *Environment*:
   - automate trash sorting and collecting
   - prevent and deal with animal pests (snails, rats, and foxes)
   - improve drinking water quality
4) *Infrastructure*:
   - improve the work quality of public servants (firefighters and so on)
   - increase the frequency of infrastructure maintenance (roads, sewers, and so on)
   - accelerate public infrastructure and construction projects
5) *Governance*:
   - help citizens efficiently and inclusively at service desks
   - offer continuous guidance to encourage ecotourism
   - make relevant public data available to citizens.

The participants then formed groups and chose one of the challenges to elaborate concepts and finally prototypes. Figure 3 displays six prototypes that can be described as

1) *One robot to solve them all*: Assistive robot for public transportation accessibility, cleaning/maintenance, and information
2) *Communication and language assistive robot for administration*: Personal assistant to help citizens, visitors, and clerks with translation, body language, and data handling
3) *Guiding stick*: Assistive physical tool to give information and guide citizens at municipalities
4) *AppPTG (Public Transport Guide)*: Hub with physical tools to help organize and plan commutes and trips more efficiently and optimize travel time
5) *SearchE*: Small mobile robot to roam villages and detect street and underfloor piping maintenance issues
6) *Water solution for the masses*: Bundle of digital and physical tools to position Brussels as the capital of pure water.

FIGURE 3. Cardboard prototypes for urban service robots. (a) Public assistant robot, (b) personal help desk assistant, (c) guiding tool at municipalities, (d) Public Transportation Guide & Hub, (e) underfloor maintenance surveillance robot, and (f) tools and concept for clean water management.

PRINCIPLES AND RECOMMENDATIONS

In the next step, we developed a set of principles capturing the challenges essential for the design and development of responsible service robots and their integration into public life. We complemented the principles with recommendations for implementation (Table 3). Those stem from research and observations made during the workshops.

USER PERSPECTIVE

During practical assignments, the participants had a strong desire to create a robotic solution that overcomes inequalities and increases accessibility to all citizens. One example is the idea of a communication assistant for municipalities to tend to language barriers and inform citizens of their rights and available social benefits. During the prototyping, they focused on functions like height adaptability for interactions to be on eye level and serving both citizens and civil servants for higher quality of service and work. We also noticed how their engagement grew as we evolved from mere problem statements to more concise concepts and tangible prototypes. Noticeably, their motivation to consider a robotic solution rose, which in turn could benefit trust and acceptance toward such technologies.

In another exercise, we discussed existing service robots and asked the participants to rate the relevance of the tackled problem and the fit of the presented solution. We translated the outcomes into three design principles. The first is relevance. For a robot to be relevant, it must concern itself with solving the root of a problem, not the symptoms, requiring a sound understanding of the problem itself. Also, the approached problem must be relevant, which was defined as a problem related to the well-being of citizens or environmental challenges. Second, simplicity is important: "Technical devices sometimes seem so complex and overloaded with functions that it actually causes more effort to use them instead of making things easier and efficient. We need simple solutions solving an issue and not making three new ones." The third principle is welfare value creation. A robot should be accessible to all and benefit the entire society. This can be accomplished by increasing the well-being and quality of life for a majority of the citizens and making the city more inclusive by decreasing inequalities and increasing accessibility for vulnerable minorities.

ETHICAL PERSPECTIVE

Furthermore, we found various principles in the literature that relate to the intersection of ethical considerations and innovative technologies, such as AI and robotics (e.g., [2] and [8]). Yet, we see our contribution in pointing out the principles that we identified in direct relation to the deployment of urban service robots and will not list the entirety of principles found.

