The robotic production of spatiality: Predictability, partitioning, and connection

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Abstract
Robots are an increasing presence in our public spaces. Accordingly, in this paper, we make an argument for the importance of understanding how they produce spatiality by developing three robotic logics: predictability, partitioning, and connection. We show how the robotic bias towards orderly categories exists alongside processual accounts of spatiality, and how the forms of anticipatory knowability that robots require play out in the contingent flow of everyday human life, where knowledge emerges as we move in and become engaged with our environments. We analyse the tensions at play here, reviewing how robotic programming and behaviours treat the spaces in which robots operate, and then interrogating robotic ways of understanding, structuring, and acting in their surroundings. This paper argues that, through the emplaced bodies of robots, their computational logics participate in an emergent production of spatiality that always exceeds their preference for knowability. Given that robots are already beginning to reconfigure our cities, we argue that unreflective accommodations of these logics should be resisted, and that we instead need better understandings of how robots’ logics shape their agential capacities in our shared worlds.

KEYWORDS
production of space, programming, public space, robots, spatiality

1 | INTRODUCTION

In this paper we give an account of how robotic programming and behaviours produce the spaces in which robots operate. We argue that, through the emplaced bodies of robots, their computational logics participate in an emergent production of spatiality that always exceeds their preference for knowability. We do so by framing robots through the braided logics of predictability, partitioning, and connection, and use this to explore the frictions and possibilities for our cities that configure through this dynamic technology.
Such an analysis is necessary because of the growing potential for robots to reconfigure our cities, which has been highlighed during the COVID-19 pandemic, when robots have demonstrated their distinctive capacity to shape a variety of spaces they share with humans (Sumartojo & Lugli, 2021). Novel uses saw the rapid modification or expansion of existing applications of robots, such as an increase in the delivery of groceries, take-away food, or prescription medicines to people’s homes (Cook & Valdez, 2021; Marr, 2020a); their use to patrol public parks to encourage social distancing (BBC, 2020); and the repurposing of existing platforms to sanitise hospital spaces with roving UV lights (Murphy et al., 2020). Moreover, a new generation of ‘social robots’, based in part on advances in facial and voice recognition, mobility, and machine learning, are starting to take on tasks that require sensitive, responsive, and flexible interactions with people and their surroundings (Del Casino, 2016). The growth in the use of these technologies during the pandemic was only an acceleration of a much longer process of the development and deployment of robots across multiple public and private settings. We will discuss how robots, such as in these examples, can contribute to the production of the spaces we share with them. Through their design and programming, they express a set of distinctive logics, derived from computational processes – and while these are not necessarily unique to robots, we argue that they articulate spatially through the bodies and actions of robots in ways that need to be considered as these technologies become more commonplace.

As in the examples above, we consider robots as self-contained machines, rather than, for example, chatbots or other dispersed or immaterial automated processes. They are often connected to networks of data and control beyond their individual bodies, and have some level of independent capacity to sense and act within their surroundings. Their physical presence – the way they move, the sounds they make, and how they look – are design aspects that often seek to visibly signal that they are robots. This is important to our arguments because it means that they are productive of space not only by what they do, but also that this productive capacity is apprehendable to the people around them as distinctively *robotic*. We return to this point in the final section.

We think with the types of robots mentioned above, ones that operate in public settings such as city streets, parks or train stations, or in shared interior spaces such as hospitals or restaurants. The robots that we consider are not spatially separated from people, in contradistinction to robots that operate, for example, in warehouses or factories where care is often taken to isolate them from the people working in the same environment (Delfanti, 2021). Our interest is in urban settings with distinctive forms of contingency and visibility to the general public, as opposed to those machines that operate in industrial or agricultural locations away from public view. This is not to deny the complexity of the range of settings where other robots might operate, or to preclude where our arguments might travel, but rather to be clear about the types of robots that sparked our arguments. Indeed, ‘robot’ is a very broad category of technology, defined by many different criteria – in this article, as we have described elsewhere, we discuss what we generalise as ‘robots in public space’ (Sumartojo et al., 2021; Tian et al., 2021) as machines that operate with and amongst people and many other creatures, objects, built environments, and technologies.

Despite the history of robotic technologies, the ones we think with are only beginning to appear in our public spaces – and these settings are dynamic, complex, and shared. Indeed, While et al. (2021, p. 770) point out that, so far, ‘robotic applications have been in controlled or semi-controlled environments, with relatively limited human interaction and controls to protect human safety’, but that ‘visions for the rolling out of robotic urbanism are proliferating’. As above, examples of the types of robots currently in use include delivery robots on footpaths, canals, and city precincts; security robots in neighbourhoods and transport hubs; robots undertaking cleaning or rubbish collection in airports and train stations; robots delivering food in restaurants; and robots doing a range of tasks in hospitals such as disinfection, information provision, and small-scale selection and delivery of medical equipment and pharmacy items. These robots are at work in settings that are usually not able to be modified specifically for robots – they must work *within* already existing flows of tasks, people, things, and materials, as opposed to, for example, manufacturing hubs designed specifically to accommodate them. We are interested in the implications of robots being part of everything else going on in complex and dynamic spatial environments.

