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The governance of artificial intelligence in the "autonomous city"

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The governance of artificial intelligence in the "autonomous city"

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Editorial: The governance of artificial intelligence in the "autonomous city"

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Editorial on the Research Topic
The governance of artificial intelligence in the "autonomous city"

Artificial intelligence (AI) is now mediating key urban services and infrastructures (Barns, 2021; Yigitcanlar et al., 2023a). As portrayed in recent studies, the "autonomous city" (also known as the "algorithmic city") can be understood as a city where urban artificial intelligences perform tasks and take on roles which have traditionally been the domain of humans (Cugurullo, 2021; Son et al., 2023). For example, while autonomous cars transport people and drones deliver goods, large-scale AIs, such as *city brains,* can potentially govern entire cities. This literature stakes out a number of questions related to the meaning of intelligence, for both humans and machines. For instance, we have to ask what human intelligence means, as we seek to define AI at the same time (Lynch and Del Casino, 2020). Moreover, as humans are shifted to new sectors of the economy or pushed aside by algorithms creating new ways of seeing and governing the city, we need to ask what kinds of cities we are making when increasingly autonomous systems are operating in place of human decisions.

This Research Topic focuses on the governance of the autonomous city, from two interrelated perspectives. First, it develops an empirical and theoretical understanding of the emerging forms of governance that are enabled by urban artificial intelligences, as well as how the socio-political and economic structures of urban (human) life are starting to being changed in relation to AI. On these terms, this Research Topic begins to explore and chart the complex political processes, stakeholder networks, logics and policies through which autonomous cars, urban robots and city brains, for example, are integrated into cities and how such emergences are complementing and, at times, replacing existing urban infrastructures and services. Second, the contributors show through multiple case studies how AI is employed in urban governance, by examining how different urban artificial intelligences take on responsibility for urban domains ranging from transport to health and from planning to security.

Overall, our impression is that the "smart city" paradigm, which has characterized the configuration and governance of a myriad of cities for almost half a century, does not seem to fully hold anymore in the age of AI. Although premised upon the idea that technology can be a powerful medium to improve urban governance, the vision of smart cities has implicitly had human policymakers at its core—i.e., human agents who employ various smart devices as tools to increase the efficiency of urban services (Palmini and Cugurullo, 2023). The intelligence undergirding "smart cities" was largely human-derived. AI is changing this status quo. Many of the urban artificial intelligences discussed in this Research Topic do not need human inputs to function and often operate in an unsupervised manner. This is not to say that smart cities are going to disappear. Instead, what we want to stress is that the advent of AI elevates the need for further empirical research on the operation of urban AIs and their autonomous decision-making capacities, bringing into question some of the theoretical foundations of the smart city model. For instance, exploring the concept of "collaborative AI" in the context of smart city governance is critical (Wiesmüller and Bauer, 2023) and what *intelligence* means more broadly (Lynch and Del Casino, 2020).

We also note that the emergence of AI in urban governance is generating new ethical questions. Urban artificial intelligences will be increasingly dealing with complex moral decisions, including thorny *trolley problems* such as the inevitability of distributing harm when AI-driven cars crash (Awad et al., 2018). In a city whose services are mediated and controlled by AI, we find non-human intelligences in the position of deciding what the right course of action may be, even as the underlying algorithm was originally designed by humans. This capacity raises new challenges for governance, because there is no guarantee that AI-made decisions will be, by default, aligned with human values. Likewise, policy settings are also influenced by wider public concern and fear of AI, requiring appropriate policy and ethical responses to the presence of autonomous decision-making agents in cities (Cugurullo and Acheampong, 2023; Yigitcanlar et al., 2023b). While completely autonomous cities might be far away in the future, the emergent problems they pose are certainly already present. This Research Topic points to the necessity of searching for effective ways to govern urban AI, while also opening up the conversation of how human and artificial intelligences will develop over time in relation to each other in the city.

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ORIGINAL RESEARCH
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Urban Artificial Intelligence: From *Automation* to *Autonomy* in the Smart City

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Technological innovation is constantly reshaping the materiality and mechanics of smart-city initiatives. Recently, innovation in artificial intelligence (AI) in the shape of self-driving cars, robots and city brains, has been pushing the so-called smart city to morph into an autonomous urban creature which is largely unknown. In this emerging strand of smart urbanism, artificially intelligent entities are taking the management of urban services as well as urban governance out of the hands of humans, operating the city in an autonomous manner. This paper explores, in theory and practice, how the development of AI intersects with the development of the city. The contribution of the paper is threefold. First, the paper advances a theoretical framework to understand AI specifically in urban contexts. It develops the concept of *urban artificial intelligence*, capturing the main manifestations of AI in cities. Second, the paper examines the case of Masdar City, an Emirati urban experiment, to show how the genesis of urban artificial intelligences is part of a long-standing process of technological development and a politico-economic agenda which together are enabling the transition from *automation* to *autonomy*. Third, it proposes a research agenda to investigate what the paper terms the *autonomous city*.

Keywords: smart city, artificial intelligence, autonomous city, governance, sustainability, autonomy

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INTRODUCTION: AI ENTERS THE CITY

Many cities are currently being developed under the smart city banner. As several studies show, a plethora of smart-city initiatives are being implemented across different geographical locations, forming a complex tapestry of urban visions (Fernandez-Anez et al., 2017; Pinna et al., 2017; Cowley et al., 2018; Datta, 2018; Karvonen et al., 2018a; Valdez et al., 2018; Wu et al., 2018; Dowling et al., 2019; Joss et al., 2019; Smigiel, 2019). A single definition and understanding of the smart-city ideal does not exist, and the very existence of a smart city is debatable. As Picon (2018, p. 270) argues, "the smart city belongs partly to the imagination": a condition which makes the incarnations of this urban ideal hard to identify. As Caprotti (2019, p. 2466) points out, "there are few places and spaces in the contemporary city that can be visualized and made legible as clearly belonging to the smart city." Moreover, although advocates and practitioners tend to draw upon a fairly homogeneous set of ideas inspired by an adamant faith in technology, actually existing smart-city projects manifest a number of contextual variegations (Angelidou, 2015; Shelton et al., 2015; Cugurullo, 2018a; Karvonen et al., 2018b; Bina et al., 2020).

Within this vast pool of alleged smart cities, information and communication technology (ICT) is a common denominator (Caragliu et al., 2011; Kitchin, 2014; Marvin et al., 2015; Coletta et al., 2018). The portfolio of a smart city normally includes smart grids, smart sensors and Internet of Things (IoT) technologies, deployed to produce large volumes of data on the metabolism of cities regarding, for instance, energy consumption and mobility. According to the narrative of smart urbanism, such *big data* can then be employed to penetrate and wipe out, metaphorically speaking, the "heart of darkness" of cities, in order to scientifically understand how they function and improve their sustainability. However, the presumed scientific mission of smart cities has frequently served the purpose of hiding economic and political agendas. Like in Conrad (2007)'s novel, *science* and *progress* have been used as rhetorical devices to legitimize the reproduction of existing power relations, ideologies and political economies. Smart technologies have not always been *lights* dispelling ignorance or *darkness* on the way the city functions, but rather profitable commodities for tech companies. As Trencher (2019, p. 117) remarks, in smart-city initiatives it is often the case that "neoliberal economic interests are prevailing at the expense of environmental and social concerns." In essence, as many studies show, *smart* and *sustainable* are not necessarily synonymous with each other (Vanolo, 2016; Ahvenniemi et al., 2017; Bibri and Krogstie, 2017; Kaika, 2017; Cugurullo, 2018b; Machado Junior et al., 2018; Martin et al., 2018; Perng et al., 2018; Haarstad and Wathne, 2019; Parks and Rohracher, 2019; Colding et al., 2020).

