Making Sense of Public Space for Robot Design

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***Abstract*—If robots are to be deployed in public places, we need to understand what factors their design should consider. Informed by sociological studies of urban settings, particularly the work of William H. Whyte and the *Street Life Project*, we describe four characteristics of public places that affect and are affected by robot design: (1) *localism*—how robot design aligns with the identity, culture, and character of the place(s) they reside within; (2) *environments*—the physical characteristics of the environment in which public robots operate; (3) *activities*—consideration for the various daily, occasional, and situational activities that are tied to place(s) robots inhabit; and (4) *sociability*—how people collectively and individually relate to, interact with, and make sense of robots deployed in public places. Throughout, we illustrate these characteristics with examples drawn from empirical studies of public robots. We discuss how these key characteristics of public places can inform HRI design.**

***Index Terms*—Human-robot interaction; design frameworks; public robots; urban robots; public mobile robots**

I. INTRODUCTION

With multiplying instances of robot deployment on urban streets [1, 2], shopping complexes [3], and airports [4], there is a need for HRI research to improve its understanding of how public deployments of robots will affect and be affected by the nature of public places. These places are highly complex even in the absence of robots, as demonstrated by the large and growing body of literature on urban *placemaking* [e.g. 5, 6, 7]. Putting robots in public places involves a multitude of new considerations that both respect and appreciate that complexity. We need to mature the approaches of HRI towards public robots by taking an interest in research that contends with the design of/for public places and of/for public interactions.

The purpose here is to synthesise our HRI research on public robots [1, 8, 9] with work from urban sociology and Human-Computer Interaction (HCI) on *placemaking* (*i.e.*, the design, improvement, and purposeful use of public places) [10, 11]. We offer a simple but implicative set of *characteristics of/for public spaces* that robot-oriented research can use to reflect on present design challenges. Our characteristics build on a tradition of understanding and designing for placemaking initiated by William H. Whyte [12] and continued via organisations such as the *Project for Public Spaces (PPS)* [13].

We filter placemaking literature through present concerns around robots in public to reach the following key characteristics: *localism*—how robot design addresses the identity, expectations, and culture of local places they are intended for; *environments*—how the physical qualities—whether designed or emergent—of the environment impact and are responded to by robot design; *activities*—how robot design takes into account both "normal" and "exceptional" activities that take place in public places and transform the nature of those places momentarily or rhythmically; and *sociability*—how design considers the way people in public places practically relate to, interact with, make sense of robots as they find them.

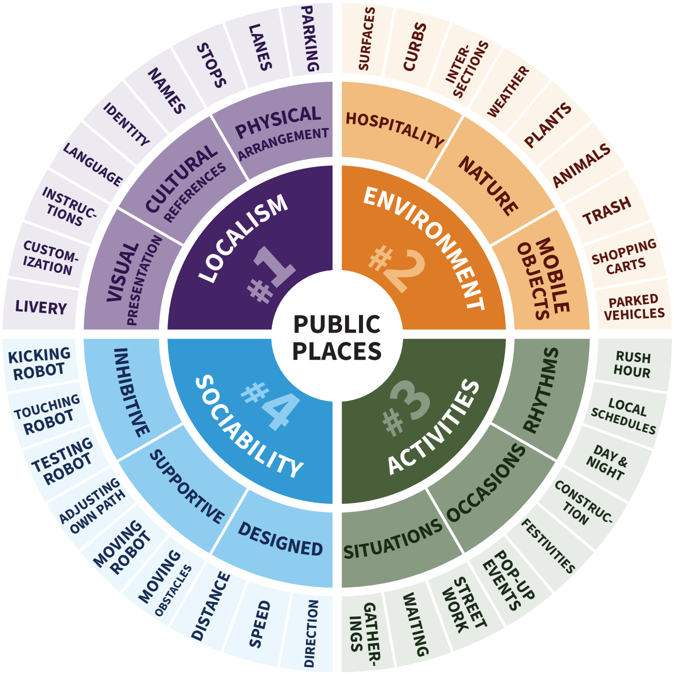

Fig. 1: Four characteristics that the design of public robots should consider. Examples presented in §IV are mapped onto this and annotated following the same colour mapping. Adapted from PPS's *The Place Diagram* [13]. (Also see https://robotsinpublic.org/making-space-framework).

We integrate these characteristics into a placemaking framework grounded in concrete examples, contributing to designerly HRI [14] with "strong concepts" [15].

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II. LITERATURE REVIEW

As HRI research moves increasingly "out of the laboratory" and into public places, previous work in urban studies, urban sociology, as well as HCI gains greater relevance. We review this emerging trend in HRI, then explore HCI research on technology in public, and finally return to notions of placemaking.