The development and increasing use of robotic technologies has been accompanied by critiques of the overblown promise of robots and other automated technologies to transform our economies and societies. Pasquale (2020), for example, argues that such advances must be tempered with new ‘laws of robotics’ to prevent the social injustice and even violence that he argues will result from robotic logics that reduce the world they operate in to thresholds and decision points. Relatedly, Amoore (2020) questions how we might hold technology accountable when the algorithms that generate automated outcomes are themselves ensnared in and generative of a dispersed, ambiguous, and concatenated ‘cloud ethics’. More generally, Lynch (2021) calls for human geographers to engage critically with social robots precisely because of what they can tell us about space, intelligence, affect and emotion, and the ‘human’. These critiques have emerged at
the same time that robotic technologies are becoming more commonplace and are entangled in ‘making and remaking the structures, conditions and relations of everyday life’ (Del Casino et al., 2020, p. 606).

In this paper, we seek to look both beyond the specific tasks that robots are intended to perform, and below the wholesale transformative promise that some ascribe to them. Instead, we locate them in their everyday spatial and material contexts, in the places that they share with people, non-humans of many kinds, other technologies, laws and policies, forms of digital connection and networking, and more. We take up the question of how robots apprehend and traverse their worlds by exploring a set of logics that govern them and construct their worlds, logics that build on their animating computational processes, but that are practically expressed in the minor, everyday, and subtle effects on our shared spaces that their ways of operating instantiate. Building on an earlier sketch of the distinct ways that robots apprehend and operationalise the spaces they work in and move through (Sumartojo et al., 2020), we consider the robotic production of spatiality, and identify its implications for how we might live with robots into the future.

### 2 | ROBOTS AND THE PRODUCTION OF SPATIALITY

The autonomy of robots means that some level of agential capacity, even if limited, can be understood as inhereing in robots – but how that is expressed is highly contextual and made in the particular spatial assemblages that robots contribute to. That is, their autonomy is contingent on their contexts and who and what they relate to within them (Sumartojo & Lugli, 2021). Our interest in the robotic production of spatialities thus locates them in lively worlds where spatialities, relations, and affects continuously come together to shape their meaning, value, and effectiveness. In particular, as discussed above, we are interested in urban environments, where many examples of new robot uses are available. Accordingly, we start with a processual concept of place and space because this allows us to highlight how the robotic logics we discuss are articulated in its ‘throwntogetherness’ (Massey, 2005). If we treat spatiality as produced in the relationship between diverse trajectories, then ‘space-as-becoming’ is the arrangement of those trajectories in relation to one another, a process of ongoing configuration that is contingent on innumerable elements. Indeed, for Massey (2005, p. 58), how the body experiences space is informed by the body’s arrangement in relation to the multiplicity of things that it encounters, also characterised as the practices of negotiation and withdrawal that such co-presence requires (Iveson, 2007). Similarly, Young (2002) reflects on public space’s material and affective openness that generates a space of exposure and possibility, and Amin (2008, p. 6) argues that ‘human dynamics in public space are centrally influenced by the entanglement and circulation of human and non-human bodies and matter in general’. Here we can see the rich enmeshment of bodies of different types in an emerging, moving world, where those bodies are themselves made in and through their being-in-the-environment (Ingold, 2008), and where this environment includes a variety of materials and technologies that act on and through those bodies.

A processual account of spatiality, reflected in this sense of contingency, entanglement, and negotiation, is taken up in treatments of digitally mediated spatialities where space, technology, code, and their contexts are ‘interdependent, relational, and mutually constituted’ (Forlano, 2013, p. 2). Indeed, ‘autonomous or smart technologies ... are always reliant on and indeed constituted by their contexts’ (Sumartojo & Lugli, 2021, p. 8). Thrift and French’s (2002, p. 309) notion of the ‘automatic production of space’ provides a foundation to subsequent accounts, through their discussion of ‘software’s ability to act as a means of providing a new and complex form of automated spatiality’ where ‘new landscapes of code ... are now beginning to make their own emergent ways’ beyond and additional to human agency.