The premise of this paper is that the challenge of critically exploring smart-city initiatives and extricating the rhetoric from what is actually happening on the ground, is exacerbated by the fact that the face of smart urbanism is constantly changing at a fast pace. Being smart-city projects fuelled by rapid processes of technological innovation, the moment a new typology of smart urban technology is released onto the market, the dynamics of smart urbanism change. This condition is of course not symptomatic of only smart-city agendas, inasmuch as the infrastructure and design of cities have historically been changing in sync with technological progress (Mumford, 1961). Emblematic is, for instance, the reconfiguration of cities in the early twentieth century due to the advent of the car (Hall, 2002). On these terms, what is new about smart urbanism is not that the evolution of the city follows the evolution of technology. The novelty springs largely from the smart technology that enters the city.

As a corollary of this premise, it can be argued that the more revolutionary and disruptive a smart technology is, the greater is likely to be the transformation of the city that integrates it. This tension has been observed by Batty (2018) in relation to artificial intelligence (AI). Today, innovation in AI in the shape of, for example, self-driving cars, robots and autonomous platforms of urban infrastructure management, is pushing the smart city to morph into an urban creature which is largely unknown (Batty, 2018; Allam and Dhunny, 2019). Arguably for the first time in history, artificially intelligent urban technologies are taking the management of urban services out of the hands of humans, operating the city in an autonomous way. There seems to be no limit to the agency of AI in cities. AI is now going beyond the provision of urban services and the maintenance of urban infrastructure. Artificial intelligences are entering the domains of urban governance and planning, thus becoming decision and policy makers (Zhang et al., 2019). This is an emerging strand of smart urbanism which the paper refers to as the *autonomous city*.

Building upon the above premise, the aim of this paper is to contribute to the understanding of the autonomous city, in empirical and theoretical terms. As noted by several scholars, to date there is little or no knowledge of the many ways through which AI is impacting on the development of smart-city initiatives (Del Casino V. J. Jr., 2016; Zakharenko, 2016; Ingrand and Ghallab, 2017; Milakis et al., 2017; Bissell, 2018; Salehi and Burgueño, 2018; Macrorie et al., 2020; Yigitcanlar et al., 2020). This study captures the evolution of smart urbanism in the era of artificial intelligence. It develops a theoretical framework to explain the manifestations and repercussions of AI in cities, and it explores empirically the emergence of artificial intelligence in an existing smart-city project. Structurally, the paper is divided into three parts. The first part discusses the theory of AI, particularly in relation to cities. It defines the concept of urban artificial intelligence and introduces three related categories (autonomous cars, robots and city brains), putting emphasis on both their revolutionary and conservative characters as opposite sides of the same coin. The second part analyses the case of Masdar City in Abu Dhabi, to show how the development of urban artificial intelligences is not an abrupt phenomenon, but rather part of a long-standing process of technological development and a politico-economic agenda which together are enabling the transition from *automation* to *autonomy*. The condition of being autonomous is examined from a technological point of view, and it is in the nascent capacity of AI to think and act in an unsupervised manner, that this study finds the key difference between traditional smart-city initiatives and emerging autonomous cities. The third and final part summarizes the main contributions of the paper, using them as foundations to build a research agenda for the study of the autonomous city.

Empirically, the paper is based on 10 months of field research in Abu Dhabi. In 2011, 20 semi-structured and 18 unstructured interviews were conducted with representatives from key state and non-state actors involved in the Masdar City project. In addition, the data that emerged from the interviews was triangulated through the analysis of key policy documents, such as masterplans and planning agendas. In 2019, five additional semi-structured interviews were carried out online, and more policy documents were collected by field assistants based in Abu Dhabi. Some of the material that is here discussed is not publicly available and the paper does not refer directly to those who disclosed it, in order to protect their anonymity. Taking into account Abu Dhabi's authoritarian regime and the safety of all research participants, sensitive data (including details about when and where exactly it was collected) has been anonymized.

URBAN ARTIFICIAL INTELLIGENCES

What is artificial intelligence? A single and universal definition of AI does not exist, nor a definitive blueprint to build one (Bostrom, 2017; Cave et al., 2020; Clifton et al., 2020). Yet, it is possible to identify the key characteristics and elements that are common among artificially intelligent entities. This section begins by discussing the core traits of artificial intelligence, to then use them as a stepping stone to clarify the meaning of *urban* artificial intelligences. In other words, the narrative starts from the notion of AI in general, subsequently narrowing down to AI specifically in urban contexts.

The concept of artificial intelligence is composed of two interrelated sub-concepts. The first one, *artificial*, is relatively easier to unpack. Something is commonly considered to be artificial when it does not arise from a natural process. As such, it is human-made or, as Bostrom (2017) observes, it can be made by machines. Whether it is created by humans or machines, the outcome of an artificial process of production is an *artifact*. Artifacts can have a multitude of shapes, ranging from a personal computer to a car. The shape of an artifact can be anthropomorphous or it might differ substantially from the physiognomy of the human body. Regardless of its shape, an AI normally resides in an artifact and this is a key characteristic to bear in mind as we continue the conceptual exploration of artificial intelligences. Many AIs, especially those that are the focus of this paper, are embodied. They possess and animate an otherwise inanimate artifact, thereby becoming an intrinsic part of it. An artifact such as a car, for example, when it is animated by an AI becomes an *autonomous car* endowed with intelligence.

The second sub-concept, *intelligence*, has been the subject of fiery debates since the birth of philosophy. The aim here is not to provide a definition of the notion of intelligence, but rather to draw upon academic studies on AI to discuss what skills and capabilities intelligent entities are supposed to have, as a way to understand how intelligence manifests itself in AI. First, an intelligent entity is supposed to be capable of learning, by acquiring information on the surrounding environment (Russell and Norvig, 2016). AIs practice learning, intended as *gaining knowledge*, both *directly* by sensing the environment through, for instance, cameras and microphones, and *indirectly* by means of large data sets installed by the developers. A second interconnected skill is the capacity to make sense of the acquired data by extracting concepts from it (Bostrom, 2017). Examples vary from a straightforward concept like *morning* which an AI extracts from visual data capturing the sun rising, to a more complex concept such as *danger* which an AI might extract from visual data showing an unauthorized individual entering a private property. Third, an AI should be able to handle uncertainty (Kanal and Lemmer, 2014; Pearl, 2014). This is the ability to deal with complex situations in which some information is missing or the data is not completely clear. Fourth, an AI would use the collected and potentially incomplete information to make decisions and then act in a rational way. For AI scholars, acting rationally is about attempting to obtain the best possible results, according to pre-defined performance measures and goals which clarify what is *right* or *wrong* (Russell and Norvig, 2016). In this regard, a classic example is provided by Asimov (2018) and his *Laws of Robotics*. Assuming that a robot is meant not to injure humans, a rational action would be one seeking to avoid any kind of harm to human beings. Fifth and finally, an AI would show intelligence by exercising the above skills and capabilities in an autonomous way or, as Levesque (2017, p. 3) puts it, in an *unsupervised* manner, meaning that humans are out of the loop and do not control or steer the AI's decisions and actions.

By combining the two sub-concepts, *artificial* and *intelligence*, we can broadly understand an AI as an artifact able to acquire information on the surrounding environment and make sense of it, in order to act rationally and autonomously even in uncertain situations. It is beyond the scope of this paper to discuss whether or not the above capabilities imply that AIs can think or manifest consciousness, which is a highly debatable topic (Warwick and Shah, 2016; Carter et al., 2018). However, it is worth noticing that the capacities of extracting concepts and making decisions autonomously, in particular, resonate with what we commonly call *thinking*. Of course, as we will soon see empirically, AI theory is not perfect and should not be approached in a dogmatic way, given that even the theoretically simplest concept extracted by an artificial intelligence can empirically turn into a nightmare. This is because AI is a disruptive technology (Batty, 2018; Yigitcanlar et al., 2020). On these terms, it changes the system where it operates. It is also, as Greenfield (2018) notes, a *radical* technology since the changes that it triggers can be deep, significant and might invest every scale of the everyday, from the personal life of individuals to the governance of cities, and from the organization of states to global geopolitics. Therefore, it is safe to assume that when abstract theories of artificial intelligence meet the sheer complexity of the real world, discrepancies and tensions are bound to emerge.

