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MAIN PAPER

Robotics in place and the places of robotics: productive tensions across human geography and human–robot interaction

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Abstract
Bringing human–robot interaction (HRI) into conversation with scholarship from human geography, this paper considers how socially interactive robots become important agents in the production of social space and explores the utility of core geographic concepts of *scale* and *place* to critically examine evolving robotic spatialities. The paper grounds this discussion through reflections on a collaborative, interdisciplinary research project studying the development and deployment of interactive museum tour-guiding robots on a North American university campus. The project is a collaboration among geographers, roboticists, a digital artist, and the directors/curators of two museums, and involves experimentation in the development of a tour-guiding robot with a "socially aware navigation system" alongside ongoing critical reflection into the socio-spatial context of human–robot interactions and their future possibilities. The paper reflects on the tensions between logics of control and contingency in robotic spatiality and argues that concepts of scale and place can help reflect on this tension in a productive way while calling attention to a broader range of stakeholders who should be included in robotic design and deployment.

Keywords Human-robot interaction in the wild · Robotics · Space · Scale · Place · Museums

1 Introduction

This paper argues that the critical perspectives on space and spatiality from human geography have an important contribution to make to the interdisciplinary fields of human-robot interaction (HRI) and robotic design, while also expanding these fields to incorporate a broader range of voices and perspectives. Reflecting on an interdisciplinary collaboration between roboticists and geographers to develop and study the deployment of a social robot as a museum tour guide, the paper puts forward fundamental geographic notions of *scale* and *place* as concepts that can help organize research and discussion around HRI "in the wild," or outside of controlled laboratory settings. The concept of scale offers a useful heuristic for bringing into focus different kinds of socio-spatial relations, moving from traditional HRI and robotics concerns with the micro-scale of human and robotic embodied interactions, to broader questions around the different social spaces robots operate in and to questions over the ways these interactions are located in more extensive social contexts. Yet, as critical geographers have long pointed out, the concept of scale has a tendency to reproduce reductive "container models" of space, obscuring the messy connections and relations through which social space is continually produced in practice (Marston 2000; Marston et al. 2005). We thus complicate a simple scalar logic by holding it in tension with the notion of place, which highlights the complex interplay among a variety of social and spatial relations that produce an experience of a site as meaningful and identifiable. In this way, the two terms introduce and maintain a tension between orderly and disorderly spatial logics—between a desire to locate, contain, and control and a desire to explore the fluidity, emergence, and unpredictability of spatial relations. We intentionally aim to sit with this tension between control and contingency, as it is one that we encountered throughout our collaborative project. We argue

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that this tension is key to the production of social space and that scholars should resist the urge to resolve this tension through adopting overly rigid or overly fluid conceptions of robotic spatiality.

In making this argument, this article intervenes in emerging conversations within and beyond the academy around the evolving spatiality of social robots. It is now perhaps cliche to write that social robots are increasingly deployed in the spaces of everyday life, from schools, hospitals, and malls to private homes and city streets and parks. Versions of this statement are now commonly repeated in the opening lines of articles and conference presentations in HRI and related fields. Many of these contributions then call for expanded research on HRI "in the wild" (Jung and Hinds, 2018), or otherwise highlight the need for more advanced forms of navigation or communication for robots to better operate in these scenarios (Salek Shahrezaie et al 2022). Beyond academia, news reports increasingly highlight the spatial proliferation of robots, from security and policing robots on city streets or office parks (Rubinstein 2023) to robots in the service and hospitality industry (Berreby 2020) or deployed in therapeutic and care settings. Many of these accounts highlight serious social, political, and ethical concerns, highlighting cases of robots surveilling public housing in New York City (Zaveri 2021) or harassing unsheltered people on the streets of San Francisco (McCormick 2017). These cases and others make clear that social robots need to be understood as an increasingly common and powerful actor in the social production of space.

Despite these developments, scholars are only beginning to interrogate the evolving socio-spatial entanglements of social robots. In HRI, calls for studies on HRI "in the wild" have seen relatively limited uptake. When HRI research has focused on interactions in uncontrolled, everyday contexts, it has largely done so with the goal of improving robot performance or acceptance, rather than examining broader social implications. Šabanovic (2010, p. 439) traces common HRI discourses in which "technological development in robotics, led by experts from academia, industry, and government, figures as the primary driver of social progress, while society fills a passive role of accepting and adapting to the results of technological innovation." As HRI moves into new spaces of everyday life, *social space* is likewise seen in a mostly passive role, as the background or context in which robots are deployed. Conversely, despite news reports highlighting a range of social, political, and ethical concerns associated with the spatial proliferation of robots, critical geographic engagements with such questions are still only emerging (Kerruish 2021; Lynch 2021a; Lynch 2021b; Sumartojo et al., 2023; Sumartojo and Lugli 2021; While et al 2020). Crucially, much of this work highlights a tension between what Sumartojo et al. (2023) identify as robotic spatial logics of "predictability, partitioning, and connection" and the contingency and emergence that is often considered key to processual and relational understandings of social space. This requires a reflection into the ways that roboticists aim to know and control a robot's environment in order to ensure its proper function, at the same time that a robot's engagements in complex environments are likely to always exceed "what its designers or programmers intend" (Sumartojo et al. 2023: 155). We argue that this in turn means that there is a need for more broad, interdisciplinary, and participatory approaches to the design, programming, and deployment of robots in which the complexity and contingencies of social space are placed at the center of attention. Building on this work, the paper offers theoretical tools to inform such processes, organizing collective reflections and investigations through the lenses of scale and place. We conclude by suggesting that robotic development and the decisions about when, where, and how to deploy them might be considered as part of a collaborative process of *placemaking*.