In their discussion of code/space, Dodge and Kitchin (2004) argue that software and spatiality are ongoingly and mutually constituted, and that therefore we must think of code/space as ‘constantly in a state of becoming’ where each aspect requires the other for spatiality to be produced. They build on this with a description of the transduction of space by digital code, a process in which software and digital technologies contribute to ‘the making anew of a domain in iterative and transformative individuations’ (Dodge & Kitchin, 2005, p. 170). Spatiality is thus ‘continually being brought into existence through ... practices that change the conditions under which space is (re)made’ (Dodge & Kitchin, 2005, p. 162) – practices which include the workings of code. While this paper is less concerned with code as such, this work explores forms of datafied spatialities that emerge through the code-based workings of computational processes, the articulations of which are not knowable in advance, and that are always changing and developing as they make contact with the world. It therefore offers a processual account of digital spatiality that this paper builds on.

Turning to social media, Merrill et al. (2020) offer a perspective on spatiality by contending that space is now always ‘more or less digital’, a phrase that ‘acknowledges that in societal contexts characterised by widespread digital technology and social media use, distinctions between the so-called “real” and “virtual” or “offline” and “online” are losing analytical utility’.
Recent work on smart cities and the distinctive spatialities they produce also discusses the deployment of robotics in urban space, arguing for attention to ‘novel manifestations of intelligence [that] are permeating the built environment and how cities are responding to them’ (Cugurullo, 2020). Because it is interested in messy and unpredictable ‘real life’ contexts, this work also shows how robotics does not account for the contingency of cities, and identifies the risk of producing limited forms of urban practice. For example, Barns (2021) questions how big data interventions into city environments, such as the creation of ‘digital twins’ to monitor and intervene in cities in aid of ‘efficiency’, might recreate routine urban patterns and the implications for possible urban futures. Batty (2018, p. 4) similarly discusses the contribution of AI to analysing patterns and, increasingly, automating urban routines, but points out that ‘it is the non-routine, the unexpected that cannot be anticipated by an AI’, with the implication that its use in planning will be limited to the short term. While et al. (2021) focus on city-scale experiments with robotics, identifying the importance of the policy and governance structures in experimental settings of robotic deployment. This body of work offers multiple critical approaches to the robotic production of spatiality, often linking it to digital processes of data collection and analysis, and the spatial interventions that can result.

Our account of robotic spatialities thus builds on an interdisciplinary body of work that takes up analysis and critiques of these emerging technologies. We do not, however, grapple directly with the critical issues of power, autonomy, and accountability that this and many other robotic applications demand. Shaw (2017), for example, posits a version of ‘robotic-being-in-the-world’ that frames robots as productive of ‘disruptive geographies’, with increasingly sophisticated capacities to embody algorithms designed to control and dominate. Focusing on policing and military applications, he demonstrates the ‘remote power topologies’ instantiated by autonomous robots, including their potential to act on ‘vast amounts of data that seize the future’ (Shaw, 2017, p. 6).

Instead, we take inspiration from Macrorie et al.’s (2021, p. 198) call to investigate robots in their capacity as a ‘mode of urban restructuring’, where life might be ‘shaped by extended and expanded robotic and automation possibilities’. However, our work shifts the focus to the immediate and emergent production of spatiality in relation to robotic bodies, rather than adopting a whole-of-city approach. In doing so, we toggle between the production of spatiality (centring the possible effects of robots on urban space) and the role of robots as participants in this production (centring the bodies, behaviours, and programming of robots). This reflects our interest in the production of urban spatiality and in the technologies that make and are made by it, taking inspiration from Ingold’s (2008, p. 1797) argument for an understanding of people as continually ‘becoming’ with their surroundings and their activities in them. Contrasting this with an ‘occupied’ world ‘furnished with already-existing things’, he says that a world ‘that is inhabited is woven from the strands of their continual coming-into-being’ (Ingold, 2008, p. 1797). We use this perspective to position robots as both productive of spatiality and ‘coming-into-being’ as emplaced inhabitants themselves. However, and as we show, the programmatic logics by which robots operate do not treat the world as one that is ongoingly ‘becoming’, or robots as continually ‘coming-into-being’, even if some resonances exist.

Accordingly, this paper extends research in robot geographies on already existing examples of robots, focused on automated labour of different types, including care (Del Casino, 2016; Sumartojo et al., 2021), agriculture (Bear &
Holloway, 2019), mining (Bissell, 2021), and transport infrastructure (Lin, 2022). However, rather than organising around a distinct economic sector or activity type, we work conceptually to interrogate robotic ways of apprehending, structuring, and acting in their surroundings, particularly for those machines that have some level of autonomy in their actions, and that we might expect to encounter in our shared public spaces. Our contribution is to show how robots can be generative of spatiality in the manner in which their processes and actions take place in their immediate surroundings. Like any other technology, robots operate in a world-in-motion, one replete with other technologies, people, things, organisms, and more. They are part of social, material, affective, political, legal, and spatial conditions, as well as digital elements that participate in this configuration in distinct ways. Moreover, the contingent and relational nature of urban space means that robotic effects and affects are unpredictable, relational, and emergent. We are interested in how the processual account of spatiality sketched out so far – one that highlights openness, relationality, and uncertainty – comes together with the robotic preference for knowability, a quality which also appears in smart city AI processes that treat the optimal outcome of analysis as improved prediction.