Nonetheless, theory is useful to orientate any meaningful discussion on AI. Specifically for the purpose of this paper, we can use the above theoretical materials to understand urban artificial intelligences as artifacts operating in cities, which are capable of acquiring and making sense of information on the surrounding urban environment, eventually using the acquired knowledge to act rationally according to pre-defined goals, in complex urban situations when some information might be missing or incomplete. Moreover, urban AIs operate autonomously. They make decisions in an unsupervised manner, thus displaying a rudimentary form of thinking, and take actions which can potentially trigger radical changes in the city. In relation to this broad definition of urban artificial intelligence, we can observe three different, and yet similar, specific examples of urban AI, each one with its own characteristics, urban domain and potential set of urban repercussions.

The first category of urban artificial intelligence is represented by autonomous cars. Here the artifact where the artificial intelligence resides is a car. This is a technology which is being employed in an increasing number of cities, thereby gradually entering the everyday (Milakis et al., 2017; Talebian and Mishra, 2018; Acheampong and Cugurullo, 2019). The AI in question is capable of sensing the surrounding urban environment by means of cameras, radars and lidar systems. In addition, it can learn about the city through downloadable data sets capturing different urban aspects, such as roadmaps and weather forecasts. The artificial intelligence employs this information to drive the car to a given location and, at the highest level of autonomy (level 5), no human input or supervision is required, with the AI theoretically capable of handling uncertain situations autonomously. Practically, as the first pedestrian fatality caused by an autonomous car proves, this is an urban artificial intelligence whose skills, capabilities and, more in general, *intelligence* are still questionable. On the 18th of March 2018, in the city of Tempe (Arizona) an autonomous Uber car was not capable of handling an unexpected scenario, a woman crossing on foot a road outside the designated pedestrian crosswalk while carrying a bike, and it run over her (see also Stilgoe, 2019). In fact, although the technology of autonomous driving is rapidly progressing, severe technological limitations currently exist which are limiting both its employment in real-life environments and people's trust in it (Fridman et al., 2019). Yet, despite these limitations, several governments, car manufactures and ridesharing companies are keen to accelerate the deployment of autonomous vehicles in cities, and sociological studies show that a significant number of urban dwellers are ready to give up their current means of transport in favor of a car driven by an artificial intelligence (Hulse et al., 2018; Cugurullo et al., 2020). The transition to an autonomous urban transport would trigger a number of substantial urban changes. If enabled by sharing services, it could decrease the number of cars on the road and so the quantity of energy and, above all, urban space that they need to operate, thereby favoring a less car-centric redesign of the built environment (Duarte and Ratti, 2018; Cugurullo et al., 2020; Guériau et al., 2020). Conversely, private and highly comfortable autonomous cars which drive themselves while their users can work or sleep, might prompt "people to travel more frequently and across greater distances," thus fostering commuting, suburbanization, an energy-intensive lifestyle and, in essence, the production of car-centric urban spaces (Hawkins and Nurul Habib, 2019, p. 69). In addition to reshaping the built environment and the geography of housing, the transition to autonomous cars is also likely to reshape urban mobility, particularly in relation to people with disabilities and minors currently not allowed to employ a car (Bennett et al., 2019). Last but not least, the emergence of artificial intelligences in urban transport poses concrete ethical challenges. Normally, the AI controlling a car is making decisions of a geographical nature: what route should be taken and where exactly in the city the car should go through, in order to reach the final destination. Occasionally, the same AI might have to make decisions of an ethical nature. Assuming a possible accident in which harm is unavoidable (perhaps because the brakes of the autonomous car are malfunctioning and the AI just does not have enough time to stop the car), how will the artificial intelligence choose to distribute inevitable harm? As several scholars have pointed out, this is a decision which could imply harming (and even killing) the passenger(s) or pedestrians, cyclists and other motorists (Goodall, 2014; Lin, 2016; Awad et al., 2018; Bonnefon et al., 2019). In the autonomous city, therefore, the AI's capacity of making decisions triggers moral dilemmas which require the machine to possess moral values.

The second category of urban artificial intelligence is represented by robots. This is a multiform category, since robots exist in many different shapes and populate diverse urban domains. We distinguish it from the first category, because autonomous cars operate in one specific domain (transport) and, despite heterogeneous brands, models and sizes, they all share the same fundamental design (they have an empty interior to accommodate passengers and need wheels to move on urban roads). On the contrary, urban robots escape rigid definitions and designs. Within this second category, the artifact animated by an AI can be an unmanned air vehicle (commonly called *drone*) as well as a humanoid machine mimicking the human body (Russell and Norvig, 2016). It can also be a *nanobot* almost invisible to the naked eye or an *android* almost indistinguishable from a person. Robots can be found in retail, customer service, hospitality, education, security and in the maintenance of urban infrastructure (Tiddi et al., 2019; Macrorie et al., 2020). Like autonomous cars, robots are equipped with sensors which make them capable of perceiving the built environment and acquiring information about what is around them. AI gives robots the ability to make sense of the acquired information, ultimately allowing them to interact with the prime inhabitants of the built environment: humans. Service robots, in particular, operate often in the frontline, communicating directing with customers (Wirtz et al., 2018; Mende et al., 2019). In this context, a robot operates in the presence of incomplete information, since every customer has an unknown personality and unknown requests which the artificial intelligence has to interpret and try to accommodate, without the help of a human operator. In so doing, the robot is *de facto* performing a job and it is precisely in the capacity of robots to generate labor their greatest source of disruption. As remarked by several scholars, robots constitute "a new class" of intelligent machines which is disrupting labor systems and "few employment fields are immune" (Bissell and Del Casino, 2017, p. 436; Del Casino V. J. Jr., 2016, p. 847). Pragmatically, unemployment is the most feared consequence of this type of urban AI, should robots in the long run outnumber and outsmart more expensive human workers (Korinek and Stiglitz, 2017).

The third category of urban artificial intelligence is the city brain. This is the most elusive manifestation of AI in the built environment. In this case, the artifact where the artificial intelligence is located is a digital platform and, for this reason, city brains can be also understood as an instance of *platform urbanism* (see van der Graaf and Ballon, 2019; Barns, 2020; Caprotti and Liu, 2020; Leszczynski, 2020). As exemplified by Alibaba's City Brain, this is an AI originally created for autonomous traffic management (Alibaba, 2020). A city brain acquires information about urban traffic directly by means of the so-called Internet of Things (more specifically, hundreds of interconnected cameras distributed all around the city) and indirectly by being fed with large data sets installed by Alibaba's computer scientists. It then uses the acquired knowledge to control traffic lights and direct the flows of vehicles and people in the city. Transport is only the initial domain influenced by the intelligence of the city brain. According to Alibaba (2020), this AI will go beyond the management of traffic and it will soon be employed in the realms of urban planning, health, safety and governance. Should this transition take place, its repercussions would be considerable and of a scale substantially larger compared to the case of autonomous cars and robots. In practice, a city brain treats the city like a giant artifact which can be controlled and optimized. However, there is a stark difference between an AI controlling a car and deciding autonomously about what the best route is, and an AI controlling an entire city and deciding autonomously about what the best strategy of urban development is. From a purely logistical point of view, formulating the best route for a car to follow implies dealing with information regarding a limited time frame while, as Batty (2018, p. 5) notes, urban planning is about *the long term* and deciding on not just what is best in the present, but also what will be beneficial to the city in the foreseeable future. From a technical perspective, this leads to the question of whether AI will be capable of dealing with high levels of uncertainty connected to the broad time windows that are typical in urban planning. From a philosophical perspective instead, given that urban planning and so urban governance are also about deciding on what is *right* or *wrong*, *good* or *bad*, *sustainable* or *unsustainable*, there is the thorny ethical question of how a non-human intelligence comes to determine what is ideal for a human environment. Here the fields of AI and urban studies overlap again with the field of ethics, showing that the autonomous city's nascent capacity of making decisions in an unsupervised manner presupposed a set of moral values which might be underdeveloped or, worse, missing.