A. HRI in Public

Recent work in HRI has identified the potential significance of *incidentally co-present persons* [16] for the design of robots in public places. These are people normally outside the purview of HRI design, people who are co-present in reality yet typically absent from design consideration. Co-present others are significant in that their identification opens up a wide range of research on the sociality of public places in general. The relevance of co-present others in public is becoming a pressing issue for HRI as highlighted by an emerging body of work that examines encounters between people and robots "in the wild" (cf. [17]). This includes observations of commercial robot operations [1, 2, 18, 19], studies of autonomous shuttle buses as part of public transport [9, 20, 21, 22, 23], trial deployments of novel robots [24, 25], and studies of user-generated videos (*e.g.*, YouTube) capturing human-robot interactions [26, 27], as well as more traditional use of stimulus material to understand response to robots in public [28]. Although these studies illuminate the complexity of public places, more structured design-oriented thinking that builds on this work is needed.

B. Designing Public Technologies

Designing for interactive technologies deployed in public is not new, and HCI research has a broad set of literature that addresses just this. Previous work has involved studies and deployments of systems in public or semi-public places [*e.g.*, 29], as well as developing frameworks and principles for design [*e.g.*, 30]. By studying examples of large public display media screens, HCI has highlighted the difficulties with embedding technology into dynamically changing local contexts, which both influence and are influenced by technology [31]. Most critical to us is work drawing conceptual distinctions between *spaces*—as material, geometric environments—and *places*—formed by the human activities that take place in those spaces [32, 33]. Recent HCI work has started to explore how robots could be part of urban places [34]. The interplay between robots and the city raises ethical questions related to social justice and responsible design, including how robots impact urban life and how they could foster desirable qualities of life in the city [35]. We need an approach that considers how HRI incorporates place, place-ness, and placemaking as aspects of design, advocating for *place-centred design* that can inform discussions of how robots impact and are shaped by the local place they are deployed in.

C. The Design of Public Places and Placemaking

Our notion of placemaking [10, 11] is drawn from the pioneering work of William H. Whyte and his team in the *Street Life Project* [12, 36] and continuations of this work by PPS. Whyte's observational studies of social life in *small urban spaces* such as plazas, parks, and shopping areas highlighted the factors contributing to their success or failure, including the built environment (*e.g.*, seating; steps), the weather (*e.g.*, sun; wind), social behaviours (*e.g.*, talking on street corners), how social issues are handled (*e.g.*, homelessness; drug addiction), and what activities take place (*e.g.*, food vending; pop up concerts by buskers). Whyte's observations, such as identifying "sittable space" and optimal heights for seating [12, p.28], or observing just where people decide to stop for conversation in a flow of pedestrians [12, p.21], illuminate the key characteristics of what makes such spaces into *places* [32].

We do not suggest that placemaking is unheard of in HRI: for instance, the Woodie urban robot [37, 38] and the speculative design of BubbleBot [39] explicitly engage with placemaking in their design. We also note that researchers in other fields, including social interaction [40] and urban mobility [41, 42] have begun to examine autonomous and robot technologies in public places.

III. OUR APPROACH TO PUBLIC ROBOTS

The term "public robot" covers a wide variety of possible definitions. We build on a normative definition for "public-area mobile robot (PMR)" from the draft ISO 4448 standard [43]:

> A *public mobile robot (PMR)* is a wheeled or legged (ambulatory) ground-based device that is designed to travel along public, shared, pedestrianized pathways without the use of visible human assistance or physical guides.

Grush [43] provides a comprehensive description of the unique aspects of PMRs, particularly their implications for vulnerable individuals. To inclusively discuss the interactions of public robots with people and the places within which they operate, we use a simpler working definition, as follows:

> A *public robot* is any autonomous mobile ground-based robot that people might use or encounter exclusively in public places.

We deliberately exclude drones, but if flying robots are specifically used to interact with people at near-ground heights, many of the ideas discussed in this paper may still apply.

To inform our four characteristics, we build on several in-depth field studies of Starship delivery robots as well as EasyMile and Navya autonomous shuttle buses (see Fig. 2 for depictions), which we conducted in the past five years [1, 8, 9]. We cross-reference and contrast these studies with observations from different sites in Europe and the USA to produce more general characteristics. Although our field studies were conducted in an inductive manner, developing concepts from specific observations, we take an abductive stance in this work. In other words, we use characteristics of great public places identified by the work of Whyte and the PPS as a starting point for our conceptual formulations, and further develop these through our observations. We used the PPS's *The Place Diagram* [13] to formulate four characteristics that the design of (great) public robots should consider.

IV. Four Characteristics for Public Robot Design

Each of the characteristics below corresponds to a quadrant in Fig. 1. We start with **localism**, focusing on the robot as a physical entity in a place (which is the least directly related to Whyte's descriptions). We then go deeper into the "place-ness" of place, looking at the **environment** and the **activities** that characterise public spaces, concluding with **sociability**, highlighting *interactions* between people and public robots.

A. Localism

Localism describes how the robot matches the character of the place in which it is operating. In contrast to an anonymous, clean, or neutral space, place-ness is established by human practices [32], signalled by the use of local language, signage, customs, etc. Current public robots deployed for commercial purposes are often adjusted to the character of the local place by choosing specific forms of *visual presentation*; the use of *cultural references*; and adjustments to the *physical arrangement* around the robot, as illustrated in Fig. 2.