To make our arguments, the next three sections detail three computational logics displayed and enacted by robots, rooted in their programming, that are productive of spatiality. These are not distinct from each other, or necessarily able to be separated out, but together offer different perspectives on how robots might contribute to urban spatial configuration, and also highlight some of the potential implications of such spatial regimes. The three logics are: predictability, partitioning, and connection. We discuss each in turn, focusing as we do so on robots that, to varying degrees, already share our homes and public spaces, across a variety of applications.

3 | PREDICTABILITY

Earlier generations of robots, such as those used in manufacturing, were designed to do specific, often repetitive, highly precise tasks that present risks to humans. These tasks often occurred in controlled settings where there were high levels of certainty about what robots would encounter and how they would manage in their environments – and indeed, the fatal consequences for humans who might unexpectedly impede these tasks are well documented (Associated Press, 2015). In essence, this meant programming behaviours based on high levels of certainty about what might happen around the robot, predictions that were usually reliable on highly controlled factory floors.

More recent robots, however, are able to respond to more complex surroundings, such as a cleaning robot that stops when something blocks its path, or changes course when it detects a spill that needs mopping up. These robots work with both a combination of a predetermined map of the space where they are active, and on-board sensors that detect obstacles and pause or divert the robot's path as necessary. Despite the appearance of spontaneity, these responses are based on predictions made by the programmer regarding what the robot might encounter, including how the people around it might move (Cao et al., 2020) and the best responses to it. In other words, what looks like a spontaneous response is based on a prediction, made in the past, outside the immediate setting of the robot in the present. The appearance of autonomy, even in complex environments, is thus largely informed by ‘a priori knowledge e.g. some pre-analyzed human behaviors’ (Tiddi et al., 2020), and ‘anticipatory’ responses to complex environments (Bršić et al., 2015). Robots thus implicitly treat their surroundings as able to be predicted, because this is how they are able to take action within them. This is because they are programmed to work on identifiable tasks that must be anticipated before they can be attempted, and separated out as distinct from everything else that might be happening, even if these computational processes occur incredibly quickly.

While such predictive logics may be effective for tasks that require efficient repetition in controlled circumstances, such as a manufacturing line or a warehouse shelf grid where conditions are fairly controlled, it becomes more problematic in contingent, complex, and ongoingly configured public space. This goes further than a problem of inflexible programming or inadequate response. Instead, as Sam Kinsley (2012, p. 1557) argues, ‘actions that are anticipatory in nature involve rendering futures apparently actionable’. That is, in order to anticipate what might happen next, we not only have to imagine the future, we also need to have a way to understand and activate our own present in participating in and making that future. This implies that robotic logics of prediction might actively shape what can happen in an unknowable and processual world precisely because they work with predefined versions of that world in order to best respond in line with their programming. This is because when robotic programming is enacted, it brings the foresight and imagination of the programmer into the world.

This means that any response to new things that the robot encounters is often based on something that has happened before. An example might be withdrawal from a space where the robots can detect the presence of several small people. While these responses appear to anticipate a seemingly unknowable incident, such as the physical abuse of robots by
children (Brščić et al., 2015), such actions have been imagined and then programmed based on previous instances of such abuse. This is akin to what Amoore (2020) describes as a process of ‘precomputation’, describing how neural network algorithms work with probability to try and reduce uncertainty as they sift through and learn from enormous amounts of data. She identifies that such algorithms in robotics are trying to move towards forms of precomputation to help robots recognise aspects of their environments and make decisions about them, based on data sets necessarily based on the past. She uses the example of a surgical robot intended to recognise cancer tumours and help human surgeons excise it completely. As she explains:

To precompute is to already be able to recognise the attributes of something in advance, to make all actions imaginable in advance, to anticipate every encounter with a new subject or object, a new tumor or terrorist, by virtue of its proximity to or distance from a nearer neighbor.

(Amoore, 2020, p. 79)

Drawing together these ideas of anticipation, precomputation, and actionability, and applying them to robots in public space, we can see how reductive such logics could be as they drive recognition and decision-making in complex, dynamic, and emergent public spaces. Moreover, and as Amoore discusses at length, an effect of this is to scramble conventional logics of responsibility for the sometimes unjust or even violent outcomes of these processes.

