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Regulating sidewalk delivery robots as a disruptive new urban technology

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ABSTRACT

Sidewalk delivery robots are increasingly being deployed in diverse urban contexts, raising issues about the most appropriate form of regulation to maintain pedestrian flows and protect the public. This paper examines the evolution of sidewalk robot governance in a "hot spot" of urban robotic application in the State of California (USA), where different municipal authorities have experimented with prohibitive, permissive and collaborative forms of sidewalk re-regulation in response to the various potential disruptions and risks associated with the new technology. Combining detailed policy analysis and interviews, the paper takes forward literature on the regulatory challenges and opportunities in making space for urban robotics as a disruptive technology.

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Delivery; robot; sidewalk; California; urban; governance

Introduction

Internationally there is growing interest in the possibilities for automation of human mobility, delivery services and urban security services in the public realm of cities (Macrorie et al., 2019). Robotic applications create opportunities for enhancing the efficiency of urban infrastructure and management, but they also create significant challenges for human–robotic interaction, including issues of public safety, the physical constraints of existing urban form and potential ethical and political concerns about privacy, increased surveillance and social control (Woo et al., 2020). Urban robots are a disruptive technology because they need to operate in the messy complexities of the public realm coexisting with flows of humans and motorized vehicles, challenging established regulatory frameworks and disturbing accepted conventions of human–machine interaction, such as traffic lights, air traffic control, street crossing behavior and so on (Sumartojo et al., 2021). This is happening when the safety of urban robots is unproven and undemonstrated in the existing urban environment, and their design is being refined and modified through the co-evolution of application, learning and technological development.

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Disruptive technologies are social, socio-technical and spatial active interventions within the existing material and immaterial structures and infrastructures of, everyday life and human experience (Hopster, 2021, p. 1). Urban research and policy have started to explore the challenges and opportunities in "opening up urban space" for potentially disruptive urban robotic applications in relation to autonomous aerial vehicles (drones), autonomous vehicles and street-level service, delivery and policing robots (Urban Robotics Foundation, 2021; While et al., 2020). This novel landscape of urban robotics is a fascinating site of the socio-technical development of new machinic assemblages. Constructing new relationships between robots and everyday familiar surroundings brings robots into new social and material urban networks (Latour, 1987, 2005). Attention in urban robotics is increasingly turning to the ways in which new potentially disruptive robotic applications are being governed, including the capacity of governments to create facilitating legislation, the degree of public acceptance and the strategies of technology firms. This is very much a geographically specific and differentiated process. As Sumartojo et al. (2022) suggest, "robot geographies" produce spatiality through logics such as predictability, partitioning and connection, and "the anticipatory knowability". Robot geographies thus necessitate better understandings of how computational robotic logics "shape their agential capacities in our shared worlds" (Sumartojo et al., 2022, p. 56).

Our concern in this paper is with a particular type of urban robotics – the street-level autonomous delivery vehicle (ADV)[1] and, specifically, the sidewalk delivery robot (SDR) – distinguished from autonomous vehicles (AVs) and flying ADVs by their presence on sidewalks rather than roads or in the skies. Different SDR companies have different designs for different delivery purposes but, in essence, a SDR is (in its initial manifestations at least) a fairly small box-like wheeled robot around 70 cm long, 60 cm wide and 60 cm high, with a weight of around 23 kg, that operates autonomously to navigate streets and sidewalks with the possibility of human intervention. SDRs typically move at a pedestrian speed up to 6 km/h (3.7 mph) and can carry a payload of around 10 kg within a 6 km (4-mile radius). The cargo bay is opened by the recipient through a smartphone. SDR use many of the same features as autonomous cars, including cameras for vision, ultrasonic sensors, GPS navigation, gyroscopes and so on. The use of SDR has been developed and used by established delivery firms such as Amazon and Fedex, but also robotic-led firms such as KiwiBot, Postmates, Marble, Starship Technologies, BoxBot, Dispatch, Nuro and Robby Technologies.

SDR application has been particularly prevalent in the USA, reflecting the vibrant urban robotic start-up milieu and the impact of just-in-time personalized delivery of goods and food pioneered by Amazon, Deliveroo and other companies. SDRs are being seen as the solution to the so-called "last mile delivery" problem – how to get goods and food to multiple individual customers from restaurants or delivery hubs given the congestion of city streets and reducing dependence of human labor. In many urban contexts SDRs are likely to be the first visible signs of the urban robotic transformation because they are potentially less dangerous and less disruptive than autonomous vehicles and drones. Their small-scale, boxiness and attractive design invariably means that SDR tends to be seen as a benign novelty, even though some have been vandalized. Nevertheless, SDR have the potential to disrupt and damage existing sidewalk and road used and often require a change in land-use planning and transport ordinances to

regulate their co-existence with existing uses of streets and sidewalks. In this respect, issues about making space for SDRs might overlap with the challenges of making space for non-robotic e-bikes and e-scooters and certainly with the regulation of AVs. Whilst overlaps with e-bikes and e-scooters will be explored, our interest is primarily on the direct and complex combination of human–robotic interaction on the restricted space of sidewalks. In most cases e-bikes and e-scooters have been limited to on-road use or cycle lanes, building on existing modes of regulation and they do not operate at a distance from direct human control. In contrast, the SDR is entirely new and has required a new regulatory framework to be developed with no antecedent technologies. For the most part, AVs will, initially at least, operate on roadways with limited human interaction. Nevertheless, these disruptive technologies are seen as part of the most significant rethinking of urban mobility (and urban mobility infrastructure) since the extended use of the automobile.