Visual presentation, such as distinctive livery (see ⓐ in Fig. 2), can be used to present robots as "belonging" to a local environment. Similar to rental bikes, scooters, and public transport vehicles, robots may be made visible as part of a service fleet, recognisable from a distance. Some customisation may be less permanent; for example, stickers may adjust robots to seasonal festivities specific to the locale ⓑ. Signage on the robots may also be used, for example to provide instructions in the local language ⓐ, ⓒ.

Cultural references tie public robots to local norms. Instructional texts reflect local linguistic practices, (*e.g.*, bilingual information on an international campus ⓐ). References to local characters may shape the robot's identity. For example, on a US campus, delivery robots are made at home by referring to the local mascot ⓒ. In Sweden, a country with a strong first-name culture, self-driving shuttle buses were given crowd-sourced nicknames (printed above the windows ⓐ, ⓓ).

Local placemaking practices can also extend to ways of integrating the robot with local *physical arrangements*. For self-driving shuttle buses, stops that are specific only for those shuttles are marked with custom stop signs ⓓ. Coloured dots were painted to mark their presence in a mixed traffic area shortly after starting operation, indicating a sense of legitimacy and presenting their movement trajectory in the space ⓔ. Delivery robots present similar examples. In Finland, supermarkets painted parking areas where robots wait for the next order of food delivery ⓕ. The robot areas were then signed as forbidden for bikes. In the UK or Estonia, the same robots park in specific zones but are *not* marked, reflecting the nature of these locally managed aspects of placemaking ⓖ.

Localism parallels a phenomenon described in the literature on telepresence robots, often decorated by their users with scarfs, banners, or name tags as a way of incorporating them into the specific setting [44]. Designers may want to explore how to support local customisation, including borrowing methods from service design and marketing to effectively communicate the robots' presence [45]. Robots as part of larger fleets bear similarities to mobility technologies, including e-scooters, rental bikes, and taxis. Urban designers, planners, and architects may provide valuable insights into how to fit robots into local environments. Embracing localism may also involve exploring responsible innovation [35] and social justice [46] in the design of robots for urban settings.

B. Environments

The physical characteristics of the **environment** affect how robots move in them. Whyte describes at length how the weather and the built environment shape the experience of public places, characterising how social spaces in a city feel.

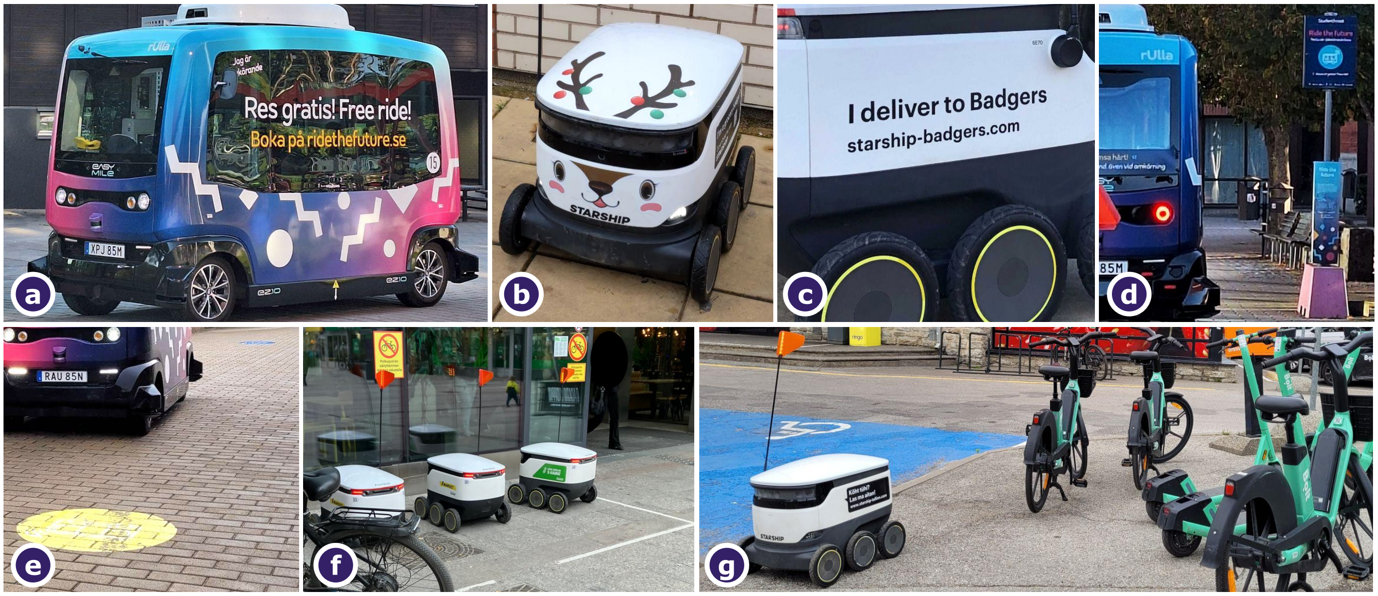

Fig. 2: *Localism.* ⓐ Different entities of self-driving shuttle buses are marked as part of the same fleet by coloured foliage. ⓑ Delivery robot with seasonal decoration. ⓒ Delivery robot text referring to the local mascot. ⓓ, ⓔ and ⓕ The infrastructure around robots includes signage and floor painting. ⓖ The robot parked among rental bikes and scooters.