A practical application of the robotic logic of predictability (or that the world is able to be predicted) is how delivery robots navigate public space. Here, one way the robot orders and moves through the world is by using maps that provide data about the machine’s immediate surroundings and what it might move through next. The map is treated by the robot as a guide to its surroundings, even though it is actually a form of predictive technology which, while powerful, is fallible. Indeed, the effectiveness of wayfinding technologies hinges on their capacity to not only make the world legible, but to introduce consistency to an otherwise complex space (Bosch & Gharaveis, 2017). By smoothing out space, digital wayfinding systems structure it in particular ways depending on what we anticipate we will want to know, such as features of the built environment like stairs or streets, or places to buy coffee or catch public transport (Sato et al., 2019). This contrasts with the lived experience of public space as the entanglement of diverse bodies, mass, and matter (Amin, 2008), that is constantly in flux. Even if robots continually are on the lookout for obstacles along the way, they still begin with a map to make sense of their surroundings and the best ways through it.

Recent advances in simultaneous localisation and mapping (SLAM), a technology through which robotic machines, including autonomous driving vehicles, continuously scan, monitor, and map their surroundings, offers an approach that simulates Ingold’s (2008) description of how humans are always ‘becoming’ with their worlds. However, even here, for robots the implication is that the world can be known if only enough data is gathered and processed. The robot’s ability to operate in its surroundings is only a matter of filling data gaps, but this knowability assumes a finite world exterior to the robot, rather than a processual one through which the robot and its surroundings are co-constituting. These algorithms also assume properties of the environment based on the sensors they use to create knowledge about the world. For example, when building a map using sensors (such as a camera and Lidar), if the space is empty of obstacles that are able to be detected by these sensors, then it is assumed to be available for navigation. There is usually no consideration of how the space is or might be used by people, or those things that the robot’s sensors are simply not designed to apprehend.

Thus, navigability exemplifies the tension between the process and contingency of public space on the one hand, and the logic of perfectible knowledge. In seeking to anticipate what the machine will encounter, and to be ready with a response to those conditions, robot programming treats the world’s becoming as able to be known in advance – and in so doing, calls particular futures into being by defining at least some of the parameters of what can happen. This is a way of understanding spatiality that is literally built into robotic technologies of many kinds, and that also flattens and simplifies their working environments into ‘data’. An implication is that such predictive or anticipatory responses treat the unknowable complexity of public space as something that can be parcelled into knowable parts, and thereby managed, as we discuss next.

4 | PARTITIONING

Just as the logic of prediction treats the world as knowable in advance, the logic of partition structures robots’ responses to that world as parcelled into discrete units of apprehension, assessment, and decision-making. This is because most programming generates robot activities as composed of many smaller decisions and movements strung together. For
example, in a study conducted by the authors, we used a programming interface designed for novice users that represented discrete robot behaviours as interlocking blocks (Tian et al., 2021). These could be moved around on the computer screen and placed in sequence to reflect the behaviours that our research participants wanted the robot to enact. The simple modularised system was a visual representation of programming code created by the roboticists in preparation for the project, and highlighted how the code was itself a series of smaller pre-programmed behaviours and decision points beaded together, even if these unspooled as one continuous behaviour. This showed precisely how robot programming dictates the partitioning of robot behaviours into small actions or decisions.

An implication is that the spaces in which robots operate must be similarly partitioned into manageable fields of action, with clearly assessable aspects (rendered as data, which we discuss below) against which decisions can be made. Robotic spatial logics replicate the structures, sequences, and flows of programming logics, where things happen in steps, and the spaces where they happen are fixed, even if only temporarily. In contrast, Ingold’s (2008) account of the spatialities of lived experience treat them as a category not of enclosure, where things are somehow frozen or complete, but of inhabitation, where we ongoingly create knowledge through our activities. As a result of always ‘knowing as we go’ the world is therefore always in a state of becoming, and he describes this ongoing engagement with the world, made as we listen, watch (and importantly) feel our way through it as ‘attentionality’ (Ingold, 2018). Attentionality is a way of participating in our surroundings through our bodies and senses, attending to ‘the terrain, the path and the elements … joining and participating with them’ as we move along (Ingold, 2018, p. 25).

This version of being in and with our surroundings, of knowing them through our inhabitation of them, is a contrast to the robotic pull to partition surroundings into discrete points of assessment and decision-making in order to respond to them. While attentionality recognises and accounts for how we might know the world and ourselves in it through a process of ongoing participation, robots are not enrolled in processes of becoming through experiential knowledge-making of their surroundings in the same way, even if artificial intelligence developments where robots accumulate information about their surroundings would seem to promise this. Rather, robots treat the flow of the ‘becoming of the world’ not only as able to be predicted, as above, but also as divisible into partitioned segments that become the focus of decision-making in order to meet programmed goals. Much like map-based navigability, this partitioning flattens the ongoing flow of life into points of action or decision, pulling against notions of spatiality as fluid, processual, ongoing, or experiential. Partitioning is a result of programming that is based on assessing and responding, which means decision-making along programming routes that require some form of computational prediction, as discussed above. Robots cannot enact attentionality, because they are fundamentally operating based on predictions about what might happen, and even if they are responsive to their surroundings, these responses are limited to what the programmer was able to predict and equip the robot with before the point of assessment and decision.