Transparency, including clear communication about robot limitations and capabilities, is fundamental for building public trust [10], [17]. Public education and socialization initiatives help individuals understand and interact safely with robots, fostering an informed and responsible user base. Closely related is the principle we named *public relations*. Society and robotics evolve together, each shaping and responding to the other. This dialectical relationship should be encouraged, allowing societal values to inform the ethical frameworks of HRI and vice versa [10]. This adaptive approach is crucial for ensuring that ethical guidelines remain relevant and responsive to recent insights and developments. They can also raise trust, which was reflected by participants who expressed their trust in the compulsory licensing of technical products in terms of safety. Norms, such as IEEE 7010-2020 or 7007-2021, provide metrics for the impact on well-being and an ontology to enable development in accordance with ethical principles. Incorporating such norms could increase conformity with ethical values, raising trust and acceptance further. To facilitate that, we want to stress the importance of stakeholder involvement by appointing it as one of our principles. Including diverse stakeholders in the design, development, and deployment processes ensures that robots are aligned with societal values and address the public's concerns. Stakeholders should include representatives from sectors such as government, industry, academia, and community groups [17]. The integrity of citizens, both physical and mental, is paramount. It can be affected by safety issues due to operation but also by surveillance, misuse, job displacement, or trust and acceptance issues. The behavior and programming of a robot as well as the robot designers or treatment of robots must follow a code of ethics to limit or negate these risks [33]. This is a complex task calling for a thorough examination of each individual use case.

LEGAL PERSPECTIVE

The identified legal challenges mostly require compliance with existing laws stating design imperatives rather than recommendations. Concerning national law, we advise involving lawmakers and local politicians in the development process. This fosters their comprehension of technology and communicates benefits to increase their willingness to grant permissions. It could even serve as a precedent for shaping future legislation in favor of a technology. For necessary data protection, the EU encourages the inclusion of data protection measures in the earliest design stage or handling any personal data with the highest privacy protection. A data protection impact assessment provides a tool to analyze risks and mitigate them by catering to data protection by design. In terms of liability, the EU gives recommendations and underscores the importance of establishing a compulsory insurance scheme and compensation fund as well as transparent communication of the two to consumers. This is described in the GDPR (see Table 1).

DISCUSSION

In the previous sections, we talked about the ethical, legal, and sustainability challenges that are related to deploying a service robot for public missions or generally in public spaces. Our overview of relevant legislation (Table 1) and design principles coupled with recommendations (Table 2) is intended to support designers and developers in managing the number and variety of challenges. However, the process of using tools

TABLE 3. Recommendations for urban service robot design.

PRINCIPLE	RECOMMENDATION
Relevance	Divers/interdisciplinary design team
	Environmental and functional analyses
	Structured design process
	Emphasis on early development phase
	Stakeholder research
	User feedback/participation
Simplicity	Design for ease of use/maintenance
	Modular design for repairability/reuse
	Design for recyclability
	Focus on core functions
	User feedback/participation
Welfare value creation	Design for public services/interest
	Human-centered design
	Civil servant involvement
	Innovate from demand side
	Extensive stakeholder research and involvement
Transparency/ public education	Clear and transparent design
	Communicate intentions and functions by design
	Motion design
	Lighting/signaling
	Accessible information and promotion of robot
Public relations	Expert consultation on standards and ethics
	User feedback/participation
	Networking/cooperation with civil organizations
Stakeholder involvement	Stakeholder research
	Cocreation/design workshops
	Citizen jury
	Surveys/interviews
	Bottom-up innovation process
Integrity	Divers/interdisciplinary design team
	Expert consultation
	Human-centered design
	Lifecycle engineering (LCA/SLCA)
	Real-world labs/testing
	User feedback/participation
Legal compliance	Involve lawmakers/local politicians
	Design for data protection
	Data protection impact assessment
	Establish compulsory insurance scheme
	Create compensation fund
	Transparency on insurance and compensation

like this poses a challenge of its own. Therefore, we want to discuss limitations affecting feasibility as well as benefits from incorporating the given recommendations.

The development process of a mechatronic and cyberphysical product, such as an urban service robot, is already complex and associated with many working steps from different disciplines and experts when focusing on functional requirements only. Introducing new design dimensions as we suggested will inflate the process and increase the time to attain a viable product concept for the market. As we suggested, expert consultation and the forming of more diverse and interdisciplinary teams will further increase the cost of the product. Additionally, more goals and requirements, and, hence, more assessment criteria, will increase the complexity of the process even more. Although we focused on ethical, environmental, and legal challenges, it is of importance to heed the economic dimension, as it is essential to successfully realize a robotic project. However, incorporating ethics in the design phase cannot be omitted as a tradeoff, suggesting that increased costs of robot development must be financially supported (e.g., through public procurement and national or European funding).