For example, he described how areas can be made welcoming (or not) by different kinds of surfaces (*e.g.*, spikes on benches to prevent homeless people from sleeping on them) [12, p.29]. We also discover that for robots, the specific environment can play an important role in their public deployment. We divide this into three further subcharacteristics: the *hospitability* of the built environment and its physical infrastructure; *nature*; and *mobile objects*. All are illustrated with examples in Fig. 3.

A persistent concern for the design of public places is how hospitable they are to people—consider long-running arguments over urban planning and design prioritising cars over humans. Such discourses are highly pertinent for the introduction of robots in public, which complexify such issues—we describe this as robot *hospitability*. Environments are simply not designed for robots; for example, they can be very difficult to navigate using existing sensors and wayfinding techniques. Uneven surfaces, sometimes intentionally designed to make public places more accessible to people, can cause reductions in speed or even emergency braking for robots ⓐ. Steep roads or high curbs can be difficult to climb for robots ⓑ, and some obstacles can require manual takeover. Crossing the road is already difficult, and challenging traffic conditions can cause robots to get stuck at intersections and driveways.

Whyte also describes how *nature*—including trees, parks and changing shadows as the sun moves during the day—shape the quality of the human experience [12, pp.40-44]. Natural features of environments, such as weather, can affect robot operation, but for very different reasons. Snow, rain, and fog can be particularly challenging, as they tend to disturb the sensors so much that operation may be made impossible [42, 47]. Plant growth can pose unexpected problems. Robots may detect fallen autumn leaves that are dancing in the wind as an obstacle; and safety drivers on the self-driving shuttle buses had to rip out grass ⓒ to prevent the buses from stopping repeatedly. They now ride with grass clippers to trim grass close to the stone curb, which is difficult to cut with gardening machines. Finally, wild animals such as birds may become unexpected obstacles when moving close to robots.

Mobile objects—as traces of human activities in public places—may block a robot's way. For example, we observed an abandoned shopping cart slowly drifting into a delivery robot ⓓ. Trash bags and mobile trash bins can obstruct delivery robots on the pavement ⓔ. For autonomous shuttle buses, parked scooters or bikes are common obstacles that need to be removed by safety drivers ⓕ since the buses were not designed to deviate from their pre-programmed route.

Despite advancements in computer vision and motion planning, navigation in natural environments will remain challenging. HRI can explore how to make robot sensors more explainable, drawing from the literature on autonomous vehicles when designing legible robot motion [48, 49]. Collaborations with city councils could explore how the infrastructure can better accommodate public mobile robots without conflicting with human use. Robots are not only heavily influenced by the environment, but they themselves influence how people experience a place, similar to other interactive urban technologies [31]). If robots contribute substantively to public civic services, it may be that guidelines on how to live with robots becomes a necessary tradeoff, *e.g.*, within traffic education, driving schools, as well as information for local residents.

C. Activities

Places change over time. Whyte describes the rhythms of human **activities**, using video recordings and time-lapse footage to show how people transform public spaces over the course of a day, week, month, and so on (see *e.g.*, Whyte's discussion of Rockefeller Plaza's changing with the seasons [12, p. 59]). Momentarily, places may change charac-