Considered together, urban artificial intelligences like autonomous cars, robots and city brains, raise important questions regarding the future of the city. Because of the technological innovation that they embody and the novel urban scenarios that they are shaping, theirs is a narrative which easily tends to focus on the future and the extraordinary, thus risking to neglect the past and the ordinary. Indeed, some of the prospects presented by contemporary urban artificial intelligences are unprecedented. For example, the possibility of an entire city governed by a single artificial intelligence, as it is now presented by Alibaba's City Brain, escapes even the realm of mainstream science fiction. However, AI as an idea, as a field of research and as a technology is not new, nor is its application in cities. The field of artificial intelligence begun to be cultivated in the middle of the twentieth century and, since then, many applications of AI (albeit in an embryonic form compared to what we see today) have touched the built environment. Particularly in relation to cars, for instance, in the early 2000s scholars were already noticing how "it is not just the driver who possesses intelligence" and "has the capacity to act," the car itself is "able to sense its environment, make judgments, and act accordingly" (Featherstone, 2004, p. 10; Thrift, 2004; Dodge and Kitchin, 2007). Meanwhile, in the domestic space, Dodge and Kitchin (2009, p. 1349) were finding several objects possessing "awareness of their environment" by means of sensors, and the ability to share information through the then emerging Internet of Things. "It is a world where we not only think of cities, but cities think of us" Crang and Graham (2007, p. 789) reflected, starting to feel the formation of an intelligence within urban infrastructure.

AI has a genealogy and it is therefore important to consider urban artificial intelligences as part of a broader process of technological and philosophical development in which new pieces are constantly added to a long-standing mosaic. On these terms then, it is equally important to identify what new technologies and ideas are being added, how they relate with the older pieces of the mosaic, and how the big picture that the whole mosaic is showing has been changing over the years. Moreover, although AI is a disruptive and radical technology, this does not necessarily mean that everything that AI touches is drastically altered. On the contrary, as Greenfield (2018, p. 8) stresses, "allegedly disruptive technologies" like artificial intelligence often "leave existing modes of domination mostly intact." The technology *per se* might change and so its design and packaging, but the broader politico-economic dynamics underpinning its production, as well as the elites that benefit the most from the fruits of technological innovation, might remain unchallenged. In the case of autonomous cars, for instance, recent studies suggest that while the presence of a non-biological intelligence behind the wheel is out of the ordinary, the politics of autonomous urban transport follows ordinary neoliberal trajectories leading to all-too-familiar episodes of social injustice and undemocratic governance (Henderson, 2018; Cugurullo et al., 2020).

In light of the above, it is essential then to empirically examine recent urban artificial intelligences, bearing in mind that they are part of a broader and older process of technological innovation which might radically change some aspects of the city while leaving others intact. It is empirical research which can determine, on a case-by-case basis, what novel manifestations of intelligence are permeating the built environment and how cities are responding to them. This is the purpose of the next section which shifts the focus from the theory to a single case study, in the attempt to capture an example of the evolution of urban artificial intelligence from a condition of *automation* to one of *autonomy* while also picturing the surrounding politico-economic context. The paper now turns to the case of Masdar City and operationalizes the theoretical framework illustrated above, by identifying an instance of urban artificial intelligence and unpacking its core skills and capabilities. In so doing, the paper sheds light on how the Masdarian urban artificial intelligence learns, makes decisions and acts autonomously in a real-life environment, simultaneously triggering and preventing radical changes.

FROM *AUTOMATION* TO *AUTONOMY* IN MASDAR CITY

Masdar City is a new master-planned settlement under construction in Abu Dhabi (United Arab Emirates). The project was launched in 2007 by the ruler of Abu Dhabi, Sheikh Khalifa, and is expected to be completed in 2030. Masdar City is a state-led and funded urban project managed by a public company called the Masdar Initiative. This ambitious US$ 20 billion-project is now in its second decade of development. Built with the aim of serving as a testbed for experimental urban technology, Masdar City has seen for over 10 years the development of a plethora of smart technologies ranging from smart grids to driverless vehicles (Cugurullo, 2016; Griffiths and Sovacool, 2020). During this time frame, the Masdarian technology has been exposed to the influence of innovation and modernization and, like most technologies, it has evolved, thereby changing its shape, mechanics and function. More recently, AI has become a prominent feature of the technological portfolio of the Emirati city which, due to its experimental nature and prolonged experience in smart urbanism, is a useful case study to observe the gradual emergence of urban artificial intelligence and trace back empirically its origin.

This section focuses on *urban transport* and its technological evolution in Masdar City, as arguably the most emblematic dimension of the Emirati project where AI manifests itself not as an abrupt phenomenon, but rather as part of a broader and multifaceted process of development. The story of Masdar City's system of urban transport begins in 2009, shortly after the launch of the Emirati project, with the construction of the Personal Rapid Transit (PRT). The PRT is a system of driverless cars operating in an underground level of the city, called *the undercroft* (see **Figure 1**). The original vision of the planners of Masdar City, the international architecture firm Foster+Partners, was that of a city divided into two levels: *above* a compact car-free city characterized by narrow pedestrian streets, *below* the undercroft with shared PRT cars functioning as a public transport system. The image of the PRT (cars not driven by a human being) might resonate with the notion of artificial intelligence, but in reality this is not the case. The PRT is an *automated* technology, not an *autonomous* technology and to understand this crucial difference, the first step is to examine in more detail how and where PRT cars operate.

A journey on the PRT starts always in a PRT station which looks and is experienced like a common metro station. As a passenger you find yourself in an underground environment designed and built exclusively for PRT cars to stop and take on passengers. Before entering a PRT car, it is necessary to press a button which opens first the locked sliding door of the glass box where the vehicle is parked, and then the door of the vehicle itself. The first door only opens if there is an available PRT car behind it, meaning that this is a confined urban space which can be entered only by entering a PRT car. Once inside, it is time to choose the destination. To do so, next to the seats is a touchscreen where your options are visualized. PRT cars can move only from a PRT station to another PRT station, according to routes pre-determined by the planners of Masdar City. After one of the pre-defined destinations has been selected, the PRT begins to move, leaving its glass box and traversing the undercroft at a speed of maximum 40 km/h.

The journey has begun and there are three important aspects to note. First, there is no driver nor any form of intelligence which is sensing the surrounding environment and then deciding on what the best route is. Second, the PRT is just following a pre-defined track which is clearly visible on the surface of the road (see **Figure 2**). What is happening has little to do with AI as it was understood in the previous theoretical section. The roads

FIGURE 1 | PRT driverless cars in a station located in Masdar City's undercroft. Source: author's original.

FIGURE 2 | View from inside a PRT vehicle in motion. The machine is traversing Masdar City's undercroft. The two parallel lines visible on the road ahead form the track that the PRT car is following. Source: author's original.

of the undercroft are simply filled with sensors drilled into the ground, and placed in a sequential manner. Every sequence of sensors forms a PRT track. These sensors send a signal to the PRT car which is capable of detecting them. In practice, they act like *magnets* and this is how an engineer from the Masdar Initiative described them in an interview. The magnets irresistibly attract the machine which is uncapable of sensing anything else. During an interview with one of the managers of Masdar City, the following exchange occurred:

> Interviewer: *What would happen if, hypothetically speaking, I walked in front of a PRT car in motion?*
> Interviewee: *It's very simple. The PRT would run over you.*

This second aspect is connected to the third one: the design of the built environment. The undercroft was designed as a confined space where pedestrians and non-PRT vehicles are not allowed. This type of urban design serves the purpose of eliminating uncertainty. More specifically, given that the machine is not capable of sensing the passage of humans and other vehicles, the surrounding environment is designed precisely to prevent the passage of humans and other vehicles, thereby ultimately preventing the risk of pedestrian fatalities and car accidents. The boundaries of the undercroft are walled and the few entrances close to the PRT tracks are blocked by means of barriers (see **Figure 3**). Essentially, the undercroft is a *space of repetition* where the same exact action is supposed to take place under the same exact conditions. Any variation on the Masdarian theme could be deadly, and the built environment is literally a barrier blocking the out of the ordinary.