This paper examines local regulatory responses to novel robotic assemblages focusing on how new modes of regulation are being constructed to accommodate them, and what that might mean for the shaping of robot–human relations. Empirically we focus on California (USA), which has been a key geographical locale for SDR regulation that also spans a range of urban land use, morphological and governance contexts. The objectives of the paper are three-fold: (i) to explore how robotic applications are being conducted and what socio-spatial issues they reveal/generate; (ii) to analyze how new regulations that are regulating both robots and urban infrastructure are being relationally developed and applied; and (iii) to examine the broader outcomes of robotic-urban relations in order to identify how to responsibly accommodate emerging technologies in urban spaces.

SDRs are especially interesting because they involve multiple robots with complicated individual journeys that interact with humans in socially and physically complex spaces, rather than "built environments" (Cugurullo, 2020, p. 9). Consequently, given the complexity of the human-only sidewalk we conceive of the robot-urban relationship as a form of co-production that "both embeds and is embedded in social practices, identities, norms, conventions, discourses, instruments and institutions – in short, in all the building blocks of what we term the social" (Jasanoff, 2004, p. 3). The paper is based on 13 formal interviews and over 20 informal interviews and multiple site visits with the city and state government officials and private companies involved in introducing robots in San Francisco, the Berkeley campus of the University of California, Palo Alto, Sunnyvale, Mountain View, Redwood City and San Jose undertaken in a month study visit in late 2018. These cities and municipalities are located in various places in the San Francisco Bay Area, with the city San Francisco and the Berkeley campus to the north of the Bay Area and Palo Alto, Sunnyvale, Mountain View and Redwood City clustered in "Silicon Valley" to the south of the Bay Area. These different places represent a range of "urban" contexts in terms of population size, urban morphology and local socio-political context. The methodology "chased" robots and followed robots "in action", in a version of Bruno Latour's (1987) following of scientists and engineers through society. The idea was to observe social interactions and interfaces between humans and robots, between robotics designers and firms and governments, and between robots and urban space, to discern the emerging socio-technical-regulatory structures of robotized urban infrastructure. The empirical research methods were an interplay between desk-

based analysis of policy (including regulations and legal frameworks) and interviews with municipal officials and robot delivery firms. In total 21 interviews were undertaken between 1 October 2018 and 1 November 2018. The interviews included specific questions about the changes in regulation in different localities as well as broader questions about the unfolding possibilities for robotic applications in urban areas.

The paper is divided into five sections. The second section outlines the key issues involved in the process of robots moving from closed spaces into the public realm of cities. The third section identifies the core issues of managing access to the sidewalk and the devolved processes through which SDRs as a disruptive technology are being regulated. The fourth section examines California's development of regulatory capacity for SDRs and the three modes of application that have emerged. The fifth section focuses on robot-urban regulatory practice in San Francisco exploring the movement between different regulatory modes and the challenges of creating a collaborative framework for emerging technologies. The sixth section synthesizes the key findings illustrating the difficulties and limits of governing emerging disruptive technologies at the urban level and identifying the implications for further research.

SDRs: a new disruptive urban technology

SDR are part of the extended application of robotics and autonomous systems in urban areas because of advances in machine learning, field robotics and AI (Cugurullo, 2020; Woo et al., 2020). Other examples of public realm "urban field robots" include unmanned aerial vehicles (notably drones), autonomous vehicles and various service robots. Academic research and media articles have charted the rise of urban robotic initiatives with urban governments, firms, robotics researchers and police and security forces seeking to "open up" the public realm to robotic applications (Masterson, 2023). For urban governments, urban robotics might be seen as a way of addressing congestion, improving logistics, reducing dependence on human labor, extending policing and surveillance, embracing modernity or promoting economic development. For firms and robotic developers, the city is a new frontier and robotics are a potential answer to issues such as the "last mile" problem in increasingly personalized just-in-time delivery systems. The affordances of the urban robot are about reducing dependence on human labor but also the potential to rework, rethink and perhaps intensify the use of urban streets, sidewalks and skies in search of the freer flow of goods and people (Loke & Rakotonirainy, 2021). Furthermore, as a form of disruption, smart mobility shows that the governance solutions are shaped by how the logistics and mobility problems are framed, with smart mobility being both a disruptor as well as affirming the existing ways that the logistics of urban mobility are understood and presented (Dowling, 2018).

Urban robotics are therefore potentially a new infrastructure within the city that is distinctive because robots can operate with different levels of autonomy. For instance, Starship Technologies' SDRs can function with 99–100% autonomy (Starship, n.d.b). The degree of autonomy, however, refers to the ability of SDRs to perform the programmed, defined, task without human intervention and not the ability to operate autonomously beyond what they are pre-programmed to do. This means that regulations do not currently need to accommodate differing levels of autonomy as there is a universal

requirement that the SDR is always monitored, either by a human attendant or undertaken remotely.

Sumartojo et al. (2021) define robots as "physically and digitally autonomous machines with defined tasks, that interact with their surroundings in limited but active ways" – *active* being the key point. Despite their limitations, by being *actively* involved in the urban space, robots open up a set of future developmental possibilities. This is why Sumartojo et al. (2021) shift their "focus to feelings and understanding of what robots *might* or *could* do", shaping "the nature of its intervention into public space" (pp. 99–100, emphasis in the original). This is precisely the meaning of the idea of "emerging" technology. However, in our interviews with governments and companies, both admitted that they do not know what robots *might* or *could* do in the future. Therefore, the regulation is focused on what they *can* do in the present. Thus, the immediate concern for robotic interests seeking to open up the city (at least in applications outside of policing) has been fairly narrowly focused on issues of public safety (see Salvini et al., 2021). This is partly an issue of finding urban spaces where technology can be trialed and demonstrated to allay concerns about public health and the ability of robots to negotiate other users of streets, skies and, for our particular concern in this paper, sidewalks.