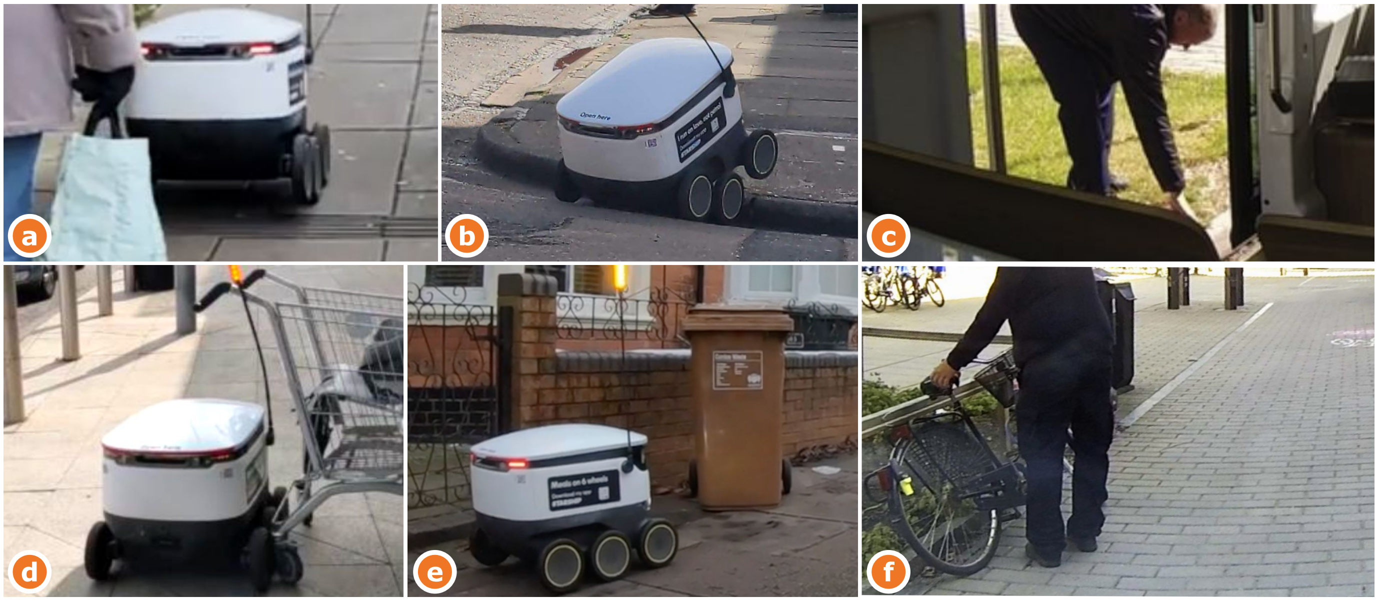

Fig. 3: *Environment.* ⓐ Uneven surfaces can be difficult to navigate. ⓑ High curbs may be difficult to overcome. ⓒ Natural elements may disturb sensors; a safety driver is ripping out grass that caused emergency stops. ⓓ An abandoned shopping trolley rolls into a robot. ⓔ Trash bins can become obstacles. ⓕ A safety driver removes a bike parked in the robot's way.

ter as people run their errands, stopping a car to pick someone up, or parking their bike in front of a shop that they briefly visit. At the other end of the scale, seasonal changes affect public places: festivities can reshape them and affect who is present. The challenge here for designing robots is that this dynamism of activities can sometimes rub up against the fixity of computational rule sets. We break these patterns down into subcharacteristics: the *daily rhythms* of places; activities tied to special *occasions* that impact places; and *situations* that emerge spontaneously. Fig. 4 provides illustrative examples.

The *daily rhythm* leads to recurring activities that can be well anticipated in the space. Flows of people rhythmically change throughout the day. The phenomenon of rush hour describes such changes in the density of vehicles and pedestrians. In the neighbourhood of a school the self-driving buses repeatedly ended up blocking the road, getting honked at by parents who were dropping off their children. To avoid conflict, operators adjusted the service to start after the morning rush hour when traffic was calmer. For robots operating on a university campus, teaching schedules heavily shape the number of people present; there is a pattern of emptiness (few pedestrians, cyclists, and cars during class time) and subsequent bursts of activity (*e.g.*, when students move between classes) ⓐ. Robots need to adapt to such rhythms, with operation focused on daytime when people want to use the robots' services, but also adjusted to existing rhythms of activity, avoiding times of very high density of people. Rhythms are also visible in the "byproducts" of human activities, for instance, the use of household waste containers on the street on specific days [1].

Beyond rhythmic activities, there are also activities tied to specific *occasions* that change the nature of the place. This includes construction work and seasonal festivities, which can affect robot operation. Construction work often comes with scaffolding and waste, which can obstruct the path of a delivery robot ⓑ. Festivities occur frequently at certain times of the year, such as during the start and end of the semester in a campus environment. In the case of autonomous shuttle buses, during campus festivals, the road may be blocked for several days with signs and metal gates ⓒ. Occasionally, students set up advertising booths ignoring the marked route of self-driving buses (blue stripes in ⓓ). Such activities can cause major disruptions to robot operations, including route changes and manual takeovers. Anticipating such activities may be possible by keeping close contact with local authorities and groups. However, ultimately, many occasional activities result in crowds and a corresponding raft of circumstances that unfold as a result of that, which are difficult to plan for.

Activities in public that arise in unfolding *situations* are even harder to anticipate. Situational activities often emerge around work that is carried out on the street, such as restaurant staff unloading a food delivery or someone cleaning a window, as described in [1]. Temporarily obstructed passages pose problems for robots, which require fine coordination to resolve, such as the need for a maintenance worker to move their vehicle to allow a self-driving bus to pass through ⓔ. Situational activities often become visible in the objects that they are tied to, such as someone parking their bike or stopping their car outside a designated parking spot ⓕ while waiting to pick up a friend. Even trivialities for people, like two persons gathering and having a chat in the middle of the street, can become unexpectedly difficult to navigate, for instance when they emerge on the designated route of a self-driving bus ⓖ.