Ten years after the beginning of the PRT experiment, the Masdar Initiative started to experiment with another form of urban transport: the autonomous car. The model introduced and currently operational in the Emirati City is a Navya *Autonom*, a technology which is considerably different from the PRT (Navya, 2020a). The three key aspects observed earlier along a trip on a PRT car are absent. First, although like in the case of the PRT there is no apparent driver, the Autonom is an artifact animated by an artificial intelligence capable of perceiving the surrounding environment. The AI itself is the driver. The Autonom is equipped with two lidar systems and two cameras which acquire information on the space where the car operates and detect obstacles (Navya, 2020b). Second, the Autonom does not follow a track nor any pre-determined route. On the basis of the data collected, it makes a decision on the run, determining the route in an unsupervised manner (Navya, 2020c). The roads that will be taken to get to the final destination are chosen by the AI. Third, the Autonom's environment is not a confined space. This is a machine employed in open urban spaces designed to accommodate the flow of people and other vehicles, instead of preventing them like the undercroft does.

When compared, the PRT and the Autonom present remarkable differences. The former is an example of automation since its actions are pre-determined by decisions made beforehand by engineers and computer scientists working for the Masdar Initiative. The PRT operates without a human driver, but it possesses no intelligence. It is automated in the sense that it endlessly repeats what was instructed to do, in a confined space designed by Masdar City's planners to allow no variation. The latter instead represents autonomy because its actions are based on decisions which the machine itself has reached in an unsupervised manner. The Autonom is artificially intelligent due to the fact that it is an artifact able to learn about the surrounding environment and then act in the face of uncertainty. The built environment is here a key differential. The Autonom functions in urban spaces where repeating the same exact action under the same exact conditions is not possible. A city (contrary to the

FIGURE 3 | On its way to the next station, the PRT car turns passing close to a blocked entrance leading outside Masdar City. The track that the vehicle is following is still visible on the ground. Source: author's original.

undercroft) is an open and ever-changing system. Specifically in relation to transport and mobility, every day a single ordinary road can be experienced by different vehicles and people moving according to geometries which will not be exactly the same the day after. Weather conditions might change too, and so the road itself as a result of repair works. Road closures can temporarily remove some spaces from the map, but such uncertain factors do not stop an intelligent machine like the Autonom from determining the best route. In automation, there is one pre-defined *best* and it is static. In autonomy, the understanding of *best* is constantly changing with the changing scenarios where urban artificial intelligences operate.

On the one hand, the advent of autonomous cars in Masdar City has considerably altered urban transport and mobility in the new Emirati city. Just the simple fact that now it is not necessary anymore to walk to an underground station to get access to a car, is a significant difference. While PRT vehicles continue to be operative exclusively in the undercroft, the rest of Masdar City is served by the Autonom which is accessible overground in unconfined spaces. Above all, the crucial distinction between the Autonom and Masdar City's conventional road transport lies in the AI's capacity of making decisions autonomously. As an urban artificial intelligence, the Autonom is capable of extracting concepts and choosing what to do. These are skills that, as noted in the previous section, are not simply logistical and geographical. An autonomous car does not just choose a route, it also executes the chosen route thereby placing itself in a scenario in which accidents and, thus, unavoidable harm are possible. What is new and different then is that, in Masdar City, there are machines which sooner or later will have to make ethical choices.

On the other hand however, despite the novelty brought by the Autonom, there is a considerable tripartite continuity between this recent urban artificial intelligence and Masdar City's older automated transport system. First, both the PRT and the Autonom are part of the same process of urban experimentation. As an experimental city, Masdar City has been trialing innovative technologies of urban transport for more than 10 years. This endeavor started in 2009 with the PRT and recently ended (at least for now) with cars driven by an AI. Members of the Masdar Initiative have tested both the PRT and the Autonom in the real-life environment provided by the new city, and it is the autonomous car that the Emirati company has judged the most successful transport technology. The implementation of the PRT has been halted and its service limited to ∼10% of Masdar City. Newly paved roads for autonomous cars are the current priority of the Masdar Initiative.

The reason why the PRT experiment was ended, while the deployment of autonomous cars continues, relates to the second common denominator between the two transport technologies. They are both part of the same business project. In Masdar City, urban experimentation goes hand in hand with commodification. Every smart technology tested in Masdar City eventually becomes a product which is commercialized and sold internationally by the company that develops it. The Masdar Initiative offers the real-life environment where experimental technologies are tested, together with a team of engineers and computer scientists providing assistance during the experiment. For these services, once a product which was tested in Masdar City is sold, the Emirati company gets a percentage of the total revenues (Cugurullo, 2013a). Given these overarching economic dynamics, it is not surprising that the Masdar Initiative tends to prioritize the experimentation of those technologies for which there is more demand and that are more likely to generate revenues. On these terms, the shift from the PRT to the autonomous car follows a predictable business rationale as, with many countries around the world now keen to deploy autonomous cars, the Emirati company is simply betting on the most trending technology.

The third interconnected continuity is about what the Masdarian experimental technology and business project are supposed to sustain which, put simply, is the *status quo*. The Masdar Initiative (a public company and instrument in the hands of the government of Abu Dhabi) has been testing and commercializing smart technologies to diversify the national economy, so to preserve the political position of the royal family in the inevitable post-oil era (Luomi, 2009; Cugurullo, 2016). The political stability of the Emirati ruling class depends on the stability of the Emirati economy which is currently based on oil and meant to collapse, unless alternative sources of capital are soon found. Seen from this perspective, in the context of the Emirati political economy, AI is technologically new but politically it serves the purpose of keeping the long-standing power of the sheikh intact, thus conserving a regime which as critical scholars have repeatedly remarked is authoritarian and undemocratic in nature (Ponzini, 2011; Crot, 2013; Cugurullo, 2013b; Caprotti, 2014). In the desert of Abu Dhabi, technological progress has been fast, with a newly built city showing in the space of 10 years the passage from automation to autonomy and, yet, the broader politico-economic vision remains unchallenged showing little or no sign of progress.

CONCLUSIONS: APPROACHING THE AUTONOMOUS CITY

The emergence of artificial intelligence in cities is a complex phenomenon, both theoretically and empirically, in which question marks outnumber the theories and empirics currently present in urban scholarship. This paper has taken some of the initial theoretical and empirical steps toward an understanding of the autonomous city. While the term *autonomous city* was previously used by scholars like Vasudevan (2017) and Norman (2018) to describe cities which are politically and economically independent, the word *autonomous* has been here employed to stress the presence of urban artificial intelligences capable of thinking and acting in an unsupervised manner. On these terms, an autonomous city is a city where autonomous cars, robots and city brains are increasingly performing tasks and taking on roles which have traditionally been the domain of humans. With humans left out of the loop, a city becomes autonomous in the sense that it is capable of operating without human inputs.

By developing the concept of urban artificial intelligence, this study has illuminated a fundamental aspect of the autonomous city. Theoretically, the paper has unpacked the core skills and capabilities of artificial intelligences operating in cities, explaining the meaning of being intelligent in relation to cars, robots and digital platforms, and exposing the principal urban challenges of non-biological intelligence. Empirically, it has tracked the emergence of AI in Masdar City, showing how smart-city solutions are evolving into autonomous technologies which manage parts of the city without human supervision. However, substantial gaps in knowledge remain unexplored and, rather than a portrait of the autonomous city, this contribution should be intended as a door to enter the autonomous city and begin its empirical and theoretical investigation. This final section highlights the key findings of the paper, using them as stepping stones to advance a research agenda. Technological innovation in the field of AI is progressing rapidly, and the social sciences and humanities should not lag behind. The following six points seek to orientate urban studies and cognate disciplines toward a critical understanding of AI in cities.