The paper explores the question of robotic spatiality through a reflection on an ongoing interdisciplinary research project involving roboticists, geographers, an artist, and museum directors in the design and deployment of a robotic museum tour guide. This project emerged in the context of the COVID-19 pandemic. In spring 2020, pandemic restrictions forced two museums on the University of Nevada, Reno campus—an art museum and an Earth science museum—to close their doors. Even as restrictions were loosened later in the year, the museums faced serious limitations to their activities, including the inability to offer guided tours. In this context, the museum directors became interested in socially interactive robots as potential tools for facilitating new kinds of interactive experiences for museum visitors, both through the remainder of the pandemic and into the future. This turn toward socially interactive robots during the COVID-19 pandemic has been documented across multiple sites and contexts beyond museums, including in hospitality, delivery services, and public safety (Valdez and Cook 2023; Lin 2022; Zaroushani and Khajehnesiri 2020; Seidita et al. 2021; Sumartojo and Lugli 2021). The interest led to the formation of a collaborative research project in which a team of roboticists would develop a robot guide equipped with a socially aware navigation (SAN) system and a team of geographers would study how the processes of robotic development and deployment come to impact the ongoing reproduction of the museum as a social space. This paper reflects on the earliest stages of the project, as the project team began conducting preliminary research into the museum spaces and visitor expectations of those spaces and attempted to use insights from this work to inform robotic programming and design.

The next section situates the project in the history of spatial thinking in social robotics and in scholarship on (digital) spatiality in geography. Section III introduces the collaborative project on which the paper is based and discusses the socio-spatial questions that emerged through the project across three scales. Section IV concludes with a discussion. It draws insight from the preceding discussion to complicate neat spatial logics through the lens of place and proposes an approach to robotic design and deployment informed by collaborative processes of *placemaking*.

2 Robotic spatiality

2.1 Spatial thinking in robotics and HRI

The question of how to understand the dynamism of the "real world" and design artificial agents to effectively operate in the world has been foundational to contemporary robotics research since its inception in the mid-twentieth century. Indeed, as embodied machines designed to operate physically in the world, the problem of robotic design and programming is inherently a spatial one: how might a machine be made to sense and respond to its surrounding environment? Experimentation with mobile robots began to take off in the mid-1960s and early 1970s with the invention of robots like the BEAST at Johns Hopkins University and SHAKEY, and later FLAKEY, at Stanford University (Nocks 2008). Early robots like SHAKEY relied on a series of sensors to collect data from the surrounding environment as well as an "internal world model" (IWM) that was adaptable to new information but pre-programmed based on prior assumptions about the external world and the relevant objects in it. In other words, the problem of space for early roboticists was constituted around attempts to comprehensively model a robot's environment and to create methods of properly sensing and responding to that environment. Limitations in processing power meant that the robot was slow in reconciling sensor data with its IWM and unable to adapt quickly to changes in its surroundings. The need to fully model the environment and the limits of early computation meant that, as Nocks (2008) explains: "the 'real world' that SHAKEY was reasoning about had to be a very simple one where its objects were simple geometric blocks, and not people or soft-edged inanimate objects" (p. 102).

By the mid-1980s, Rodney Brooks and others at the MIT Artificial Intelligence Laboratory began questioning approaches to robotic intelligence based on abstract and simplified models of the world. Instead, Brooks (1999) argued for a direct link between sensing and action without having to reconcile sensor data with an IWM. He writes: "At each step we should build complete intelligent systems that we let loose in the real world with real sensing and real action… It turns out to be better to use the world as its own model" (p. 80–81). This development radically changed roboticists' conception of and relation to the 'real world'– social space. Rather than something to be simplified, abstracted, and modeled, the dynamism of the 'real world' and an agent's interactions in that world became seen as the basis of intelligent behavior. Doing away with the IWM, Brooks' robots, or Creatures, instead functioned as "a collection of competing behaviors" (Brooks 1991: 145). He explains: "Out of the local chaos of their interactions there emerges, in the eye of an observer, a coherent pattern of behavior. There is no central purposeful locus of control" (Ibid). Brooks' conception of intelligence, in what became known as "New AI" or Behavior-Based Robotics (BBR), allowed for breakthroughs in the design of autonomous and semi-autonomous robotic systems, including the invention of the Mars rovers (Brooks 1999; Nocks 2008; Vertesi 2015). It also marks a significant shift in robotic logics of space from one centered on control to one that broadly embraces and aims to work through the radical contingency and emergence of spatial relations.

While Brooks' insights allowed for more complex forms of spatial behavior, the robots produced still only interacted with their environments physically—through movement in relation to other bodies and objects. By the late 1990s, Cynthia Breazeal, a student of Brooks', began to design robots capable of more complex forms of social interaction. As Atanasoski and Vora (2019) explain: "The perception of the human for social robotics involves more than sensing the physical presence of an object… Rather, the problem of perception also involves sensing social cues and responding to human emotional states" (p. 113). Breazeal (2002) explains: "For robots to be human-aware, technologies for sensing and perceiving human behavior must be complemented with social cognition capabilities for understanding this behavior in social terms" (p. 9); this requires "that it continuously learn about itself, those it interacts with, and its environment" (p. 11). Reflecting on the possibilities for more complex social forms of HRI, Breazeal developed the first socially interactive robot, Kismet—capable of recognizing and expressing an array of emotional facial expressions and communicating through sound and gesture, though not independently mobile. Breazeal's work and those of later social roboticists constitute a key development in robotics in which robotic spaces become seen as not just physically complex and dynamic, but also *socially* complex and dynamic.

Developments in social robotics over the past two decades have built on work from these earlier innovators and others, combining the control logics of Internal World Models, direct links between sensing and action, and various forms of social and emotional interaction to produce robots capable of a broader range of functions in more complex environments. As discussed earlier, robots are increasingly taking on new roles in care settings (Feil-Seifer and Matarić, 2011; Sharkey & Sharkey, 2012), hospitality (de Kervenoael et al., 2020), education (Reich-Stiebert, N., & Eyssel, 2015), security and policing (Theodoridis & Hu, 2012), and as personal companions (Odekerken-Schröder et al 2020). As this occurs, roboticists have begun recognizing the need to study HRI "in the wild"—that is, in more dynamic, everyday social environments (Sabanovic et al. 2006). Jung and Hinds (2018, p. 1) explain how "[social] robots interact with people in everyday contexts across a wide range of tasks and situations, yet our research reflects a time when studies of HRI were possible almost exclusively only in laboratory settings… Our theories reflect an oversimplified view of HRI." There are several aspects of existing literature on HRI that pose limitations to understanding HRI in the wild. Many HRI studies are based on one-on-one interactions in environments with limited noise or interruption, are based on scripted or semi-scripted encounters, or otherwise may rely on short experiments that fail to capture the dynamism of long-term interaction. Thus, the limited work that does exist on HRI in the wild has sought to answer questions like how robots respond in unscripted interactions in complex settings (Rosenthal-von der Pütten et al. 2014), or incidental encounters in public spaces (Rosenthal-von der Pütten et al. 2020). Yet, this notion of "the wild" and the understanding of *social space* it is meant to represent has been undertheorized and underexplored. Those who call for studies of HRI in the wild highlight questions of 'context', 'setting', 'social environments', 'proximity and human contact,' and 'in situ' social dynamics (Jung & Hinds, 2018)—but have not engaged in explicit discussions about what these terms represent. In the following section, we aim to put these questions of social space in HRI into conversation with human geographic theory in order to then set up our empirical discussion.