Studying the activities in a place before robot deployment can help to anticipate challenges in robot operation. Collaborating with community representatives, local governments, and building operators as well as people whose activities

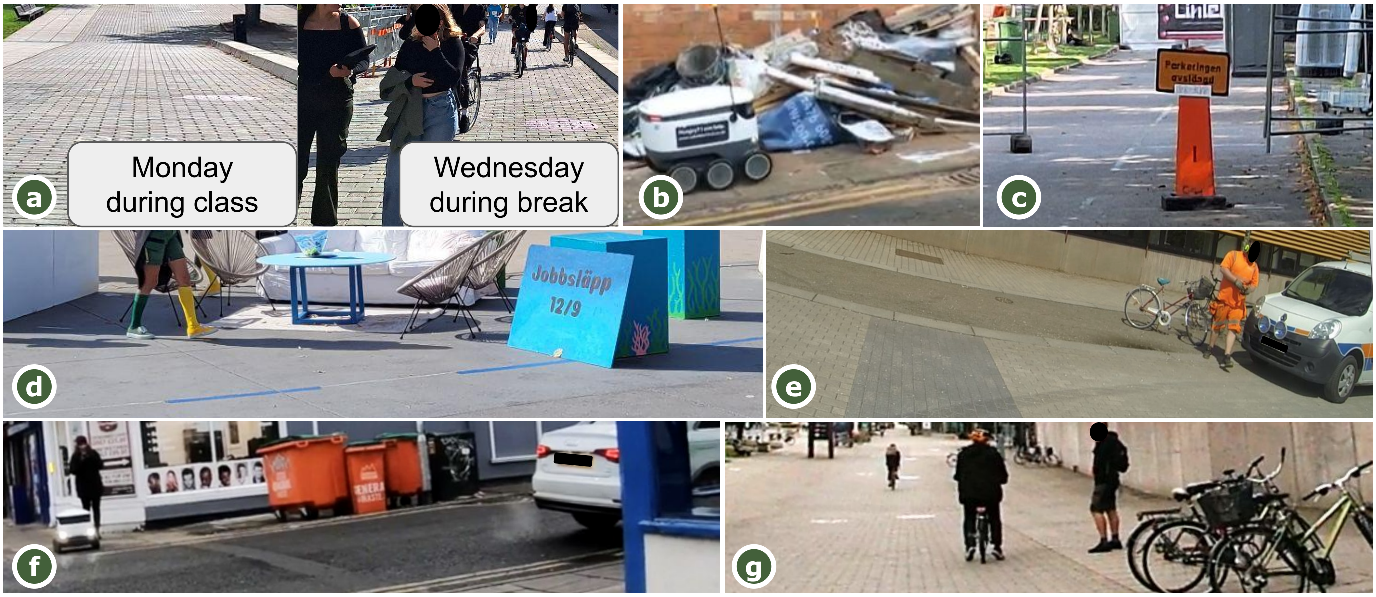

Fig. 4: *Activities*. ⓐ Robot route (marked with pink circle) during class time *versus* during break. ⓑ Robot route blocked by construction waste. ⓒ Robot route blocked by fences, signs, and a party tent. ⓓ Robot lane (painted with a blue dashed line) obstructed by a student information booth. ⓔ Maintenance vehicle obstructing the robot's route, requiring the worker to move it. ⓕ Robot waiting for a car stopped at the intersection. ⓖ Two people chatting, standing in the way of the robot.

continuously get disrupted by robots, including gardeners, construction workers and building maintenance staff, has become increasingly important for HRI researchers. In some current robot deployments, safety operators step in to coordinate with local activities [9]. Learning from their work and following robots on their routes [1] can reveal the temporal dynamics of a place and the activities that robots may encounter there.

D. Sociability

Whyte [12] argued that **sociability** is another key distinction in placemaking, whether it is through musicians that bring people together [12, p.96] or street corners that attract social life [12, p.54]. In this context, sociability refers to the ways in which place and social interaction coincide [50], shaping social connections, the psychological wellbeing of individuals, and cooperation between members of public places.

This characteristic has perhaps had the greatest focus in existing studies of public robots. Applying sociability to public robot design, we consider moments in which robots elicit social responses, positive and negative. People volunteer to assist robots designed to show help-seeking behaviours [51] and may even support robots that are not explicitly designed to do so, but are visibly in need of help [1, 47]. Similarly, it is reported that people may abuse robots in public [19, 52]. We divide this characteristic into two broad aspects for the design of robots for sociability: *intended* aspects, in the sense of "designed-for", and *unintended* aspects that are difficult to anticipate and may support or inhibit robots. Although difficult to anticipate, designers still need to think about what might happen should they arise. Fig. 5 showcases examples.

Intended interactions follow types of interactions that the robot is designed to support, including the specific purpose for which the robot is designed, such as making deliveries or approaching and leaving stops along a route. To manage encounters with passersby, public robots typically communicate direction of movement, system status, and dysfunction. Lights and sounds are used to inform people that a robot is approaching or aware of their presence [9, 53, 54, 55]. Robots deployed in public spaces typically follow local traffic regulations and conventions. For sidewalk robots, programmed intentions to turn left or right are shown through indicator lights, and blinking lights draw attention to the robot when moving through a challenging area ⓐ. Different kinds of vehicle signs communicate that a self-driving bus is moving slower than the local speed limit ⓑ. Although speed is mostly adjusted to keep robots safe, adherence to safety can also interrupt traffic flow [see e.g. 1, 56]. As current robots typically stop when they detect obstacles in a safety bubble around them, designers often try to advise proximate people to maintain distance, for example, by textual displays ⓒ.