First, AI is being incarnated in an number of urban artifacts. Urban artificial intelligences are artifacts located and operative in cities, which have the capacity to learn, think and act autonomously. Specifically, in relation to the categories presented in this paper, examples can be found in urban transport services managed by autonomous vehicles, in restaurants and shops managed by service robots, and in the governance of cities managed by city brains. However, the three categories of urban artificial intelligence proposed here remain empirically underexplored and are open to be theoretically refined and expanded on the basis of empirical data. For example, while there is a burgeoning literature on autonomous cars, little is known about urban robots and city brains. This paper has remarked that robots represent an extremely diverse category of urban artificial intelligence. A taxonomy of urban robots is therefore needed to identify what specific types of robot are populating cities, and to locate their sphere of influence. Similarly, there is a lack of understanding of the range of action of city brains, from a geographical and operational perspective. What outdoor and indoor urban spaces are exactly being sensed by a city brain, in what urban domains this large-scale AI is operative and what kind of decisions it has the power to make, are aspects in need of research. Furthermore, besides the embodied AIs discussed in this paper, many artificial intelligences exist without a physical incarnation. In AI literature, they are commonly called *software agents* because of their capacity to act despite missing a body (Russell and Norvig, 2016). These AIs abound in cities and, although their actions are immaterial, their consequences are tangible. A computer program deciding autonomously on who is worthy of an insurance or a mortgage (O'Neil, 2016). Contact-tracing apps monitoring the mobility and health of people, and determining who has to be in quarantine during a pandemic (Kitchin, 2020; Morley et al., 2020). The autonomous city has an immaterial and invisible dimension which has to be urgently examined.

Second, this paper has emphasized the presence of intelligence in urban artifacts and discussed the notion of artificial intelligence by drawing upon AI literature. However, the concept of *intelligence* goes well-beyond the field of AI and encompasses a plethora of other disciplines such as philosophy, neuroscience, psychology, linguistics and behavioral economics (Sternberg, 2020). It is therefore crucial to interrogate from an interdisciplinary perspective the intelligence of autonomous cars, robots, city brains and other urban artificial intelligences, by clarifying what exactly makes them intelligent and in relation to what urban domain. Intelligence, and so artificial intelligence, should not be approached nor depicted in black and white. Being intelligent is a hyper complex quality full of gray areas. A person might manifest intelligence in one domain, while showing stupidity in others. Likewise, urban artificial intelligences might intelligently perform a specific task and utterly fail to comprehend another activity. Moreover, intelligence is not a box to tick, but rather a quality expressed at different levels and degrees. Research questions like *Are city brains, robots and autonomous cars intelligent?* should then be rephrased by adding *To what extent* in the beginning.

Third, this paper has shown that the manifestation of AI in cities is neither a sudden phenomenon, nor an extensive urban revolution. From a technological point of view, urban artificial intelligences are part of a broader process of development which is now culminating in the passage from *automation* to *autonomy*. While this passage presents some innovative elements, such as the formation of novel technologies capable of thinking and acting autonomously, there are also components which have been around for several decades. Autonomous cars, for example, employ sensors to perceive the surrounding environment. The cameras of the city brain capture information and then pass it to a central digital platform by means of the Internet of Things. City brains, autonomous cars and robots can all be fed with large data sets, the so-called *big data*, to indirectly learn about the city where they operate. Smart sensors, the Internet of Things and big data are traditional features of smart-city initiatives, far from being novel, and can be seen as points of intersection between *smart urbanism* and an emerging *autonomous urbanism*. From a politico-economic perspective instead, artificial intelligence is part of broader programmes of economic growth and diversification, as well as it is embedded in political agendas and ideologies that long predate the genesis of AI. Urban artificial intelligences can thus be technologically revolutionary while, at the same time, preventing the outbreak of political, economic and ideological revolutions. Careful empirical research is therefore much needed to identify the technological lineage of autonomous urbanism and, above all, what doors this urbanism is opening or keeping closed in politico-economic and ideological terms. There is a tension in particular which should be investigated and exposed. If smart-city operations and technologies have been about producing data and gaining knowledge, then the passage to autonomy via AI suggests a further step: the capacity to use data in order to extract concepts and make decisions. In this sense, the key innovation differentiating the smart city from the autonomous city, is in the latter's ability of thinking. Assuming that, as originally theorized by Turing (1950), machines can indeed think, it is vital to understand and evaluate *what* they are thinking. This line of research would shed light on what concepts and decisions are being developed by urban artificial intelligences, and assess the extent to which their thinking echoes existing ideologies and regimes. The machine's act of thinking might be innovative, but the thinking per se could be conservative.

Fourth, the case study examined in this book has demonstrated that the emergence of urban artificial intelligences is context dependent. The specific experience of Masdar City is that of an experimental city built from scratch which has been trialing and commercializing new technologies for over a decade, in order to preserve the political structure and power of a sheikhdom. Similar experiences are certainly possible. For example, Saudi Arabia (a Middle Eastern authoritarian state like Abu Dhabi) is investing $500 billion in the construction of a new master-planned city, Neom, in which according to the Saudi Crown Prince "everything will have a link with artificial intelligence" and robots will outnumber humans (Bloomberg, 2017; Neom, 2020). In a different geographical and political context, experimental urbanism meets again autonomous urbanism in China where the Government of Shanghai has released official plans to build the first town in the world to be completely operated by an artificial intelligence: Beiyang AI Town. However, these ambitious urban experiments *à la* Masdar are likely to remain exceptional, due to the sky-high costs and planning challenges typical of *ex novo* experimental urban mega projects (see Cugurullo and Ponzini, 2018). It is therefore important to study urban artificial intelligences in other strands of experimental urbanism, particularly in small-scale experimental urban projects affecting existing cities (Evans et al., 2016; Bulkeley et al., 2019). Besides avant-garde experimental cities, geographical studies are essential to understand how AI penetrates inside ordinary cities, coexisting or clashing with older automated and manual technologies, across a broad spectrum of political systems and ideologies ranging from neoliberalism to socialism. While, as shown in this paper, experimental urbanism tends to promote the formation of confined *spaces of repetition*, outside urban experiments uncertainties are everywhere (Scoones and Stirling, 2020). It is in *spaces of uncertainty* that AI will reveal its greatest limitations and that is the terrain where it should be observed the most.

Fifth, this paper has argued that, from an AI perspective, the city itself can be seen as an artifact animated by a non-human intelligence. This view does not necessarily negate that of the fluid city made of flows, as it is commonly pictured in urban political ecology (Heynen et al., 2005; Kaika, 2005; Gandy, 2014). On the contrary, the image of the artifact implies changes and flows, because cities are constantly (re)built, modified, expanded and traversed by flows of energy, data, people and capital. What matters for the study of the autonomous city is that like an AI can possess an inanimate object such as a car, so it can possess the built environment and the infrastructure of a city. This is the idea at the foundation of large-scale urban artificial intelligences, like Alibaba's City Brain, which are developed to animate and control entire cities. Although the principle is the same, the paper has noted how there is a substantial difference between managing the route of a car and the development of a city. The bottom line is that every urban artificial intelligence is different and will impact differently on the city. Researchers should avoid treating AI as a homogeneous category of intelligence, because too much divergence exists among and within urban artificial intelligences. What is needed is empirical research examining how specific (and diverse) models of autonomous cars, robots and city brains are reshaping cities. As in science we do not generalize biological intelligence, instead appreciating the variety of intelligent life forms on Earth, the same logic applies to the study of artificial intelligence.