2.2 (Digital) spatiality

Geographic theory has long held that space is not simply a container of social relations or a given external environment in which a subject is passively situated; rather, space is continually produced as a social process among situated and entangled human and nonhuman actors (Dodge & Kitchin, 2005; Murdoch 1998; Thrift and French 2002). As robots increasingly enter the spaces of everyday life, it is not only that they must function in these spaces, but they also necessarily reshape these spaces through their interactions—the function, purpose, and meaning of the space, the social practices that (re)produce them, and the ways they are experienced. Emerging research in robotic geographies have examined robotic deployments through a variety of theoretical lenses, each drawing attention to distinct scales of analysis. For instance, while Macrorie et al. (2019) or Cugurullo (2020) focus on robotic reorganization of urban systems and spaces or Delfanti (2021) on specific sites of labor, Sumartojo and Lugli (2021) focus on the 'liveliness' of robots in their emergent embodied interactions with humans and Lynch et al. (2022) on the micropolitics of specific affective displacements in care settings. This literature demonstrates a growing concern with the ways robots are emerging as new kinds of actors involved in the dynamic reorganization and reproduction of everyday spaces. Yet, with the exception of Sumartojo et al. (2021), there has been little explicit theorization of the robotic production of space and little consideration of how to facilitate critical interdisciplinary conversations on this topic with roboticists and HRI scholars themselves.

It is perhaps difficult to know where to begin in establishing such an interdisciplinary dialog around social space, as indeed the question of space goes to the core of geography as a discipline constituted by a long history and myriad theoretical turns and divisions (see Cresswell 2024). Critical scholars in human geography have long theorized and researched the complex and dynamic production of space as a social process (Hubbard et al., 2002; Massey 2005; Jones 2009) and have explored those processes across scales—from the production of global, national, and urban spaces to the intimate spaces of the home and the body (Longhurst 1995; Marston 2000). Relatedly, geographers have theorized social space from a broad range of theoretical perspectives. For instance, Henri Lefebvre's (1991) influential theorization of the spatial triad calls attention to the dialectical interactions among spatial plans and representations, material processes and flows, and individual and shared experiences of space. Others have theorized the production of space in relation to theories of affect and embodiment (Davidson and Milligan 2004; Anderson 2006), Actor-Network Theory (Murdoch 1998; Farías and Bender 2012), assemblage theory (Legg 2011), and other forms of posthuman thinking (Panelli, 2010; Rose 2017). What these and other theoretical approaches have in common is an appreciation for the production of space as an ongoing socio-material process involving a range of human and non-human actors—that is, a rejection of space as static and as a background or container of social relations. The notion of "spatiality" highlights this inextricable entanglement between the spatial and the social—as space is both the materialization of social relations but also productive of social relations and social life. As Merriman et al. (2012, p. 4) argue: "it is precisely the multiplicitous and heterogeneous nature of space and spatiality—as abstract and concrete, produced and producing, imagined and materialized, structured and lived, relational, relative and absolute—which lends the concept a powerful functionality that appeals to many geographers and thinkers in the social sciences and humanities."

A recent "digital turn" in geography (Ash et al 2018) has given rise to scholarship examining the proliferation of digital objects and systems and their roles as agents in the social production of space across scales (Thrift and French 2002; Kitchin and Dodge 2014; Leszczynski 2015; Cugurullo 2020; Dalton et al. 2020). For instance, in their early account of the "automatic production of space," Thrift and French (2002, p. 329) explain how "[s]oftware signals a fundamental reorganization of the environment, a vast system of distributed cognition through which the environment increasingly thinks for itself, an extra layer of thinking." In this case, the authors reflect on the integration of software into a vast array of everyday objects and systems that work to maintain particular kinds of spatial arrangements. Kitchin and Dodge (2014) expand on this approach, highlighting the role of software in domestic spaces, work, communication, transport, and consumption. These coded infrastructures and assemblages fade into the background of everyday life consistently reproducing social space in particular ways. More recently, scholars have considered the roles of smartphones, wearable devices, and augmented reality—and the extensive algorithmic assemblages that sustain them—in producing particular practices and experiences of space (Graham et al., 2013; Leszczynski 2016; Pink and Fors 2017; Lynch and Sweeney 2024). Digital systems are increasingly transforming the ways space is abstracted, represented, and imagined (such as through smart city or smart home systems); practiced in embodied and material ways (as they redirect flows of people, goods, and information); and experienced (as they mediate spatial encounters and produce particular affects).

This paper builds on this work by considering how social robots pose a unique challenge to geographers' understanding of space, as they imply new kinds of mobile, embodied actors, collecting new kinds of spatial data, and capable of exerting direct influence on their environments in ways that may not always be predictable (Lynch 2021b). Robots are not simply integrated into existing, stable spatial orders, but rather need to be understood as "both productive of spatiality and 'coming-into-being' as emplaced inhabitants themselves" (Sumartojo et al. 2023, p. 4). In questioning the robotic production of spatiality, Sumartojo et al. (2023), for instance, trace the computational logics of predictability, partitioning, and connection to explore the tensions between robotic design and programming and processual and relational accounts of spatiality as irreducibly contingent and emergent. In this paper, we build and reflect on this work. In particular, we aim to sit with this tension between control and contingency, predictability and emergence, and reflect on the ways it presented itself throughout our collaborative research project. Aiming to facilitate further interdisciplinary conversations across geography and HRI, we explore the utility of further modes of spatial thinking—specifically, conceptions of scale and place—to make sense of this evolving phenomenon while also refusing the temptation to resolve this tension, seeing it rather as a productive opportunity for reflection.