Robots in public encounter a range of *unintended* interactions, which include behaviours people show toward the robot that designers are unlikely to count on (or even disprefer). Many such interactions are *supportive*, *e.g.*, people lifting obstacles out of the robot's way [2], and helping it when it gets stuck [47]. Help-giving may involve pushing a robot forward onto a ramp or lifting it out of the snow ⓓ. Supporting actions may be more subtle, such as when people step off the pavement where the robot is approaching or swerve to make way, giving the robot enough space to move seamlessly ⓔ.

Unintended interactions are also sometimes *inhibitive* from a designer's perspective. Especially when robots are new, people tend to test the robot's capabilities and responses by getting (too) close, jumping into the robot's path, or putting obstacles in the robot's way. Touching a robot often ends up inhibiting the robot, for instance, when someone pulls a delivery robot's antenna ⓕ. Whether intended as an act of vandalism or done out of frustration over robots that get stuck or take up space, pushing or kicking robots can also be seen as inhibiting the robot from a design point of view ⓖ.

Fig. 5: *Sociability.* ⓐ Robot design with indicators and warning light. ⓑ Robot with warning triangle for vehicles with low speed and speed indication sticker (15 km/h). ⓒ Warning text in Swedish instructing that the robot can brake hard, both on a display and a more permanent sticker. ⓓ Someone lifts the robot out of the snow. ⓔ Cyclist swerving around the robot. ⓕ A pedestrian bending the robot's antenna. ⓖ A window cleaner kicking the robot when it slows down while passing him.

Building on aspects of public place outlined by Whyte [12], we map out three design challenges that robot designers face: *street life*; *volunteerism and neighborliness*; and *friendliness and playfulness*.

Street life broadly refers to everyday social life on urban streets and, more specifically, the use of public spaces for "public congregation, encounter, and community-making" [57]. The term "street" here mainly refers to sidewalks [58] but also includes plazas, squares, courtyards, and other areas that are open to and designed for public use. *Liveliness* is highly desirable in public spaces, and the liveliness of the street is determined by factors like the availability of commercial and public seating; the presence of a variety of functions in each city block; the number of independent businesses; and the availability of community gathering places [59]. Public robot design largely ignores street life and treats these spaces as areas for navigation around obstacles (*e.g.*, people). HRI design must not only recognise and accommodate street life, including street vendors and performers, café seating, and various groups and crowds of people, but also be sensitive to it. Designers will need to consider whether their robots should join temporary installations on sidewalks, such as street vendors and performances, and spontaneous gatherings of people, or instead purposely avoid them.

Volunteerism is seen as a key strategy for placemaking [12, 60, 61]. Community activities such as cleaning or gardening in public places can contribute to placemaking [62, 63]. Similarly, robots could integrate messaging or demonstrations to encourage volunteer activity in placemaking. Prior HRI research has shown that seeing humans clean reduced study participants' littering intent, but the same effect was not observed for robots [64], possibly because cleaning was perceived as the robot's job. HRI design can also explore creative strategies, such as playfulness, which has been shown to improve people's willingness to help the robot [51], to promote volunteerism. However, designers must also determine when this is an inappropriate use of robots (*e.g.*, if they come to be seen negatively as part of a coercive public surveillance apparatus [65]).

A recent study found that people helped robots stuck in snow, because they perceived robots as "cute and helpful" [47]. This study illustrates the important role of sociability in making public HRI work and of displays of friendliness and cooperation in promoting help-giving. Research on placemaking suggests that spaces and opportunities for leisure and recreation improve the sociability of public spaces [66] and that social activities, such as street parties, promote "conviviality," which in turn fosters playful engagement among people and reinforces a sense of community [67]. Promoting playfulness through ludic design, for example, through the use of location-based games [*e.g.*, 68], has been proposed as a way of creating "playful cities" [69, 70]. These ideas point to an opportunity to design robots for "ludic engagement" [71] as part of placemaking (see also work by Brown et al. [24]).

V. DISCUSSION

This paper explored the notions of *placemaking*, the conscious and continuous act of improving neighbourhoods, cities, and regions to make them welcoming places for people [12]. We aimed to offer a framework of interrelated characteristics (in Fig. 1) that describes the state of the art of robots in public places grounded in real-world observations. As a resource for design and research, the framework is intended to be flexible, similar to other frameworks in HCI research [30, p. 180]: (1) as a tool of sensitisation toward public places; (2) as a shared language to support HRI designers and engineers on public robot projects; and (3) as a collection of constraints to support anticipation and categorisation for design and future HRI studies. Next we discuss how the framework may be used and our own (informal) experiences in applying it.

A. Implications for Design

1) Guiding HRI Education and Technical Implementation: The characteristics we present in the framework point to concrete technical challenges specifically related to navigation, computer vision, and teleoperation capabilities.

We have piloted our framework in teaching engineers interested in autonomous vehicle planning, control and learning and observed that students could use the framework to identify problems that can be addressed through more targeted navigation, motion planning, and computer vision algorithms. We found the framework helped students identify and reflect on similar situations in their own environments, regardless of whether robots are currently present in these spaces. The framework, the video supplement, and the interactive presentation on our website[1] can be used for teaching public HRI, contributing to curricula developed within the HRI community to teach engineers about public places [72, 73, 74].