People can follow similar logics of partitioning when data is applied to everyday activities, orientating towards tasks as discrete and segmented rather than part of the ongoing flow of everyday life. In a study of cycle commuters, for example, Pink et al. (2017) investigated the experiences of people who make use of data as part of self-tracking routines, divide their travel routes into segments, and come to know the trace of their commuting routes in terms of the data created along it, such as speed and time. Individual segments of the route are assessed, measured, and compared with the data created by others in the cycling community. Here, a process of partitioning is generative of spatiality precisely because of and through the data created as part of this everyday activity. However, even when segmented into discrete distances that people aim to complete within certain time or speed parameters, such routines remain open as sites of improvisation (Pink et al., 2017). People experience, evaluate, and respond to unexpected events such as a tyre puncture or a broken spoke, or a change in after-work plans. So, while the logics of partitioning and connection (discussed next) may produce the experience of spatiality in particular ways, they recognise that what will actually happen, even during routine tasks, cannot be predetermined. Put differently, even if people have internalised data-driven logics, they retain the capacity for improvisation, flexibility, and change within the contexts they inhabit and the routines they enact. In contrast, for robots, routine tasks are enacted as part of programmed sequences which anticipate and thus prefigure their surroundings.

One reason for this is that robots are necessarily task-focused – to deliver, clean, or patrol, for example – and these tasks are broken down into smaller component parts, each of which require a decision for action or response. The programming sequences described above play out in stacked activities. A simple example might be when a cleaning robot moves to a particular place, and then assesses if the spot needs cleaning, and then executes the cleaning activity. Along the way, it needs to monitor who and what is around it, stop if it encounters something in its path, and perhaps navigate around this impediment. Tasks might be tackled sequentially or in parallel, such as when a robot moves and monitors at the same time, or stops, assesses, and then cleans in that order. That is, even when robots are able to do more than one thing at a time, they still partition those things into separable actions. However, they do not inhabit environments in
terms of becoming along with it – rather their worlds are ‘furnished with already-existing things’ (Ingold, 2008, p. 1797). A robot must thus categorise its environment into aspects that it already knows about, and if it encounters something novel, its options are limited by what it already knows. There is currently a debate in robotics about using partitioning in this way as opposed to end-to-end learning, where a single neural network provides the mapping between sensor observations (e.g., camera) and action (e.g., robot movement) without any design of sub-modules. However, even if end-to-end learning promises to enable robots to continually absorb, categorise, and act on new information, and perhaps respond to novel situations more appropriately as a result, the simple tasks of delivery or cleaning robots do not yet stretch to this level of computational sophistication.

5  |  CONNECTION

A third logic of robot spatialities is connection – or the ability of robots to access and add to networked data about their spatial surroundings and the people and things in them. Like many other technologies around us all the time, robots operate in a world of existing and potential data, and the networked connections that make this data available and actionable. While robots have always required some understanding of their surroundings (rendered as data) to support their computational processes of autonomous action and decision-making, their ability to join shared networks and connect to other robots, smart devices, remote cloud-based storage, and computational resources is increasing rapidly. One instance of how robotic connection can work is in networked robots, with multiple devices working together, and connected via a communication network, such as the internet or a local area network. An example of their use is in manufacturing where robots might operate in ‘workcells’ connected with other robots, sensors, and people overseeing their actions. ‘Pipebots’ are a practical application being developed, groups of robots that map and monitor urban water and sewerage infrastructure, feeding back information about leaks or blockages to enable necessary repairs or upgrades (Doychinov, 2021). The capacity to autonomously monitor, create new flows of information, and act on what they can sense also has more invasive applications: drones were deployed during the COVID-19 pandemic in 2020 in several Chinese cities to identify people not wearing face masks, broadcast official messages via loudspeakers, and use thermal sensors to identify people with higher-than-usual temperatures, a symptom of viral infection (Marr, 2020b).

Recent developments in the ‘Internet of Robotic Things’ (IoRT) bring together two distinct types of technology: Internet of Things technology that can sense, track, and monitor, and robotic systems that can produce ‘action, interaction and autonomous behaviour’ (Simoens et al., 2018, p. 1). By connecting the networked sensing capacities of existing smart technologies with the autonomous spatial and physical abilities of robots, early versions of the IoRT already exist in agriculture, for example, where mobile robots are deployed to collect precise sensor-based information about weather or soil conditions, and share this online (Villa et al., 2021). An implication of the IoRT is that robots themselves can act as mobile sensors, feeding data to other machines; they might also access and control other ‘smart’ things, such as automatic doors or elevators, in logistics or assistive applications, or set up communication nodes in remote locations that people cannot reach during search and rescue operations (Simoens et al., 2018, p. 3). Integrating robots into massive data streams, such as those created through smart cities, is being pursued by connecting them to dispersed computing power. ‘Cloud robotics’ (Kuffner, 2010) is a way to hold computational processing and storage not in the robot itself, but on servers that robots are wirelessly connected to, making them much more capable for tasks that require a lot of processing, like speech, image, or facial recognition, or real-time scanning of surroundings.