3 Interdisciplinary explorations of robotic spatiality

The collaborative project on which this paper is based has been ongoing since 2021 on the campus of the University of Nevada, Reno. The project involves the development of a museum tour-guiding robot to be integrated into two university museums—the John and Geraldine Lilley Museum of Art (hereafter, the Lilley) and the W. M. Keck Earth Science and Mineral Engineering Museum (hereafter, the Keck). The project team includes a human geographer, a social roboticist, a digital artist, the curators of both museums, and several undergraduate and graduate student assistants from across multiple disciplines. The aim of the project is to develop a robot to give museum tours while taking into consideration the unique needs and desires of the specific museums. At the same time, the project was intended as an opportunity to conduct sustained research into issues related to robotics in dynamic everyday spaces—including HRI research on the part of the roboticists and ethnographic research into robotic spatiality on the part of the geographers. In the first phases of the project, the robotics team has aimed to develop a socially aware navigation (SAN) system for the robot to ensure it behaves in ways that will not be disruptive to the museum environment (discussed further below). At the same time, the geography team conducted interviews with museum visitors and stakeholders to understand the different perspectives, preferences, or concerns involved in the eventual integration of the robot in the museums. In order to assist in the development of the SAN, these interviews included questions about individuals' perceptions of specific robotic behaviors or more broadly about the kinds of social norms they expect of the museum space.

As we conducted this research and participated in broader team discussions about the development and deployment of the robot, our attention and reflections tended to focus on issues across three spatial scales: the embodied scale of human–robot interaction, the scale of the museum as a social space, and the museum's situation in the broader context of the university campus, the City of Reno, and the region beyond. While we separate discussion of each in the three sections below, we also aim to highlight the ways particular questions or concerns quickly spill over into other scales of analysis. In doing so, we highlight the need for a broader, more holistic approach to theorizing and research on robotics *in place* and the places of robotics. In other words, we first employ the lens of scale in order to push reflection on the spatiality of human–robot interaction beyond micro-level attention to immediate human–robot embodied interactions (as common in robotics research on proxemics, discussed below).

In our discussion, we then turn to a theorization of place in order to highlight the messy and shifting relations that cut across scale, connecting a micropolitics of human and robotic affect (Lynch et al., 2022) to broader local and regional social realities.

3.1 Scale 1: embodied human-robot interactions

Traditional approaches to HRI have tended to focus on the scale of human and robotic bodies. This is perhaps unsurprising given that robotics researchers are generally interested in better designing robotic bodies or programming specific forms of robotic interaction or movement. That is to say, the robot is perhaps the natural scale of analysis for robotics and HRI. While interventions like Brooks' behavior-based robotics call greater attention to the robots' environmental entanglements, in the end the task of designing and building the robot inherently returns focus to this scale. A focus on robotic and human bodies (and consequently, the bracketing out of broader spatial relations) has also been reinforced by the controlled, experimental approach to much HRI research. Yet, this work has been effective perhaps precisely because it works at a scale and through an epistemology that lends itself to making decisions about robot design or performance. For instance, work on proxemics in social robotics has concerned itself with the ways distance between human and robot bodies shape experiences of interactions, including levels of comfort and perceptions of the robot (Mumm and Mutlu 2011; Mead and Matarić, 2015). HRI work contributing to proxemics has helped establish rules for robotic behavior by remaining at this scale of analysis. Socially aware navigation (SAN) builds on this previous work, building further layers of complexity into robotic navigation behavior, so that a navigation planner does not only consider the shortest distance from point A to point B, but also appropriate distance to humans, and other (often implicit) social norms for movement through specific social spaces (Banisetty 2020; Banisetty et al. 2021). For instance, early SAN systems have analyzed human–human passing behavior in hallway settings in order to model and plan similar kinds of human-robot interactions (Sebastian et al. 2017).

In the collaborative project from which this paper is based, the robotics team was interested in developing a SAN for the museum tour guide robot. This meant they were interested in understanding which norms constitute "appropriate" behavior in a museum environment. This is an instance when roboticists begin to think beyond the micro-scale of human and robotic bodies, engaging the museum context and the social norms attached to that context—which will be discussed further in the next section. Yet, in the end, the aim is to utilize that knowledge to engineer robotic movement in relation to humans; in other words, it maintains a certain focus on the micro-scale. As our collaborators explain regarding the robotics objectives of the project:

> We are interested in using environmental context and object information for more appropriate social navigation. We introduce a novel approach to use context recognition and object detection to execute context-appropriate social rules. For example, a robot's social navigation strategy in an art gallery or a museum differs from the social navigation strategy for hallway navigation. Similarly, the social rules within the same context vary based on other factors in the environment. For example, social navigation rules in a gallery with a person are different from social navigation in a gallery with a person viewing artwork. In the former case, the robot may only need to account for the proxemic rules around the person, whereas in the latter case, the robot has to account for both proxemic rules and rules associated with activity space (the space between human and the artwork). (Salek Shahrezaie et al. 2021: 515)

> Socially-Aware Navigation should acquire information from the environment to detect the context in order to select environmentally-appropriate behavior. Context detection has mainly relied on deep learning techniques such as convolutional neural networks, which has been successful in object detection, people detection, pose detection, etc. However, in semantic navigation, knowledge is stored in the relation of concepts such as objects, utilities, or space type, then uses the relationships between these concepts to understand the context better… Following the example of a museum tour, social norms were created as guidelines for navigating a more complex social environment by using identifiable tour practices. (Salek Shahrezaie et al 2022: 1015).

The SAN approach described here demonstrates a clear awareness of and concern with the importance of social spaces and the meaning, experiences, and expectations that human inhabitants attach to them. It also demonstrates an awareness of social space as complex and emergent—it is not enough to simply identify a broad context (a museum gallery or hallway), but also to recognize the dynamic relationships between people and objects in that space.