> "PUBLIC EDUCATION AND SOCIALIZATION INITIATIVES HELP INDIVIDUALS UNDERSTAND AND INTERACT SAFELY WITH ROBOTS, FOSTERING AN INFORMED AND RESPONSIBLE USER BASE."

Once a thorough analysis is set in motion in early design stages, benefits are at hand. Financially speaking, the dilemma of design illustrates that graphically. Necessary changes in the later stages of a product caused by lack of information come at much higher cost and time expenditures. This lack of information can be navigated by various methods to acquire data on the surrounding system, requirements, and stakeholder groups. Furthermore, ample assessment in the domain of ethics can increase trust and acceptance in the product and thus boost market adoption and success. It also avoids the overall risk aversion of a failing product, unwanted impacts, or misuse, as conflicting goals become visible early on, and tradeoffs can be evaluated with more information at hand.

As our recommendations show, we advocate stakeholder involvement and participation in the design process. It is important to note that these methods do not guarantee success. In our workshops, we saw how some participants were not as engaged as others and how some concepts already existed or did not adhere to the principles the participants themselves had established earlier. For a reimplementation of the method, we suggest confining the area of interest and focusing on more homogenous groups of stakeholders one at a time. For concept creation, additional experts guiding the groups could boost the quality of the outcome. Also, the problem statements derived from our first session showcased how some of tasks do not require a robot, as it is still a complex and costly solution, especially with respect to sustainability. Responsible robotics sometimes leads to not using a robot at all.

We also have to clarify that for stakeholder involvement, we have so far mentioned only groups that relate to the use phase of the robot. People dealing with the extraction of resources, production of materials, and intermediates as well as waste disposal or remanufacturing and recycling are important stakeholders that are too often left out. Although methods like the SLCA help to facilitate awareness and understanding, designers are limited in managing these deficits by the choice of companies and their code of conduct further down the value chain. It is up to companies and regulatory policies to facilitate more ethical and sustainable production. This in turn raises the essential question of whether we can ethically account for such social and environmental deficits in continuing robotic developments for the benefit of our quality of life.

In the workshops, the concern of legal clarity was voiced by the civil servants as a barrier to final implementation. The regulations we mentioned in the "Legal Challenges" section can form a good foundation and will potentially be proved sufficient. However, challenges regarding public spaces, like crowd management; proxemic rules; other road users; peoples' misbehaviors (e.g., vandalism), as referred to in ISO 13482:2014; or the allowance to be deployed on sidewalks, remain unclear. This must be addressed in the future and would benefit from collaboration between policy makers and robotics experts on specific use cases to recognize associated risks, complexities, and effects. This could be beneficial for the legal framework by creating a clearer depiction of robotics.

CONCLUSION

In conclusion, the deployment of service robots for public missions, in a city context, presents a multifaceted challenge that intersects with ethics, legislation, and sustainability. Our research and stakeholder involvement have highlighted key challenges and provided insights into addressing them. The principles and recommendations we developed aim to guide the design and development of responsible urban robots, ensuring that they are relevant, simple, and beneficial to society.

The complexity of developing such robots is compounded by the need to integrate ethical, environmental, and legal considerations into the design process. While this increases the time and cost of development, it is essential for creating robots that are trustworthy, accepted by the public, and compliant with regulations. Early and thorough analysis can mitigate later-stage costs and foster market adoption by building trust and acceptance.

Stakeholder involvement is crucial in this process, though it comes with its own set of challenges. Engaging a diverse and interdisciplinary group of stakeholders can enhance the quality of the design but also requires careful management to ensure meaningful participation. Additionally, the inclusion of stakeholders from all stages of the robot's lifecycle, from resource extraction to disposal, is necessary to address the broader social and environmental impacts.

Legal clarity remains a significant barrier, particularly concerning the deployment of robots in public spaces. Collaboration between policy makers and robotics experts is essential to develop a legal framework that addresses these challenges and supports the safe and effective integration of robots into society.

Ultimately, the responsible development of urban service robots requires a balanced approach that considers ethical, legal, and sustainability aspects. By adhering to the principles and recommendations outlined in this article, designers and developers can create robots that not only meet functional requirements but also contribute positively to society and the environment.

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