Amoore (2020, pp. 76–77) identifies how computer scientists are similarly exploring whether exposure to massive amounts of data might help, as she says ‘optimise the neural networks’ capacity to learn how to recognise and how to act. The development of ‘regimes of recognition’ (Amoore, 2020, p. 71) has ethicopolitical implications in its determination and valuing of what is able to be apprehended. That is, data is not just information about the world that is somehow usable or actionable if only it can be reckoned with quickly enough, but is also a means for robotic technologies to learn how to exercise new forms of agency. This chimes with Kinsley’s (2012) notion of how anticipation is a form of making the future actionable, as discussed above, and also goes beyond conventional notions of data as the ordering, management, or regulation of our world. Instead, Amoore moves towards a distinctive account of how datafied logics might give rise to complex new forms of computerised and robotic agency that cannot be traced directly or neatly back to human programming.

Although robotic data connectivity such as the IoRT is not yet widespread, it nevertheless resonates with critiques of the dramatic inequalities of code-based automated smart cities, if we extend this to the ways that spatialities can be produced through computational processes that include this aspect. Klauser et al. (2014, p. 870) provide examples of
the problematic discursive landscapes and inequitable power dynamics in everyday lives where code has a governing function, worlds where social life is optimised, ordered, and regulated through computational and software logics. One reason for the concerns about the uneven impact and inequity that could accompany these visions of connected and autonomous ‘ubiquitous robotics’ is the fact that the data streams and networks in which robots are immersed are just as contingent, unknowable, and emergent as the other spaces we have been discussing so far. That is, the ‘thrown-togetherness’ that typifies processual accounts of public space extends to its digital and datafied aspects. Leszczynski (2015, p. 745) argues that spatiality is ‘always-already mediated’; an effect of the ‘multiple yet momentary comings-together of person places, and emergent spatial technologies’. Similarly, Pink et al. (2016) argue that we also need new concepts of ongoing ‘digital materialities’ that show how they emerge from the processes and experiences of everyday life.

Building on this to develop a concept of ‘datafied space’, Sumartojo et al. (2016, p. 35) propose ‘to draw together the ways that we move through the world as ongoing, processual and unfinished with the emergent and contingent affective intensities that accompany that movement, and the accompanying creation of data’. This introduces the question of how digital technologies, datafication, and connection to data networks feel, by drawing attention to the affective ebbs and flows that emerge from our production, interaction, and reflection on data, which are already normalised in our lives. Indeed, one way the robotic logic of connection supports distinct forms of feeling is through how they can extend how we sense our worlds. In a discussion of drones, for example, Garrett and Anderson (2018) explain how drones’ ability to perceive their surroundings, and to connect to the senses and feelings of their human operators, opens up new ways of knowing aerial spaces that previously were not so readily accessible. Building in this, Lockhart et al. (2021, p. 853) argue that ‘drone ecosystems’ can be thought of as infrastructures for ‘exploiting volumetric space as a useable resource’ for a wide range of purposes – that is, the connections between human and robotic forms of apprehension create new forms of datafied space through sensor and affective routes.

However, a computational logic of connection can come together with a processual account of spatiality, only if we recognise and embrace its entanglement with the unpredictable, immaterial, felt, and emergent qualities of our worlds. By exploring the notion of connection to data flows through the bodies and actions of robots, which are themselves unwitting participants in an emergent world, we locate it in the actions of mobile technologies in a world imbued with processes and pools of data creation and collection, data flows and glitches, and data-driven decision-making that has a range of unpredictable, uncertain, and unending consequences. This is decidedly not a flattened or simplified world in stasis, as the logics of prediction and partition discussed so far would suggest. Instead, a processual account of the spaces that robots operate in extends to their connected aspects.

Accordingly, the robotic logic of connection as we have discussed it here does two things. First, it has the potential to link robots to large amounts of data, and the capacity to compute with it. This effectively treats the robot’s surroundings as a form of datafied space that is reducible to these specific points of information, similar to our discussion above of prediction and partitioning. Second, it renders this data actionable because the robots are able to interact with their environments in some way. Questions like: ‘Is that pipe broken?’ or ‘How damp is that patch of soil?’ or ‘Is this person following the mask-wearing rules?’ can be answered by sharing visual information or enacting a set of sensing behaviours. That information can then become the basis upon which the robot takes subsequent action. While this aspect of coordinated and networked robots is not yet commonplace, it implies new forms of agency and raises important questions about the ethics and autonomy of these technologies.