The aim of producing systems that are able to recognize and respond to diverse kinds of interactions in specific contexts is to allow the robot to move through space in relation to people and objects in ways that produce certain kinds of effects (or affects) in human users/observers. Similar to many other design and programming goals in social robotics, the intent is to increase observers' perceptions of the robots' intelligence—and increasingly, perceptions of more specific forms of intelligence, like perceived social intelligence (Barchard et al., 2020). More broadly, the goals of SAN systems are to make a robot appear to fit or belong in a particular space, making it more likely to establish and maintain successful interactions while minimizing unwanted disruptions to the space. In other words, through the analysis of human and robotic embodied interactions, the robotics team hoped to better refine and direct those interactions in desirable directions—the smooth integration and functionality of the robot.

Yet, the roboticists are also very aware that not every interaction will unfold as intended. We find that there are several ways that geographic thinking about spatiality is potentially relevant to this conversation and that can help temper the more structured control logics inherent to planning a SAN system. Geographers have long been interested in the relationship between space and affect. While in robotics and AI research affect is often understood as more or less synonymous with emotion, human geographers draw on theories of affect derived from thinkers like Gilles Deleuze, Henri Bergson, or Gilbert Simondon, which view affect quite broadly as an indeterminate capacity to affect and be affected (Bille and Simonsen 2021; Lynch et al. 2022). In other words, affect is about the dynamic relationships between bodies (human and non-human) which cannot always be reduced into neat representations—for instance, labeled as a specific emotion—or directly attributed to the actions or intentions of a specific actor.

Geographers view space and affect as inherently entwined. As Anderson (2006: 736) explains: "The emergence of affect from the relations between bodies, and from the encounters that those relations are entangled within, make the materialities of space–time always-already affective." This way of thinking has had a significant impact on geographers' engagements with (digital) technologies, including their understanding of the agency exercised by technology, the ways it makes people feel, and the ways its own agency is constrained by the actions of other embodied agents. Significantly, some of this work has explicitly called attention to the limits of technological design and the intentions of designers/engineers. Ash (2015: 89) writes that by adopting an object-oriented approach to affect: "issues of affective design or manufacture become downplayed in place of an emphasis on the multiple ways that a piece of technology is used or experienced by a variety of different bodies." In relation to robotics, for instance, such an approach calls attention to the "liveliness" of robots in the spaces of everyday life which produce affects through their encounters in ways that cannot be predetermined (Sumartojo and Lugli 2021). Such reflections from geography would appear to temper the ambitions of roboticists to develop SAN systems, questioning to what extent social norms around spatial behavior in specific contexts can be programmed or even determined through sensing the surrounding environment. At the same time, such attempts to add complexity and nuance to robotic behaviors could also be seen as contributing to the "liveliness" of robots as long as it does not attempt to over-determine the outcome of the resulting human–robotic encounters. In other words, robots with a broader behavioral repertoire may indeed be more "lively" than a robot that simply moves from point A to point B.

Thus, coming into the project, both the roboticists and geographers had thought extensively about the spatial relationships between robot and human bodies. However, approaches to this relationship from HRI have traditionally focused on attempts to engineer specific kinds of affective relations—a human–robot encounter in which the human perceives the robot as intelligent, friendly, or some other desired trait. While HRI scholars are well aware that the desired affect will not be successful 100% of the time, the goal is to reduce unexpected or undesirable affects to the extent possible. In other words, HRI research continually struggles to determine (or at least strongly influence) the affectivity of encounters. In contrast, geographic scholarship has tended to focus on and embrace this inherent indeterminacy as key to understanding and promoting the vibrancy of space and place. Yet, neither a fully robotic/predetermined affect nor affective chaos are likely desirable outcomes of human–robotic encounters. We thus argue that reflecting on the nature of robotic spatiality at this micro-scale is a potentially productive point of tension for interdisciplinary engagements around robotic spatiality. As we wish to stress throughout this paper, interdisciplinary teams studying robotic spatiality should not shy away from this tension, but rather recognize and work through the tension to collectively reflect on and experiment with desirable human–robot encounters. This may mean, for example, working through and reflecting on epistemological and methodological tensions in such collaborations.

In the specific project in question, the first attempt to develop a SAN system aimed to make use of interviews conducted by the geographers with museum visitors and stakeholders in order to extract rules for robotic navigation. However, it quickly became clear that the kind of data produced through these interviews (long, sometimes rambling reflections on people's experiences and expectations in relation to museums) did not offer the kinds of details that might determine, for instance, how a robot should navigate through a crowded setting. Thus, in later iterations of these interviews, the team integrated a mix of more open-ended questions about visitor experiences and expectations with more specific questions and photo and video elicitation exercises that asked respondents to identify desirable and undesirable behaviors. Reflecting on this tension, part of what became clear was that the roboticists and geographers were asking questions at different scales. While the geographers were interested in understanding affective encounters between humans and robots, they were perhaps less concerned with the robot itself and more with its interactions and effects on the museum as a specific social space.

3.2 Scale 2: museum spaces

At several points throughout project discussions, attention turned to the question of the museum as a social space. From the beginning of the project, several project conversations focused on thinking through different aspects of museums: To what extent can we generalize about museums? What about different kinds of museums? What purposes do museums serve? How do different communities interact with the museums? What are people's expectations of the spaces and broader museum experiences? How might the introduction of a robot tour guide affect some of these questions? These questions had different significance for the different members of the project team. A key tension in the development of the SAN system discussed above is that while the system requires knowledge about minute bodily movements and behaviors, designing the system also calls attention to museums as unique social spaces with their own sets of rules, expectations, and meanings that may be shared to some extent, but are also fluid and subjective. In other words, the conceptualization of the SAN system requires a reflection at a different spatial scale and from a different perspective that creates a tension between control and contingency. At the same time, within the broader project, the geographers were particularly concerned with thinking through and understanding the ways the introduction of robot tour guides would affect the museum environment. Naturally, the museum directors/curators themselves were also interested in questions at this scale, concerned with how they might use the robots to complement or augment the museum experience. Indeed, the museum directors were a major impetus behind the project and the development of the SAN and the geographic study was conceived as a way of working toward this broader goal.