In the US, sidewalk r applications developed rapidly since 2016 when Starship Technologies, an Estonian company founded in 2014 by two Skype co-founders, launched delivery robots on sidewalks, reflecting the relative maturity of the underlying technology (Hoffman & Prause, 2018). The first application on city streets was in San Francisco and Redwood City. The SDR have been developed and promoted by new robotic delivery companies (which transport the goods and food of other companies) and by established delivery companies (Amazon, FedEx) seeking to improve service delivery. It is estimated that SDRs reduce delivery costs by up to 15 times compared with other methods of last mile delivery (Hoffman & Prause, 2018). Starship is an example of a pioneering robotic delivery company that began early sidewalk testing in London, Berlin and San Francisco, continuously opening up global testing ground. The technology to operate effective SDRs was developed quickly, and – as with drones – the challenge is not technical but the issue of opening up spaces to trial, demonstrate and refine the systems given the potential disruption to sidewalks and uncertainty about safety.

There is a large and diverse literature on ideas of disruptive technologies and disruptive innovation. Following Hopster (2021), our preference when examining the transformative impacts of urban robotics is to use the two terms "social" and "sociotechnical" disruption because:

> with its focus on processes of market disruption, disruptive innovation theory [per se] does little to illuminate the broader dynamics of social transformation engendered by new technologies … an understanding of technological disruption is needed that is not limited to markets and business, but that also serves to illuminate how technologies can disrupt social relations, institutions, epistemic paradigms, foundational concepts, values, and the very nature of human cognition and experience. (p. 1)

Furthermore, we would add the word "spatial" to this enlarged formulation of disruption because of the place-based nature of urban robotics and their transformative-disruptive impacts in specific socio-material contexts. The disruptive-transformative impact of SDRs is about the combination of disruptive innovations in personalized delivery

systems and the means of facilitating delivery through robotic application. However, our focus is not on the disruptive impacts of personalized delivery systems on the operation and location of retail and restaurants but is instead focused on the material spatial disruption of the public realm of the sidewalk.

Governing SDRs as socio-technical spatial disruption

At the core of making space for sidewalk robots is the question of how the introduction of potentially disruptive technologies is managed and regulated. SDR needs various forms of regulation and management to protect infrastructures and interests from their disruptive impacts. In the case of SDR, these are a combination of public safety and protecting the rights, flows and movement patterns of citizens. Some form of "adaptive" or "soft" regulation (Fenwick et al., 2017; Hagemann et al., 2018) might be required to account for the "pacing problem" (whereby innovation runs more quickly than the capacity for regulatory change) and the co-evolution of technology, human behavior and changes in the built environment:

> In an age of constant, complex and disruptive technological innovation, knowing what, when, and how to structure regulatory interventions has become more difficult. Regulators find themselves in a situation where they believe they must opt for either reckless action (regulation without sufficient facts) or paralysis (doing nothing). Inevitably in such a case, caution tends to trump risk. But such caution merely functions to reinforce the status quo and makes it harder for new technologies to reach the market in a timely or efficient manner. The solution: law making and regulatory design needs to become more proactive, dynamic, and responsive. So how can regulators actually achieve these goals? (Fenwick et al., 2017, p. 561)

As the disruptive technology co-evolves with the surrounding environment it becomes part of the fabric of everyday life. This form of co-evolution can involve a mix of infrastructural changes, restrictions on the application of technology, technological innovation or changes in human attitudes and behavior. The mix of co-evolution factors in case of SDR will be contingent on the existing infrastructure, the nature of the robot and the extent of robotic activity that is proposed.

Understanding the context for the use of robots on sidewalks means we need to examine the historical development of sidewalks and trace the co-evolution of robotics with urban context, forms of application and regulatory frameworks (see Diamandis & Kotler, 2020). The infrastructure of urban sidewalks has been so well established that most of us take sidewalks for "granted" as an "undervalued element of the urban form" (Loukaitou-Sideris & Ehrenfeucht, 2009, p. 3). In *Sidewalks*, Loukaitou-Sideris and Ehrenfeucht examine the history of conflicts, contestations, and other forms of social engagement on and around sidewalks from the eighteenth century to the present. This includes the creation of sidewalks, using sidewalks to negotiate, challenge and assert social hierarchies, and sidewalks as economic and political forms, shelters and spaces for regulation and control (2009). Walk San Francisco, an NGO advocating the safety of sidewalks and challenging non-human users of sidewalks, suggest that:

> Sidewalks are our refuge as pedestrians. Sidewalks are the one place where we are safe. It's where we get to relax a little, soak up the energy of the city, and connect with others. (Medeiros, 2018)

Crucially, although there can be an intense politics of the sidewalk, that politics historically has revolved around the right of *humans* to roam in the city, first in relation to the balance between public and private interests in the zoning of the city, and second in relation to the impact of technologies such as the car (and car-based urban planning) that have been criticized for constraining the nature and quality of urban walking (see Jane Jacobs 1961). In many countries, since the 1970s there have been initiatives to reverse the dominance of pedestrian-unfriendly automobile-based planning in order to prioritize rather than marginalize the pedestrian experience (Yassin, 2019). The critical issue then is how robots interconnect with an existing space of networked infrastructure that already has to contain complex and conflicting uses primarily designed for human pedestrians.

Within urban governments, multiple departments are usually involved in the regulation of sidewalks, and users have the right to use them in everyday travel and social interaction, in a safe and protected way. Urban robotics introduces new relationships and entanglements between human and robots because application occurs in social spaces and through everyday interactions with *multiple* urban actors. As is explored below, regulatory permittance is primarily a matter of discretion for urban authority land-use planning (or zoning) and highways/transportation. Furthermore, it involves working within frameworks for health and safety management, pavement/highways regulation and also prevailing insurance regimes. As Starship pointed out in the context of the US, SDRs are trending because of lack of federal laws and regulatory agencies, and plentiful of perceived benefits from "the tech boom" by both sides (quoted in Marks, 2019, p. 8).