6 | IMPLICATIONS

The logics we have discussed above are not unique to robots – indeed, they are extensions of computational processes that also animate other digital systems productive of urban spatiality, such as predictive analytics related to policing and surveillance or intelligent traffic control. However, robots offer valuable insight into the technological production of urban spatiality because robots are individual machines, with distinctive materialities that contribute to their surroundings, even if they connect beyond their self-contained bodies to larger networks of sensing, data collection, and control. Their agency is exercised through physical actions in the material world, recalling Bratton’s (2021, p. 1308) argument that we need to consider how computational processes animated by artificial intelligence actually touch the world, with ‘synthetic sensing and intelligence ... a distributed function of the material world’. These actually existing materialities are excessive of robots’ computational preference for knowability – an excess that has been described as a form of ‘liveliness’ (Sumartojo & Lugli, 2021) which might create new possibilities through their very presence in ways that cannot be anticipated or prefigured. These might be problematic, as in the example of
a delivery robot that did not recognise a woman in a wheelchair as a person to which it should defer shared space, and blocked her access to a footpath (Ackerman, 2019). This excessive quality, however, also offers rich material for engineers and designers to think with, such as how robots might best signal their ‘robotness’ and how this could contribute to more playful or even inclusive public spaces.

The framework we present in this paper has emerged from collaborative projects between social scientists and engineers that considered the contribution of different kinds of robots in the everyday urban places we already or might one day share with them (Sumartojo et al., 2021; Tian et al., 2021). We have argued that their programming shapes how they produce spatiality, and that there is a tension between this and processual accounts of space and place. This means that their material presence offers up intriguing potential for public space, and that we need to understand this to best reckon with robots’ increasing presence and agential capacities in our shared worlds – and to contribute to their development into the future. Moreover, we contend that this work needs to be done in collaboration between social scientists and robot designers and programmers.

This work is needed because one implication of robots becoming more commonplace is the possibility of simplifying their surroundings to make it easier for robots to be effective. Cities purposefully designed for robots would have more predictable rhythms and patterns, flowing in partitionable packets of super-connected data. We already see examples of robot-centric spaces with the creation of lanes on highways where it is easier for automated driving vehicles to operate, and more recently, proposals for dedicated roads solely for these technologies. Some cities’ orderly planning and spacious urban design already lend themselves to the use of public space robots (see Cook & Valdez, 2021). These cases show how designing urban spaces for robots’ preference for a world that is knowable, where uncertainty is managed and diminished as far as possible, could emerge. This includes enabling connection to more and more data, intended to result in more precise predictions and better robotic responses.

In contrast, some robotics research explicitly seeks to work with uncertainty, for example in the context of driverless vehicles, in systems that seek to learn alongside people, in ‘end-to-end’ programming that seeks to train the robot system as a whole, or in work on curiosity-driven robots. Indeed, Sun et al. (2019) propose ‘adaptive learning’ as an approach by which robots might respond to complexity on-the-go, seeing this as an opportunity for robots to not only draw on their immediate sensory data, but to combine that data with other sources such as maps. This could help robots enact near-real-time anticipation of potential obstacles, such as where someone might walk, and avoid blocking them.

Even here, however, the anticipation and response that underpin adaptive learning, for example, highlights the logics that simplify and flatten space. For example, in the emerging field of robot–city interaction (RCI), where the problem of the relationship between robots and cities is framed as a problem of how robots can better cooperate with city environments (Tiddi et al., 2020), the robot remains centred. A more expansive approach would put urban space at the centre of inquiry, rather than robots themselves, and position them as productive of spatiality: indeed, Amin (2008, p. 8) avers that ‘the formative sites of urban public culture – collective forms of being human through shared practices – need not be restricted to those with a purely human/inter-human character, but should also include other inputs such as space, technological intermediaries, objects, nature and so on’. The logics we discuss here are not the only logics present in robots – indeed, more dynamic approaches, such as non-linearity and adaptive learning discussed above, have contributed to development and design of robotics. However, our point is that if the logics we describe here can be more explicitly understood, then robots that work with a concept of emergence, perhaps by ‘becoming’ with their environments, are possible.

Accordingly, we argue that to open new understandings of how robots are productive of spatiality, and reckon with the implications of their contributions, we need to consider how they are designed and programmed to operate, as well as the impacts they have on us and the worlds we share with them. Even as data and computational and algorithmic logics come to mediate our ways of interacting with each other more and more, the processual approach to spatiality we adopt in this paper shows how the computational bias towards orderly categories – and their articulation in robots and other technologies – will always need to grapple with the contingent flow of everyday life. It is important to understand this tension because the drive towards ever-increasing efficiency and productivity – the very forces that underpinned the invention of automated technologies in the first place – ensure that robots and their production of spatialities will only become more commonplace.

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