In the earliest stage of the project, the geographers aimed to explore these questions through a series of semi-structured interviews with both museum directors, as well as with stakeholders from other museums in the Reno area and with museum visitors—primarily at the Lilley. The intention was for the insights gained from the interviews to both help set a kind of baseline for understanding the museum experience before introducing the robots, but also to help inform the design and eventual deployment of the robots. In separate interviews with the museum directors, we asked them how they understood museums, their roles, and their purpose, and the differences between different kinds of museums (in this case, reflecting on the difference between an art museum and an earth science museum). In both interviews, the directors tended to downplay the differences between the two museums, explaining that museums are all essentially spaces where objects and artifacts of various kinds are arranged or displayed or engaged in order to "spark wonder." In other words, for both directors, museums are defined by a particular kind of *affective* experience in which attention is deliberately drawn to specific objects of interest with a certain desired (though undetermined) response. This reflection drew our attention back to the scale of affective human–robotic embodied encounters, though it introduced a third set of objects to consider—the museum artifacts themselves. Indeed, the framing of museums as spaces where artifacts "spark wonder" positions these artifacts as not simply passive objects, but as *the key* affective actors in the space in question. The robot is necessarily entering a particular affectively charged environment, one that has been intentionally curated. This required us to reflect on the robot's role from a different perspective. How might the focus on human–robot affective relations distract from or contribute to the goal of facilitating affective engagements between museum visitors and artifacts? Thinking about museums in this way, one of the concerns that arises is that the presence of a robot will become an object of interest in itself and thus distract from the intended objects of interest in the museum. Indeed, the intention of the SAN system is partly to prevent this outcome. If the robot's movements in space adhere to certain common expectations, perhaps it is more likely to fade into the background rather than draw unnecessary attention to itself.

Reflecting in this way on the importance of affective engagements to the broader museum experience also defines certain kinds of spatial relations and practices as key to museums. In the simplest form, this may be a person viewing an object (standing in a particular location, hanging from a wall, or in a display case) from a certain distance and then moving on to another. From this perspective, integrating the robot would not be too complicated. The robot could be programmed to recognize a series of activity spaces, constituted by a person or persons standing in some relation to a museum object and to navigate from one space to another to lead a tour in some set way. The first attempt to develop the SAN system discussed above aimed to use the raw data from these interview transcripts to extract a set of rules or guidelines for identifying such activity spaces and determining appropriate behavior in relation to them (for instance, that a robot should be able to recognize a person viewing an artwork and not pass between them, but rather navigate around). However, our interviews with museum visitors and staff complicated such an approach in a number of ways, demonstrating that there are several aspects of museums that are more difficult to determine or generalize about for purposes of designing a robot or planning its deployment in the space. For instance, across multiple interviews, human docents (tour guides) and museum visitors expressed the importance of fostering individualized experiences in museums. People highly value the ability to move through and experience the museum at their own pace, moving from exhibit to exhibit in a way that fits their interests, the time they have available, and other factors. This suggests (and observations of people's movements through museums confirm) that assuming a museum as an orderly space constituted by predictable movements from activity space to activity space would be an oversimplification. A robot tour guide designed to operate in such a way thus may not be of interest to many museum visitors, while a robot designed to operate in an environment constituted by such spatial practices may face challenges as it encounters a messier and more complex set of spatial behaviors in practice.

A further question arose during interviews with the museum directors and observations in the museums. As we discussed the various kinds of activities taking place within the museums, it quickly became clear that the museums host a much broader variety of activities than those discussed above—some planned and intended and others not. At a basic level, this means recognizing that museums see different kinds of visits and visitors, from individuals looking to pass time to large organized groups, which may interact with the space in a very different way. For instance, the Keck regularly hosts field trips for large groups of local primary school students. Beyond this, both museums also regularly host different kinds of public events, from launches for special exhibitions or receptions for other events on campus. In these moments, the spatial practices of the museum may be radically different, as people may move through the space to view items but may also gather in groups, while other temporary objects may be added to the space. In other words, the spaces take on multiple social functions at different moments in which the expectations and behaviors in the space may vary dramatically. A simple solution to this complexity may be to simply put the robot away during such moments, though if and when this would be necessary or desirable is an open question.

Beyond these moments, people tend to enter and make use of the museum for other purposes. As part of the broader university campus, the museums also act as spaces where students may pass time between classes or may find a corner to sit and read or study. As spaces open freely to the broader community, they may also be places where members of the public come to pass time or escape from the heat or cold outside (we reflect more on these connections between the museums and the broader community in the next section). It became clear through interviews and observation that these kinds of encounters were quite different across the two museums in question, partly due to the different publics that tend to frequent these spaces and the different aesthetics of each space that invite different kinds of practices. For instance, the Lilley is a new space, opened in 2019. It is a large, well-lit, open space with clean white walls and glass displays and paintings hanging from the walls or dividers. There are several places for students to sit and pass time (beanbag chairs), but it is rarely used as study space. The space has a highly modern look and feel. In contrast, the Keck has been open to the public since 1908. It is housed in a building with a lot of historical character and the museum collection is organized mostly in large, old wooden display cases in several narrow pathways. It has a distinctly "old West" look and feel to it. The older, more closed space leaves space for students to sit and study, as well as space for unsheltered people from the surrounding community to temporarily escape the elements—something that does not happen in the Lilly. These different aesthetics opened questions about how a robot might seem to "fit" or not in each space, but also how the different aesthetics invite different kinds of spatial practices in each museum. The presence of the robot itself, or the different kinds of behaviors the robot exhibits, might affect the ways different individuals experience the space and thus decide to engage it. These less structured and perhaps less intentional interactions with the museum were moments that the museum directors and visitors valued highly, as they add a liveliness to the space and allow people to engage (or not) in the museum exhibits in their own way. Several stakeholders expressed some concern that a robot tour guide may work (intentionally or unintentionally) to limit this dynamism and encourage or enforce a more structured engagement with the space—or instance, by approaching those entering the museum and trying to engage them in a set tour.