Yet the use of sidewalks for robots signaled a moment when pedestrians and advocacy groups started to express concerns, amid already tense relationship with tech companies, about private interests using urban spaces intended for humans as unregulated commercial testbeds. In 2016, the start-up company Starship Technologies deployed robots across California's sidewalks, creating a network of local logistical systems that stimulated a wider public debate about the relationship between cities and robots. The company was challenged by citizen groups in San Francisco – particularly active was the NGO Walk San Francisco who raised serious safety concerns (Interviews, 2018). Robotic infrastructure was primarily conceived by developers as employing aerial and terrestrial ADVs using AI-enabled navigation to increase efficiencies – a "warehouse logic" applied in public space (Marks, 2019, p. 5). Amazon's automated warehouse is "one big grid, with a unique paper pattern taped to the floor of each grid square" that robots see and navigate (Major & Shah, 2020, p. 102). Factory spaces are similarly modified and adjusted for robots, outfitted with sensors that function like virtual fences (Major & Shah, 2020, p. 103). The controlled spatial arrangements and interactions of factories and warehouses, however, is incomparable with the unpredictability and messiness of sidewalk interactions and other issues such as safety, privacy and sense of community (Marks, 2019). The "warehouse logic" came into conflict with the assumption that walking is the primary use for sidewalks even in the twenty-first century.

In the field of robotics, national governments have been under pressure to respond to corporate-driven technological innovation, and urban authorities were expected to passively accept and adapt to emerging technologies, with the expectations being "how to adapt to technology, not on how to shape it" (Sabanovic, 2010, p. 440). Furthermore, robot designers argued that:

> In order for robots to successfully navigate uncontrolled public spaces, we will need to incorporate their needs into the way we organise society. We can ensure reliable, safe robot operation if we can find ways to make space for them – literally. (Major & Shah, 2020, pp. 107–108)

However, sidewalks are not mere urban resources or physical space, but are embedded in social relations, local cultures and affordances of the city and in that context, it is perhaps to be expected that robot-urban interactions on sidewalks are being promoted and contested at the same time by various interests. On the one hand, there is a technological consciousness and drive to harness economic and socio-technical benefits which can be shared by government, citizens and private companies. Yet on the other hand, robots and humans need to jointly negotiate the social life of sidewalks as much as their uneven wet and dry, clean and dirty, surfaces full of cracks and other features that emerge organically in the anatomy of sidewalks with exposure to use and time. Moreover, a physically embodied intelligence designed to replace humans in urban mobility on human-only sidewalks generates near-future imaginations about what else these emerging AI entities *could* and *might* do to the human world (Sumartojo, 2023). The situation with SDRs is made distinctive by the promise and imagination of a leap from *automation* to *autonomy* (Cugurullo, 2020, emphasis in the original). The issue is therefore how can city governance negotiate between human needs and robot needs on their sidewalks when the regulatory framework itself also needs to be constructed? It is in this context that we now turn to the Californian experience.

The Californian landscape of urban robotics

Research on the application of automated machines in the built environment has highlighted the need to consider the different types of spaces in which urban use occurs (Diamandis & Kotler, 2020; Dowling & McGuirk, 2022). Whilst robotic developers might want access to actually existing environments, concerns about public safety, conflicts with other users, intellectual property and the need for supporting regulation, inevitably mean that spaces have to be constrained and closed in various ways before being extended and opened up further. In the US, sidewalks are largely controlled by urban authorities rather than by state or federal-level governments. Torsten Scholl, the co-founder of the Teleretail robot company found the regulations governing sidewalk applications perplexing:

> We found that each city and each district in America has their sidewalk laws. Some are weird, some don't make sense anymore. For example, we asked Sunnyvale and they said "no, sidewalks are only to be used by kids and elderly people." (…) Essentially, each town in America can rule how they like on how the sidewalks are used and they can pass laws … So that makes America more flexible in that respect. If we find a town that likes the idea, then they can issue, pass a law in a rather short period of time and enable us to test there. (Interview, October 2018)

This diverse urban regulatory landscape has produced an uneven geography of robotic use in the US. A number of cities have been more open to SDR applications offering packages of support to attract investment recognizing the potential symbolic, employment and economic benefits of new entrants. In 2019, Starship's SDR program included schemes in Wisconsin, Idaho, Virginia, Arizona, Washington and Florida where the

legislator has approved the use of delivery robots on sidewalks. Urban authorities across the US, together with university and corporate campuses, have been systematically approached by delivery robot companies to test their robots. This is usually in business-to-business partnerships, where a robot company such as Kiwibot partners up with a restaurant to deliver food or a logistics platform company like Postmates provides robot delivery services to businesses. The speed of roll-out of delivery robots means that they are appearing in the sidewalk largely in the absence of a regulatory framework (While et al., 2020), with a patchwork of consent and resistance. Consequently, the regulatory landscape at the urban level according to Postmates is difficult to navigate:

> On the one hand there is a desire from cities to be the experimentation petri dish of a lot of these new technologies, particularly if they are not Silicon Valley … We just spoke with a mayor in the Midwest that was really interested in having them deployed out there, and it's not because there won't be the same type of Walk SF concern or pedestrian safety or safety concern. The key is to pique the interest, seize the interest of those cities that are willing to experiment with this and responsibly also engage all the stakeholders in the process so that way we can be good actors and good stewards of how we would deploy these as opposed to kind of running rough shot over the city. (Interview, October 2018)

In the absence of an existing regulatory framework for delivery robots, urban authorities in the US are having to construct their own regulatory governance for robotics applications. The following case study of California explores the variation (and its impacts) of different frameworks for delivery robot regulation within that state.