Sixth, the emergence of city brains and large-scale artificial intelligences raises important questions about the governance of cities since, arguably for the first time in history, non-biological intelligences are beginning to determine urban development in an unsupervised manner. In principle, as recent findings in computer science point out, "autonomous machines can learn to establish cooperative relationships with people and other machines, even in the midst of conflicting interests and threats of being exploited" (Crandall et al., 2018, p. 8). The evident similarity between the complexity of the abstract scenarios used by computer scientists in their simulations and the complexity of real-life urban governance, suggests the hypothesis that AI might be used in the management of cities to address complex urban problems, including issues of sustainability (Vinuesa et al., 2020). Such hypothesis remains untested and should be approached with care, because as *smart* and *sustainable* are not synonymous which each other, it is unlikely that *autonomous* will suddenly become synonym for *sustainable*. This gap in knowledge calls for further empirical research on artificial intelligence in urban governance, with a focus on sustainability intended not in a one-dimensional way so to capture the full spectrum of social, environmental and economic variables that can be affected by AI (Floridi et al., 2018, 2020). This analytical task, however, requires an important preliminary conceptual step and, more specifically, "the scientific study of intelligent machines, not as engineering artifacts, but as a class of actors with particular behavioral patterns and ecology" (Rahwan et al., 2019, p. 477). In essence, humans need to learn how to cooperate with machines and vice versa, in the challenging game of governance. On these terms, an AI is seen as an actor which, similarly to a human being, has an intelligence, manifests a behavior and acts autonomously in the governance of the city.

On the one hand, the challenge is technical in nature. Codifying principles of urban governance to inform artificial intelligences, for instance, requires interdisciplinary studies conducted by AI scholars and governance scholars, under the premise that as a single universal model of governance does not exist, so a single blueprint for artificial intelligence cannot be found. On the other hand, the challenge is a deeply philosophical one. For what reason and for whose purpose should urban artificial intelligences be employed? What is *right* and what is *wrong* in urban development when cities are populated by humans as well as by intelligent machines? These are crucial questions of ethics whose answers should not be postponed until the technology is already functional. Nor should these answers be left to the technology itself. As Bostrom (2017) remarks, the values, ideals and goals of an AI might be considerably different from those of its creators, simply because we cannot expect a non-human intelligence to think exactly like humans do. By the same token, the agenda of a city brain might diverge substantially from traditional urban agendas, and thus have unexpected negative consequences for the dwellers of the autonomous city. Philosophical inquiry should therefore be proactive and inform the development of AI, as it now intersects with the development of the city.

DATA AVAILABILITY STATEMENT

The datasets generated for this study will not be made publicly available to protect the anonymity of the interviewees.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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Choosing Ethics Over Morals: A Possible Determinant to Embracing Artificial Intelligence in Future Urban Mobility

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Artificial Intelligence (AI) is becoming integral to human life, and the successful wide-scale uptake of autonomous and automated vehicles (AVs) will depend upon people's willingness to adopt and accept AI-based technology and its choices. A person's state of mind, a fundamental belief evolving out of an individual's character, personal choices, intrinsic motivation, and general way of life forming perceptions about how society should be governed, influences AVs perception. The state of mind includes perceptions about governance of autonomous vehicles' artificial intelligence (AVAI) and thus has an impact on a person's willingness to adopt and use AVs. However, one determinant of whether AVAI should be driven by society's ethics or the driver's morals, a "state of mind" variable, has not been studied. We asked 1,473 student, staff, and employee respondents at a university campus whether they prefer an AVAI learn their owners own personal morals (one's own principles) or adopt societal ethics (codes of conduct provided by an external source). Respondents were almost evenly split between whether AVAI should rely on ethics (45.6%) or morals (54.4%). Personal morals and societal ethics are not necessarily distinct and different. Sometimes both overlap and discrepancies are settled in court. However, with an AVAI these decision algorithms must be preprogrammed and the fundamental difference thus is whether an AI should learn from the individual driver (this is the status quo on how we drive today) or from society incorporating millions of drivers' choices. Both are bounded by law. Regardless, to successfully govern artificial intelligence in cities, policy-makers must thus bridge the deep divide between individuals who choose morals over ethics and vice versa.

Keywords: automation, morals (morality), ethics, autonomy, artificial intelligence, autonomous vehicle, automated

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INTRODUCTION

Autonomous, driverless, and self-driving vehicles have begun to emerge as a promising use of AI technologies (Pan, 2016; Faisal et al., 2019), because these machines may play a key role in "autonomous cities" of the future (Allam, 2020; Cugurullo, 2020). Intrinsic to any autonomous city is artificial intelligence (Allam, 2020; Cugurullo, 2020), which constantly analyzes large datasets, also called big data. Using big data, an AI can model and integrate a tremendous number of urban functions, and through those models draw conclusions about how best to govern a city. However, modeling with big data, especially for urban environments, can be flawed, biased, and in a worst case scenario wrong (Barns, 2021). Biased datasets beg questions as to the exact role an AI should play in urban governance and decision making despite its powerful ability to enhance human life. For example, an urban AI may be able to protect people from disasters (Yigitcanlar et al., 2020a,b) and reduce cities' carbon emissions (Allam, 2020; Acheampong et al., 2021), but may also severely change cities in an irrevocably negative way (Cugurullo, 2021).

Essentially, an AI is an algorithm, frequently embedded into machines, that can make its own choices, oftentimes without additional human input (Stone et al., 2016). Some of these decisions may balance cause and effect and include ethical or moral decisions with which humans may struggle (Boström and Yudkowsky, 2014). We ask whether an autonomous vehicle's artificial intelligence (AVAI) should operate according to societal ethics, or its end-users moral code, with ethics being defined as what society views as correct and morality being defined as what an individual views as correct (Bartneck et al., 2007; Applin, 2017). An AVAI may have to make a choice between protecting a pedestrian or its occupants (Hengstler et al., 2016; Etzioni and Etzioni, 2017). People may prefer AVAI to be programmed to benefit society in the abstract, but people also do not trust (and would not purchase) cars that would sacrifice their own life for the lives of others (Shabanpour et al., 2018). The moral and ethical debates about AVAI decision making discussed in this paper are a subset of the broader ethical, moral, and political implications of AVs, which include privacy, surveillance, social inequality, uneven access, and algorithmic discrimination of specific groups of people. Fully autonomous vehicles imply the presence of artificial intelligence in performing safety critical control functions at the heart of which ethical and moral decisions over their governance in cities must be made.

Over the past decade, much social science research has been devoted to understanding sentiments toward AVAI. To date, researchers agree that sentiments vary with demographics: young people, especially males, show more affinity toward AI than seniors (Liang and Lee, 2017; Kaur and Rampersad, 2018; Dos Santos et al., 2019); younger people are also more likely to ride in an AV or automated taxi (Pakusch et al., 2020). Comparatively few studies have focused on people's intrinsic motivation to adopt or sentiments toward AVs, or more precisely, what we define as their "state of mind" related to AI or AVs. For example, previous related experiences like familiarity with and trust in technology increases willingness to adopt, while risk-aversion to technology hinders wide-spread adoption of technology (Smith and Ulu, 2017; Schleich et al., 2019; Liu and Liu, 2021). One hypothesis, that to the best of our knowledge has not been tested, is whether a person's state of mind determines their affinity toward AI—specifically, whether a person who prefers ethics over morals is more likely to be comfortable with AVs, and whether those people share similar characteristics. We, thus intend to examine whether ethics/morals predicts willingness to adopt. Our contribution to the literature relates to sentiment toward AVs, AVAI, and user preference and starts filling a critical gap in how and what type of upcoming disruptions of AI in cities and societies autonomous vehicles may incur continuing Yigitcanlar et al. (2020a,b) explorations on these types of complex disruptions.