2) Facilitating Dialogue with Industry: Our framework can also provide a common conceptual language for dialogue between academia and industry, in particular robot fleet companies. Practitioners in autonomous robot companies can draw on our comparative analysis to reflect on the challenges they face, and use the framework to refer to shared problems.

The framework has supported our discussions with autonomous vehicle industry representatives, establishing a shared language and providing concrete examples to refer to. An industry representative was able to refer to challenges their company faced by citing examples from our framework. They could share experiences and describe challenges without the risk of violating their non-disclosure agreements. The framework also contextualises existing industrial solutions in completely open public environments, which may help autonomous mobile robot companies that work in more structured and controlled settings such as warehouses think about public environments. Our distinctions about robots in public places contribute intermediate-level knowledge that sits in between theory and specific examples [15], adding to designerly knowledge in HRI [14].

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[1] The framework and supplementary material are available at https://robotsinpublic.org/making-space-framework.

3) Informing Place-Centered Robotics as Urban Innovation: Our framework may critically inform governance, standardisation, and policy around robots as urban technologies. Stakeholders include agencies and authorities that regulate and plan traffic, non-governmental organisations and interest groups that lobby for specific agendas, and public facility operators such as building managers and local business representatives. The framework supports recent calls in HRI to look beyond the individual robot and encourages engagement with organisations affected by and engaged in the governance of robots [45, 75].

Our framework has facilitated conversations with different stakeholders in this space, enabling us to frame our research and exemplify the possible contributions of HRI research to robot deployments. Bringing together illustrative examples from specific field sites with abstract concepts, the framework specifically supports discussions around the development of standards, such as the draft ISO 4448 standard on PMRs [43].

We also found the framework useful for engaging with research funding bodies during site visits and *in situ* demonstrations of public robots. A physical copy of the framework provided visitors with a conceptual map during a demo; the robot's route illustrating all four quadrants of the framework. This enabled us to simultaneously contextualise the current behaviour of the system as well as broader challenges.

4) Shaping Future Research and Design: The framework demonstrates different orientations to the design of public robots. Rather than minimising their impact on place, robots should be explored as deliberate social agents inextricably intertwined in the social life of public places. Our characteristics help shape future HRI research in public in several ways. First, our characteristics can serve as a methodological guide and educational tool for *place-centred design*. Our work informs design work, opening discussion on how—where appropriate—robots could be designed to better recognise the nature of the activities they encounter and to perform relevant social actions like greetings, requests, or contribute to placemaking, *e.g.*, through entertainment.

Second, the framework is especially suitable for participatory approaches, as it can help identify, recruit, and engage relevant stakeholders in the design process. Teams including designers, accessibility advocates, and traffic planners could study the characteristics of a place using the framework, observing people engaging with a place, and designing with these observations in mind. The framework could also help structure workshops before robots are introduced to a specific area, stimulating discussion of the impact that the robot may have on the places in question.

Finally, our framework can be printed and turned into an artifact (*e.g.*, a coaster or design cards [76]), serving as a tangible tool for instructing observations, adding to emerging work of this kind [34]. Card-based methods can also be used during stakeholder participation to develop design ideas and determine how the framework can be refined, extended, or pruned. We do not claim that our framework is a finished artifact, but rather encourage HRI researchers to test it in further case studies, including different robots and different types of public sites, such as hospitals.

B. A Warning on Technosolutionism

Drawing on conversations in HCI research about non-use [77], we also acknowledge that our characteristics can also be read as arguments for designing the purposeful *absence* of robots in urban places (see also [34]). For example, being sensitive of certain activities, such as large events, may mean that designers should develop robots that avoid interference and "invasion" at specific moments to better support the dynamism of public places within which present robot technologies are simply clumsy and obstructive. This way of *inverting* the application of our framework could be used to focus on the problems of robot technosolutionism [78].

C. Limitations

Our framework and characterisations of public spaces have several limitations. First, our framework (deliberately) does not offer a systematic *taxonomy* of public robots in terms of task or integration into public environments. We have also limited our discussion to robots as objects experienced in public and have *not* considered the role of system infrastructures that support them. We excluded support infrastructure, including telecommunication and operation centers as they tend to be less visible for the public and are therefore more difficult to study. Future work needs to put more focus on the "behind-the-scenes" work to better understand how such work enables public robots to operate in the first place. Insights from swarm robotics may be important to incorporate here [79].

VI. CONCLUSION

We presented four characteristics of public places and placemaking that are critical to robot design: (1) *localism*—how robot design aligns with the identity, culture, and character of the place(s) it resides within; (2) *environments*—the physical characteristics (designed and emergent) of the environment that public robots operate within; (3) *activities*—consideration for the various permanent, temporary, and situational activities that are tied to place(s) robots inhabit, and that unfold in different scales and temporalities; and (4) *sociability*—how people collectively and individually relate to, interact with, and make sense of robots deployed in public places. We aim to bring to HRI a deeper appreciation of the complexity and also the opportunity inherent in public places, and offer an approach that is considered, measured, and subtle in its presentation of this emerging design space.

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