Our research in California on SDRs thus revealed a range of types and contexts for street-level delivery robotics. There was increasing pressure on Californian municipalities to support delivery robotic applications, in part because of the interest of high-tech and robotics firms and the search to develop business models and technologies. The Bay Area where our research was focused and has a lengthy history of technological innovation that helped build communities proud of their technological capacities as a leading region for the research and development of robotics in the US, with a particular specialism in "urban" robotics. These local technical assets are key to understanding the techno-urban relationships and the socio-cultural context in which robots are being tested in the public realm. California has been shaped by technological innovation, and that became clear early in our interviews with the urban governments and robot companies who characterized the local context as being open to emerging technologies. All the urban authorities we visited in California identified themselves as a "technological" community that has been part of technological success of Silicon Valley with "a desire to maintain the historically nurtured image of a tech-friendly city" (Alex Andrade, the Economic Development Manager at the City of Mountain View, Interview, October 2018). In this latest phase, robotic tech firms are not only shaping cities through demographics, housing markets and funding, but by transforming sidewalks into extensions of their research labs. This has also created numerous issues, particularly with its fast-paced innovation that is difficult for urban governments and the community to respond to effectively until after the robots have been released into public space. The State of California provides important insights into the uneven making of regulatory capacity and turning sidewalks into urban robotic testing landscapes, and here we focus on the two modes of application.

"Real-world" on-sidewalk applications

Our field research examined how the morphology of sidewalks shaped the emerging geography of delivery robot deployment and regulation. The more heavily used and much narrower sidewalks in San Francisco are highly congested and thus more contested than the wider and so less congested sidewalks of more suburban Palo Alto. Yet some robot companies are particularly keen on undertaking applications on sidewalks in complex urban areas. A founder of the Berkeley-based delivery robot company Kiwibot described the city as the "perfect battleground, having to deal with the conflicting demands of construction work, homeless people, students, intoxicated people, suburbs, and dense urban areas" (Interview, October 2018). Urban space is elsewhere described by the company as a "jungle of humans, cars and buildings" (Kiwibot/Food Delivery Robot, 2019). Such terminology illustrates the cultural logic of the robot creators, who imagine the city in terms of warfare and untamed messy wilderness that delivery robots need to overcome. The rationale among robot companies is that "real world" testing opens up a space for learning and preparing robots to function in a highly complex environment.

While some Californian municipalities permitted testing in busy sidewalks, others confined testing to less heavily trafficked sidewalks. For instance, San Francisco is divided into Individual Zoning Districts – Residential, Neighborhood Commercial, Downtown, Industrial and Mixed Use – and initially robots could operate only in the Industrial Zoning districts (San Francisco Planning, 2022). Torsten Scholl from TeleRetail preferred the initial testing in business and industrial zones, as he felt the technology was not yet developed enough to interact with the unpredictable reality of the urban space, including the behavior of consumers who might misuse technology (Interview, October 2018).

Modes of regulation in California during the study period were largely driven by the first-mover robot companies. Starship Technologies acted so quickly in Californian cities that sidewalk robot permitting legislation in the whole State was in 2019 largely based on their systems. Thus, when the City of Palo Alto's regulatory framework was revised in 2018, Starship Technologies was closely involved in re-negotiating the boundaries of testing, asking that the municipal government would extend permits over one year, extend testing permits in more areas, and raise the speed limit from 2.4 to 5 mph. The Council approved all of these (Sheyner, 2019). In Palo Alto, the city and private businesses share the responsibility for accidents and injuries that occur on sidewalks, as well as damages to the public infrastructure. This means that only robot companies that can afford to pay out large sums in the event of liability in accidents can take the risk of implementation. A shortened excerpt from City Council Staff Report in the City of Palo Alto (2017; see also 2018) – Resolution to Regulate Operation of Personal Delivery Devices within the City of Palo Alto – illustrates how the rules of applications are defined and conducted. The operators are permitted through Encroachment Permit issued by the Public Works Department at the Development Center whereby they assume all liability for the use of SDRs on City sidewalks and streets and provide insurance coverage of $2,000,000–4,000,000 for injury and property damage. Significant collisions and safety issues must be reported to the City within 24 h.

"Semi-enclosed" precinct trials

Precinct trials such as that on the University of California Berkeley Campus tended to be associated with a single company, with campuses offering not only a fairly closed environment (relatively free of cars) but also a bespoke regulatory environment compared with the more complicated and contested sidewalk under municipal government control. The campus trials were effectively test beds for single company development of technology and business models. For instance, Starship Technologies focused its expansion on "introducing the world's first robot delivery service for corporate and academic campuses" (Starship, n.d.a). It started at George Mason University in Virginia and, by 2023, Starship was delivering food and non-food items on 18 university campuses in the US and EU. The shift is not surprising. University campuses provide a semi-public urban space, without the need to move directly onto regular city sidewalks, but also provide some of the social complexities of regular sidewalks. Furthermore, the demographic of university campuses is considered best suited for introducing novel techno-social innovations, considering young students are mostly digital citizens who may be more comfortable ordering food via a Starship robot delivery app. By 2019 Kiwibot had acquired testing permits in 12 Californian cities, all focused on university campuses, including UC Berkeley, and have since expanded into other campus contexts at the University of Denver and San Jose State University – in partnership with Shopify and Ordermark. In mid-2023, backed by hefty investments, they operate on 26 university and college campuses across the US. In 2022, Kiwibot partnered with Sodexo, a food service company that operates on 850 colleges in the US and Canada, opening up more ground for SDRs (Kelso, 2022).