So in the end, while there may be a temptation to define what a museum is based on certain assumptions about the activities taking place, or even based on a foundational understanding of the museum as a space in which objects "spark wonder", there is a risk of underestimating the dynamism of such spaces. If a museum is really just a place where someone enters and follows a set route observing one object after another, that can be programmed and planned quite easily and the number of social rules that might have to be defined is perhaps more manageable. However, if a museum is a space where people experiment, improvise, and assemble their own experiences, then this is a different situation. Further, if a museum is not only a museum, but also a study space, a place for someone to kill time, and an event space catering to diverse audiences and publics, then this dynamism is something that needs to be accounted for and taken seriously. Yet, not all of these insights necessarily require changes or interventions in robotic design or programming, but perhaps require broader reflections about the *spaces* of HRI themselves. Reflecting at this scale highlights the limits of a robot-centric approach to HRI in which the goal of HRI is solely or primarily to inform robotic design. Instead, it perhaps highlights the potential roles of other actors, involved not just in robotic design but in decisions about when, how, and why a robot should be deployed or not, like the museum directors and community members. This became increasingly clear as we began to reflect on the broader social contexts in which the museums (and the human-robot interactions within them) are situated. We turn to some of these questions below.

3.3 Scale 3: robots in urban and regional context

The previous section highlighted several moments in which the broader social context of the museums became particularly evident in ways that contributed to making each museum unique and thus complicating generalizations about museum spaces or the activities that take place within them. This includes the ways the museums form part of a broader university campus and thus become spaces for students to pass time or study. It also includes the ways the museums are situated as part of a broader urban landscape shaped by social inequalities and a housing crisis, such that individuals may seek an escape from the elements in some of the very limited publicly accessible spaces available. As the project progressed it became increasingly clear that our reflections on the social entanglements of the museum robots (in development) needed to look beyond the museums themselves. In particular, it became clear that many of the attributes of the museums that made them unique (and thus perhaps difficult to generalize about in order to draw clear lessons for the design of a robot tour guide) stemmed from the museums' embedding in more extensive communities.

To begin, both museums are situated on the University of Nevada Reno campus, itself situated just north of downtown Reno. Reno is a highly diverse city and the main urban center in the vast and sparsely populated region of Northern Nevada. Reno has a colorful history, shaped by a gaming and tourism economy. From the 1930s to the 1960s, Reno was one of the easiest and quickest places in the USA to get a divorce, with a vibrant casino and leisure economy catering to divorcees and others (Barber 2008). These industries have historically attracted a population of transient and migrant workers. Only ~ 32% of the local population was born in the area, with large numbers of people migrating from other areas of the USA and abroad. In 2021, the city had a foreign born population of 15.6%, with Mexico, the Philippines, and El Salvador as the most common countries of origin. This diversity creates a highly dynamic cultural context. In interviews with museum stakeholders in the area, there was a clear awareness of this diversity. Indeed, many museum stakeholders see community engagement as a significant aspect of their mission, continually seeking ways to better cater to this diversity and to attract previously unreached populations to the museum. Within the museum community, there is also an active conversation about the lack of diversity in the museum docent core (which is overwhelmingly white, female, and older) and the ways to address this.

It quickly became clear that the project of designing and deploying a robot tour guide was intervening in this context, whether intended or not. This prompted a series of questions and reflections, most of which did not have clear or easy answers. For instance, a relatively easy challenge might be to ensure the robot is functional in multiple languages beyond English (based on the local population, this would be Spanish and Tagalog), or that its' communication abilities are intelligible to a non-native English speaking audience or able to understand accented English. Another question might be how a robot tour guide could help reach previously unengaged populations by creating a new attraction to the space; but also conversely, how it might repel others who do not feel comfortable around the robot. This second possibility was particularly a concern for the Keck. As mentioned above, the space is occasionally used as a place for unsheltered individuals to escape the elements and there was a concern that the robot might make these individuals feel less welcome. Additionally, the museum also attracts visitors from the more remote rural areas of the Northern Nevada region, some of whom tend to be quite skeptical of new technologies and sensitive to possible surveillance. While the Lilley tends to attract a very different public, interviews with those involved in the local art museum community also showed mixed feelings toward the integration of the robot, with some quite skeptical of such a move while others were more enthusiastic. How to use a robot to better engage the public, or to engage new publics, without alienating others is a complicated question for museum personnel to consider.

Yet, this diversity of users and perspectives also raises a difficult question for robot design and programming: If a robot tour guide is designed to meet existing expectations of museum spaces and the people within them (say, by adopting the "character" of a traditional tour guide or by reinforcing certain social conventions), would this contribute to reproducing existing practices of exclusion? An alternative, though certainly risky approach, might be to deliberately design or program a robot to subvert these conventions. These, and many other questions, remain open, but call attention to the need to understand the ways robots become entangled in more extensive and complex social geographies.

To complicate matters further, the City of Reno and the surrounding region are undergoing rapid change, as the city aims to rebrand itself as a major tech hub, distancing itself from its historical reliance on gaming. In the past decade, the city has attracted high-tech industries, including Tesla's Gigafactory (a large lithium-ion and electric vehicle battery factory) as well as smaller investments from Apple, Switch, and Google. More speculatively, in 2021, the area just outside the city was proposed as an "Innovation Zone" that would be developed into a blockchain-driven smart city catering to tech industries and entrepreneurs (Lynch and Muñoz-Viso 2024). Unsurprisingly, the university has aimed to position itself as a major player and partner in these economic shifts. While for some in the local community, this represents a welcome diversification of the local economy, for others it is much more controversial, driving shifts in the local character and culture and driving up housing costs, among other concerns. As the project of designing and deploying the tour guide robot moved ahead, it became clear that such a project would necessarily take on different significance within the context of these broader changes. Speculatively, we began to ask how the introduction of the robot might be seen as part of these changes and representative of the university's and region's interest in branding itself as a tech hub. Might people's engagement with or rejection of the robot be caught up in broader thoughts and emotions about regional changes?