Urban robot testing is highly heterogeneous, involving on-sidewalk and precincts. On-sidewalk testing is also diverse depending on the complexity of the local environment with different authorities providing more prohibitive and permissive modes of regulation. Despite this diverse landscape, the regulatory frameworks enacted tend to borrow heavily from the early frameworks already established which themselves were funded through particular companies producing a similar mode of regulation for a standard delivery robot. The problem with these frameworks is that they tend to reflect the requirements of one particular company and type of SDR. We therefore move on to consider in more detail how San Francisco sought to develop a more open and collaborative framework of SDR regulation.

San Francisco's shifting modes of robotic regulation

San Francisco's shifting approach to robotic regulation provides important insights into tensions and limits of governance of urban robotic utilization. San Francisco is distinctive in having heavily congested sidewalks whose use and occupation are contested by different social interests. Prior to the development of SDRs, the emergence of e-scooters and Segways in the early 2000s created significant new tensions between the competing users for sidewalk space – citizen groups are proactive in maintaining public access to sidewalks and ensuring that corporate interests are held accountable. Consequently, in 2010 the city banned use of Segway devices on the sidewalks (Watercutter, 2010) with Walk San Francisco also advocating a ban on electric scooters on sidewalks (Walk San Francisco quoted in Medeiros, 2018).

Robots were inserted into this already crowded context of sidewalk tech. Consequently, Kiwibot stated: "Delivery bots have proved controversial in some regulatory environments with some cities, like San Francisco, putting out laws that make it difficult for us to deploy. If this became widespread, we would have trouble going to market" (Bergman, 2021). Walk San Francisco, an advocacy organization working on pedestrian safety, approached Supervisor Norman Yee in autumn 2016 about a delivery robot in Redwood City. They were concerned it was only a matter of time before such robots showed up in San Francisco, so they asked government officials to develop a proactive response. According to Erica Maybaum, the Strategy, Public Policy, Advocacy, Government Relations & Community Coalitions Executive, the office was too busy to get involved at the time but around five months later they noticed a blog article mentioning a delivery robot in San Francisco:

> We were alerted to it and I contacted the Department of Public Works, they didn't know about it, I contacted our MTA, they didn't know about it, the local police department, they didn't know about it, the City Supervisor and District Nine in the Mission, she didn't know about it and so nobody knew about this company rolling out on our public infrastructure. So, then I looked at our regulations, and I made the assumption that, so in San Francisco, we don't allow bicycles on our sidewalks and we don't allow Segways on our sidewalks, so I kind of figured that this would go under kind of like a Segway, [but these new robots] were technically automated delivery devices, ADDs (…) So, this new technology, no one knew about, no city and department, but then also didn't fall in under any current regulation. (Interview, October 2018)

Initially proposing a ban on delivery robots in October 2017, Supervisor Norman Yee of San Francisco stated his concern that in being proactive about developing flexible regulation after the arrival of Airbnb and Uber, "somehow we have sent the signal that it is acceptable to act now and ask for forgiveness later" (Nichols, 2017). Yee was critical of tech companies' use of public space as a resource for applications, reflecting the fact that urban authorities did not have legislative framework for regulating emerging technologies. Many community groups spoke in support of the ban, including parent groups, neighborhood associations, pedestrian organizations and merchant associations that viewed SDRs as encroaching on the already congested sidewalk and posing safety issues.

The Supervisor's office was also meeting with sidewalk robot companies including local companies like Marble that manufactures and test robots in San Francisco. Concern was raised that the Board was potentially closing down the city to novel technology: "here was pushback from different offices, is this really a problem?" (Interview with Erica Maybaum, October 2018). Supervisor Yee acknowledged that "There's always a conflict in terms of what we value, and another value we also have is supporting our homegrown businesses. In this case, I think there's a way to do both" (Yee quoted in Nicols 2017). Consequently, rather than institute a ban, instead a regulation for a permitting process was developed and the Emerging Technology Working Group was also established in 2018 to look more broadly at robotics and AI-enabled urban technologies.

Co-evolution, agility and learning

Following discussions with citizen groups and robot companies, the City and County of San Francisco issued in 2018 a Public Works Order: The Establishing Regulation and

Guidelines for the Use and Operation of Autonomous Delivery Devices within the Public Right-of-Way (2018a). The order focuses on two aspects: the demands from the applicant and the operational requirements of SDR, with the Public Works Director retaining the right to set and modify conditions of approval at any time. During the testing, applicant needs to share data collected, incidents and information about the local businesses using SDRs. The operational requirements define that SDR: has a speed limit (3 mph max), a human operator within 30 feet, headlights at night, sunrise and sunset, a warning noise while operating, and identifier with the permittee's contact information and insurance. SDRs are required to give right of way to pedestrians and bicycles, operate within designated areas – zoning districts – and obey all traffic signals. They are not permitted to transport hazardous materials including flammables and must be docked on a private property when not in use. Finally, Public Works is allowed site visits and each operator agrees to "indemnify, defend and protect the City against any claims" (Public Works. City & County of San Francisco (2018a).

The initial result of introducing new regulations is that not a single company applied for a permit. Faced with these stringent requirements, the companies have moved to other cities with more permissive frameworks to implement delivery robots. Starship, the company that initiated delivery robot trials on sidewalks, re-focused on business and university campuses outside San Francisco. Erica Maybaum attributes it to the very stringent requirements that companies are asked to meet (Interview, 2018).

Although Postmates, Marble and Starship subsequently expressed their desire to be the first applicants to obtain the permit to test in San Francisco (Clark, 2019) and Postmates acquired a permit, all three companies did not continue deployment of SDRs in San Francisco. Nevertheless, Postmates has been working with cities, labor and advocacy groups to develop a "collaborative and inclusive approach to robotic deployment" that claims to "develop thoughtful regulatory regimes" (Postmates, quoted in Clark, 2019). Furthermore, Matt Delaney, the CEO of Marble, said the company has been interacting with the City during the legislative process with a commitment to "continuing San Francisco's legacy of developing the world's leading technology" (Delaney, quoted in Pershan, 2017). Starship also stated that it would "like to engage with the city to discuss the safe operation of delivery robots that benefit local businesses and residents" (Starship, quoted in Apex Insights, 2017). Despite this commercial desire to return to the city, and wider support from companies using the services such as restaurants and several business associations, in 2023 San Francisco seems to be in limbo due to its strict regulations for urban application. San Francisco's work with local communities and NGOs has produced a strict approach to robot governance that is not attractive to robot companies.

A cooperative model for responsible innovation

San Francisco was the first city in California to establish an Emerging Technologies Working Group (ETWG) (City and County of San Francisco 2018b, 2018c). This was designed to produce a set of guidelines for a new law on emerging technologies based on open discussions between private companies, citizen groups and the city government. The group met once per month for six months and produced a report in January 2019 outlining a process to regulate emerging technologies and their potential integration

into the urban context. Though prompted by SDRs, the Group discussed a wide range of emerging technologies. According to Maybaum:

> it is important that there is a democratic process and that the community is also involved that it's not just the policy makers or the big businesses making those decisions, that balance. I think what we're struggling with as a city is not only finding that balance but then, policy works slowly, right? And innovation does not, and it will not. How do we not just keep up, but kind of forecast and support? And that's why with this ETWG we really wanted not just city folks at the table or disability advocates, but we wanted academics and people in the tech sector to be at the table to help us: let's work on this together. (Interview, October 2018)

The Final Report of the Group was published in January 2019 after total of six meetings with civic groups including Elder Care Alliance and San Francisco Council of District Merchants Associations; companies such as Kiwi, Lyft, Marble, Microsoft and the civil service offices at the City Council. The definition of an emerging technology by the City Administrator Naomi W. Kelly was those systems that:

> are in development and have only been tested at market level on a limited basis; will have a measurable impact economically, socially, or morally in the next five to ten years; and do not fit within existing regulatory code. (2019, p. 10).

Examples include drones, facial recognition system, biometrics, autonomous delivery robots, and AI among others. The report focused on the anticipated impacts of emerging technologies and seven key issues were identified in the meetings: lack of trust between government and companies, regulations being reactive rather than proactive, the need for the City and companies to communicate with the public, equitable benefits, accessibility and safety, data sharing and privacy and anticipated impacts on the city (see City & County of San Francisco, 2019, p. 6).

The Report contains five recommendations for forming regulations: first to create a "Front Door" for Emerging Technology to provide a central point of contact for companies and the public; second to improve communication with the community by informing technology companies of best practices to engage local residents and businesses; third, to safety-test and evaluate new technologies with clear evaluation criteria; fourth, to support responsive policy development in areas such as equity, accessibility, privacy and data ethics and fifth, to foster smart forecasting through expert collaboration (Kelly, 2019, p. 6). The 2019 permitting model is summarized in Table 1. The model shows the parallel processes in permitting and application of emerging technology in the City, facilitated by the Emerging Tech Front Door Agency.

Critically, both the commercial and public agencies interviewed in the research frequently viewed stakeholder engagement as being key to the development of permitting processes. This form of "collaborative governance" was designed to build community-centered cooperation between public, private and government actors with the aim to co-produce legislation, to ensure stakeholders interests are represented in how the new technology is integrated into city and the ways it interacts with the users (Batory & Svensson, 2019). The novelty of trying to negotiate robotic-human relations was at the core of San Francisco framework of addressing emerging technologies.

Yet this was harder to formulate in practice. On the one hand, the process was no longer solely based on the assumption that cities "outfit the world to help robots",

Table 1. Proposed emerging technology permitting model for San Francisco.

	Discovery	Pilot Application	Pilot Evaluation	Legislation / Permission	Ongoing Evaluation
User Steps	Company identifies market opportunity in SF with a new technology	Define business model	Present impact evaluation metrics in community forums	Provide additional information as needed to BOS and permitting departments	Company scales business model to entire City, or as permit allows
	Approaches the "Emerging Tech Front Door" (ETFD) for information to pilot	Negotiate terms of pilot and data sharing rules	Collect equity, accessibility, cybersecurity, privacy data	Continue community outreach	Company shares data as needed
	Conducts early community outreach	Ongoing community engagement & user testing			
City Steps	Confirmation this is an emerging technology and level of scale worth engaging with	Assemble evaluation steering committee	Field observations	Once legislation passes, create permit terms & conditions	Permitting department conducts periodic reviews and inspections
	Front Door identifies permitting authorities	Develop pilot terms & conditions (time, place, manner)	Conduct equity, accessibility, cybersecurity, privacy assessment	Issue permit	If additional permit requirements added that existing agency does not have capacity to oversee, EFTD to take responsibility
	Provides information on ET pilot and permitting process	Identify ultimate permit authority	Make go/no go decision to get a permit		
	Analyze evidence of impact in other cities	Identify what data the company must collect versus the City collects	If go, hand-off legislative & permitting process to permitting agency		
	Evaluate whether limited pilot in SF is warranted	Issue pilot MOU	If no go, pilot stops		
	Draft pilot design and identify benchmark criteria for impact analysis				

Source: Kelly (2019, p. 23).

using digital signposts and barcodes that would help robots navigate urban spaces (Major & Shah, 2020, p. 108). The logic here was one of creating smarter environments for robots conceiving of "the city [as] a cyborg, helping to guide robots" (Major & Shah, 2020, p. 112). On the other hand, the model could hardly be viewed as a process of "mutual shaping of robotics and society" (Sabanovic, 2010, p. 440). The model does not create spaces for co-designing robotics from the start, it is not led by an exploration of social choices of the potential relevance and possibilities of urban robotics. Different

stakeholders should be included in the process while robots are still in the making, not when they are already out on the sidewalk – they need to engage critically what robots *could* do in addition to what they *can* do (Sumartojo et al., 2021). While San Francisco is to be applauded for trying to engage in collaborative and anticipatory processes for new urban technologies the model itself starts when companies have a technology to bring to market and not before. Explicitly, the process is designed to enable a pre-existing application to be used in an urban context with the presumptive logic of upscaling the roll-out. This is still a form of "technological push, social pull" (Sabanovic, 2010, p. 441). Urban authorities can still only react and adjust to SDR already in the streets. Furthermore, the developers can bypass collaborative regulatory environments when many other urban authorities are competing to provide permissive frameworks.