Further, when we first conceived of the project in 2020, we were not aware of any other social robots operating in public in the Reno area and imagined that for most people the museum robot might be the first robot they interact with in person. Indeed, this is often an assumption in traditional approaches to HRI–which has not widely considered how regular, mundane interaction with a diversity of robots may eventually shape individuals' expectations and perceptions of robotic engagements. Yet, in the years following 2020, socially interactive robots proliferated in multiple spaces across the city. This included several robot waiters in restaurants in downtown Reno, robot security guards in at least one local casino, and the introduction of delivery robots on the UNR campus itself. A museum tour guide robot would thus become part of a more extensive robotic geography of the city, with the possibility that individuals interact with a variety of different robots in their everyday experience of the city and campus. In spring 2022 the project team conducted 10 short interviews with university students, faculty, and staff (in addition to many other informal conversations) regarding their perceptions of the delivery robots that were introduced on campus the previous fall. This research found a wide variety of perspectives, from those excited or interested in the robots (describing them as cute or friendly, or excitedly describing their interactions with them) to those who found them a nuisance, an invasion of public space, or a waste of time and resources. Many people (even those who were largely in favor) described their experiences sharing public space with these robots, including occasionally having a robot block their way or even appear to follow them. These robots operate just outside of both museums. How such experiences with other robots may affect a museum visitors' perceptions, expectations, or experiences of the museum robots would be an important question to consider moving forward.

To close, as the research team began exploring the broader contexts in which the museum robots would be situated, the list of possible questions and challenges related to the design and deployment of a robot in social space grew significantly. These included questions that might be easy to address through minor design interventions or decisions regarding how the robot might be used, but also a set of more speculative questions that open up to reflection about the ways robots are situated in social space and the complex entanglements they necessarily enter into when introduced in those spaces. It is clear from these reflections that not all of these questions can or should be reduced to decisions about robot design or programming. The broader regional context cannot simply be broken down into a set of variables to be considered in robot design. The meanings attached to the robot, the expectations and feelings of different publics, the ways different people view and experience the different museums are all incredibly complex and the introduction of a robot intervenes in this milieu.

4 Discussion: robotics-in-place and robotic placemaking?

The previous sections have traced the various reflections of the project team as we adjusted our focus from the microscale of human and robot embodied interactions to the museum as a specific social space to the robot and museum within a broader urban and regional context. Each scale has raised a different set of questions. Some questions may be appropriate for roboticists themselves or may inform robotic design and programming, while others may exceed such concerns, instead requiring broader conversations about when, where, and how robots should or should not be used and about the kinds of social spaces and interactions that we want to create and support. Reflecting across scales, for instance, might help inform decisions about the languages a robot should be able to communicate in to best serve the diversity of a community, about the way it might be programmed and trained to identify certain activity spaces particular to museum environments, and about the ways it might move through the space to maximize positive perceptions of its ability and social intelligence. Thinking across scales, however, also raises questions that might be less about the robot specifically, and more about the ways a robot might interact with and affect the spaces it enters—about the ways it becomes an active agent in the ongoing reproduction of those spaces. Likewise, this highlights a need to consider social space not as a background but as an active participant in the production and performance of human–robotic sociality. To do so involves negotiating the tensions of in/determinancy. While the scalar logic employed above is a helpful heuristic for organizing reflections around robotic spatialities, it may also risk giving a sense of order where there is significant disorder and emergence. For this reason, in this discussion and conclusion, we close with a reflection on robotics-in-*place* and speculatively ask what it might mean to think of robotic design and deployment from the perspective of *placemaking*. In doing so, we specifically aim to shift attention from a robot-centric approach to HRI toward practices of research and design that put the *places* of HRI at the center. While this may appear less immediately useful for roboticists themselves (as this lens is less likely to offer clear lessons for robotic design and programming), we argue that it is important precisely for recognizing the limits of robotic logics of control and negotiating this indeterminacy through more participatory approaches to robotic deployment.

"Place" has a long and complex history in geographic theory, though the contemporary use of the term across much of human geography refers to ways spaces or locations are made meaningful for different subjects. Cresswell (2009: p. 169) explains:

> Place is a meaningful site that combines location, locale, and sense of place. Location refers to an absolute point in space with a specific set of coordinates and measurable distances from other locations. Location refers to the 'where' of place. Locale refers to the material setting for social relations—the way a place looks. Locale includes the buildings, streets, parks, and other visible and tangible aspects of a place. Sense of place refers to the more nebulous meanings associated with a place: the feelings and emotions a place evokes. These meanings can be individual and based on personal biography or they can be shared. Shared senses of place are based on mediation and representation.

Reflecting on robotics-in-place thus calls for a continual reflection about where a robot is situated, how it interacts with the other material and functional elements of the locale, and the ways it becomes entangled in messier and more "nebulous" questions around sense of place. Such a framing of HRI can offer important reflections for questions of robotic design and programming, but also expand focus to other questions that would embrace the inherent indeterminacies of affective interactions and the ways these are caught up in more extensive geographies of meaning making.

Importantly, conceptions of place in geography help maintain this core tension between control and contingency. For instance, Pierce et al. (2011) explain how "Individuals bundle—that is, make places—by referencing and (re)configuring the many simultaneous places that they participate in; these place-bundles are socially negotiated, constantly changing and contingent." The authors go on to describe how Harvey (1996: p. 241) conceives of place as "temporary permanences" with placemaking as "as an iterative, evolutionary process of defining not just boundaries or territories, but the rules and norms against which socio-spatial practices are understood." In contrast, they explain how Massey (2005: p. 141) highlights the "ephemerality" of place as "temporary constellations" or meaning and experience. In this context, practices of placemaking are ongoing processes involving a range of actors who continually reproduce and negotiate meanings, expectations, norms, and experiences in ways that can be intentionally shaped and cultivated but that necessarily exceed the agency and intentions of any single actor.

Framing robotics and HRI as part of processes of placemaking would thus require ongoing reflection into the ways robots enter into and reshape these practices, as well as normative reflection into what roles they should, should not, or might play in these processes. It also requires a recognition of the limits of designers' agency and a need to more actively engage a broader variety of subjects and actors in decisions about robotic design and deployments. Attempts to make the robot "fit" a given place by overdefining its features, behaviors, or forms of expression will likely run into issues, as they also fail to recognize the radical difference of such spaces and the contingent ways people produce meaning from such spaces. Worse, they may reinforce a limited set of meanings for a given place, thus flattening the dynamism that makes places like museums interesting sites of encounter. At the same time, leaving things vague (not defining character or behavior) may allow people to project their own assumptions, which may also be problematic. This tension is something that can be discussed and negotiated through broad interdisciplinary and participatory processes, but requires an openness to different kinds of knowledge and experiences than those traditionally highlighted in HRI and robotics research.

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Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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