The process of developing regulatory frameworks for sidewalk robotics is dynamic and contingent. In San Francisco, the absence of a regulatory framework was addressed in multiple ways, briefly considering prohibition, followed by the development of a permissive and then collaborative framework focused on emerging technologies. Yet the potential of the urban authorities to shape the pathways of robotic development is constrained by existence of more permissive frameworks that are more attractive for commercial companies in other jurisdictions.

Conclusions

Disruptive new urban technologies co-evolve with humans and the socio-material context of their application. They are negotiated over time in a process of incremental co-evolution and learning in relation to the infrastructure, urban form, human behavior and underpinning land-use and transport including regulatory, legal and insurance frameworks. This paper has examined the key challenges and opportunities for urban governments in responding to the rapid development of urban sidewalk delivery applications. The issue with the application of SDRs is not so much the need to test the technology (which is relatively mature) or public acceptance per se but the need for the redrafting of restrictive land-use and transport regulations (including the typical distinction between motorized and non-motorized transport) and regulation of the volume of robotic traffic. California was initially a key test bed for urban robotics because of the robotics R&D and platform business innovation capacity in and around Silicon Valley, and the pressures and demands for urban authorities to open up spaces of application. As our analysis demonstrates, policymakers at the local and state levels are taking a variety of approaches to regulating urban robots. Urban authorities have been forced to react to robotic applications of street-level robotics. Legislators are conscious that the regulatory system needs to be fluid and flexible to accommodate applications. The result is a complex, differentiated and combinatorial landscape of urban robotic use in response to differing levels of interest from the private sector, multiple robotic applications, context-dependent political (and public) responses and uneven levels of political commitment to develop new and flexible regulatory and legal frameworks. This is very much about the urban politics of new and emerging urban robotic applications in which human–machine interactions are being worked through and attempted to be anticipated.

Yet to understand what and how happens with delivery robots in the San Francisco sidewalks is not only about understanding the mechanisms of technological development, corporate behavior, policy-making and daily life. It is also about understanding who and how creates the "next" developmental step as something natural and taken for "granted". With the already problematic hierarchies of inequality, power and privilege, especially with tech companies encroaching on and gentrifying the Bay Area, SDRs become very visible and tangible surrogates for labor and for pedestrians. They operate in the last only human space at the edges of the prioritized techno-human traffic, taking up human space in the most explicit way. They are not only seen and felt, but have to be interacted with, be cautious about and accommodated. In other words, pedestrians are forced to include them in sidewalks, a resource exclusively for humans.

The paper makes three key contributions to literature and debate. First, it provides further evidence of the ways in which cities are being opened up selectively as sites of application for a distinctive new phase of urban robotics. SDRs have been rolled out relatively unproblematically in California, when drone delivery and AVs more generally have been less accepted. That is not surprising given the different material presence and risk associated with different technologies (drones might be fairly small, but they can cause substantial damage and are difficult to regulate; SDRs are relatively small, travel slowly and are relatively easy to avoid or stop). Despite a powerful politics of the sidewalk in places like San Francisco, there has been a certain tolerance of SDRs.

Second, our analysis demonstrates the significant demands that urban robotics can place on urban authorities to facilitate new robotic technology whilst protecting the public interest. In this respect we have demonstrated the complexities of relationships between urban governments, private companies and citizens that shape the reception of delivery robots and, through it, the remaking of regulatory frameworks for the sidewalk. For all stakeholders, putting emerging technologies on sidewalks marked the moment when the purpose and the nature of this urban space started to be questioned and redefined – a process that will continue long-term as robots increasingly become part of the city streets.

Finally, the paper highlights the need for further research to understand the complex co-evolution of robotics governance and robotics design and development in the remaking of urban infrastructure. As argued in the introduction, SDRs raise issues that are more broadly applicable across other disruptive new robotic and/or mobility machines (e-bikes, e-scooters) that are seeking to find a space in existing urban infrastructural landscapes. What makes SDR distinctive is the necessity for co-existence and interaction (or avoidance of interaction) between an increasingly autonomous machine and the unruliness and fragility of humans. SDRs have largely been facilitated early in the process of urban robotic restructuring because of their limited size and speed, but also because the technology is less complicated and more easily trialed and tested than AVs. Urban robotics is developing quickly and perhaps more rapidly than government regulation and public awareness. But that research needs to maintain a perspective on the wider urban impacts of robotics that include but far transcend issues of public safety. Indeed, it is noticeable that SDRs have largely escaped scrutiny on issues of privacy and data gathering, when, as with all robots, they have significant capacity to gather and process data on people in the public realm (Hoffman & Prause, 2018).

Beyond the seductive imagery of small-scale applications with drones, autonomous vehicles and delivery robotics, there is more systematic remaking of the urban at play through urban robotics that requires public scrutiny and scholarly attention.

Note

1. We adopt the term sidewalk delivery robot to capture the specificity of ADV designed for the sidewalk.

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