We seek to understand how people prefer AVAIs to be programmed: shall an AVAI learn its behavior from society at large (ethics) or learn the owner's own personal code of behavior (morals) and if—given their choice—whether state of mind has any relevance on perception, familiarity with, or willingness to adopt AVs? We found that people are almost evenly split between ethics and morals, but those who favor AVAIs adopting society's ethics are more willing to adopt, more familiar with, and have more favorable perceptions of AVs. We find that individuals who are younger, male, not white, and who have favorable perceptions of AVs express a statistically significantly greater willingness to adopt. Controlling for these factors, we find that individuals' familiarity with AVs and their beliefs about whether AVs should rely on ethics or morals are *not* statistically significantly associated with their willingness to adopt AVs. The contributions of our study are relevant to academia as an introduction to the state of mind variable as a factor in AV adoption and to industry: most AV programming proceeds by incorporating society's ethics as laws and connected to other vehicles, the AVAI can learn from millions of drivers' interacting on roadways through big data. In contrast, every car currently operating on roads is guided by the drivers' own morals bounded by laws. Further, different corporations choose different paths to program their vehicles in gray areas of the law, in which programmers must pre-declare how AVs make choices. These alternative options stretch well-beyond the binary of individual morals of users vs. societal ethics, but is it an important source of values emerging from for-profit companies developing the technology, and which may neither reflect users' morals or the society's ethics. Lastly, given the likelihood that AV technology will proliferate, better understanding user perceptions can ultimately lead to a faster adoption and better understanding of travel behavior. Given people are split in their perception over whether ethics or morals should guide AVAIs policy-makers need to bridge this gap when governing mobility in autonomous cities.

LITERATURE REVIEW

Assuming the worst-performing AV exceeds human capabilities, and that those human drivers are replaced entirely with their automated counterparts, it is naïve to believe such systems to be infallible. While AVs may connect to one another and analyze their environments to coordinate safe maneuvering (Siegel et al., 2017), environmental factors such as a child darting into the road will inevitably force AVs to choose among unavoidable incidents. More mundane decisions, e.g., whether to yield to an oncoming vehicle or take the right of way, will occur frequently, requiring ethical or moral decisions to be made daily. These potential shortcomings are an argument in opposition of vehicle automation: while society may suffer fewer casualties upon the introduction of AV's, *some* situations may have had more favorable outcomes when guided by human judgement.

Confronted with a challenge, humans rely on reasoning and reflexes to identify and execute a solution. Bringing similar judgment to automated vehicles may be desirable, not because humans are more "correct" than computers, but because reasoning and instinct may provide computers with a useful "backstop" in the absence of clear programming. Such a system may counter AV opponents' arguments by providing assurance that the AI's code is not merely rational and logical, but rather supported by a common and shared moral or ethical code. In particular, people's adoption of AI is likely if AI solution remain a tool to support work and not replace human-centered interaction (Kassens-Noor et al., 2021a). Precedence in other fields that had to make crucial choices between the greater public good and individual choices exist as they too have come to rely on AI analyzing big data. Crucially, big data analytics are inundated with ethical questions about when, how, and why someone's data should be used and how decisions are being made based on it (Spector-Bagdady and Jagsi, 2018; Barns, 2021). For example, one field is medical technology that frequently presents similar moral vs ethics questions for treatments involving scarce resources and end-of-life care (Demiris et al., 2006). The Covid-19 pandemic has brought these critical questions painfully to light when AI and doctors choose how to disseminate oxygen in overflowing hospitals (Zheng et al., 2021). Another field example is disaster recovery and preparedness that can be enhanced by technology (Yigitcanlar et al., 2020a,b), when AI evaluates big data like twitter to support search and rescue operations and supply distribution. However, these AI decisions bring about ethical and moral questions centered around who gets what (Geale, 2012).

Autonomous vehicles (AVs) and their associated artificial intelligence (AI) are similarly prolific in the ethical quandaries their existence produces (Liu and Liu, 2021). Before these technologies proliferate into our everyday lives, governments deciding over autonomous cities would be well-served to better understand exactly how individuals and society as a whole all want these machines to behave, especially in critical situations. In this manuscript, we consider the role morals and ethics may play in driving the adoption of AVs and examine contemporary approaches to incorporating morals and ethics into self-driving development, as well as potential future directions.

Ethical and Moral AIs

A core component of AI is the ability to make decisions in response to the environment (Stone et al., 2016). Some choices an AI may make are likely to include an ethical or moral component. An AI must take heed of the same "social requirements" that humans have, foresee the consequences of their decisions, and avoid harm to humans (Boström and Yudkowsky, 2014). The topic of ethics and AI is hotly debated, as are the legal implications of an AV injuring a person (De Sio, 2017), as well as their policy implications (Acheampong et al., 2021). In the interest of the public good lies the notion of making sustainable choices that serve society in the long-term. Yet, individual choices and preferences will play a key role and are likely to prevail, such as the preference for privately owned vehicles, even if our society becomes more autonomous. In contrast, currently there are numerous ways in which an AI is and can be programmed to make choices that are not bound by sustainability.

An AVAI's morals may be pre-loaded into the machine using a transparent algorithm, one that humans constantly regulate, monitor, and update (Rahwan, 2018). Such an algorithm may be required to place specific values on outcomes and weigh them against one another; reminiscent of the classical ethical dilemma involving a train, where a person must make the choice to save multiple human lives, by directly ending the life of a single individual. However, this may be overcome by allowing an AVAI more agency and giving it the capacity to seek out additional outcomes to maximize good, though this would increasingly empower an AVAI (Vamplew et al., 2018). Yet another option would involve removing the human element even further, for instance each individual AVAI does not need to undergo the process of learning from outcomes, they could simply learn from previous AVAIs while consistently allowing new data to be analyzed and used in decisions going forward. For example, there is little need to teach machines ethics (if this can be done in the first place) thus allowing AI to adjust their own reference framework (Etzioni and Etzioni, 2017). Cell phones could also prove to be a valuable data source for AVAIs to learn from, as well as provide information about pedestrian location and travel behavior (Wang et al., 2018).

In contrast to limited human involvement, maximizing human input is another option for developing ethical AVAIs; a system where humans are constantly checking AVAI for ethical correctness is another possible way to limit unethical behavior (Arnold and Scheutz, 2018). Some even go as far to suggest that all AVAIs be built with a form of off-switch, or a system in which humans are always the go to for determining moral correctness. However, systems like the above may be counterintuitive to the concept of an AVAI as an autonomous entity and may even lead to erroneous behavior or stalled learning (Arnold and Scheutz, 2018). Finally, speaking of ethics and AVAI begs the question of whether their creation itself is a "good" idea. Arguments are being made suggesting that if AVAIs are allowed to author their own moral, such codes could potentially value "machine nature," as opposed to human values (Bryson, 2018, p. 23).

Regardless of how an AVAI makes its choices, perception of them will still matter. Educated people, those with higher incomes, and males report being the least concerned about the technology compared to other demographics (Liang and Lee, 2017). Fears can range from issues surrounding privacy, economic components such as job loss, and specifically, whether an AVAI will act in an ethical way. Usefulness also builds trust in technology, as more people become aware of the benefits of AI, trust increases (Mcknight et al., 2011). When medical students were asked about their opinions of AI, the majority agreed that AI could revolutionize certain aspects of the medical field, and males, specifically ones that were more familiar with technology in general, had a more favorable opinion of AI than did their female counterparts (Dos Santos et al., 2019). Media also has a major impact on how people perceive AVs (Du et al., 2021), with positive examples in media leading to positive sentiments.

The physical appearance of an AI-associated system can affect a person's sentiment toward it. An AI inside of an anthropomorphic robot generates more empathy than does one inhabiting a robotic vacuum cleaner, or inside a car's dashboard. Additionally, AIs are increasingly able to emulate human emotions, which will likely lead to more favorable/pleasant interactions (Nomura et al., 2006; Riek et al., 2009; Huang and Rust, 2018). Increasing peoples' trust of AI may be as simple as having the initial stages of an interaction preformulated, and/or programming an AI to behave in a more human-like fashion (Liang and Lee, 2016).

The State of Ethical Codes for AVs

Other studies have sought to outline an ethical code for how an AVAI should behave. Perhaps most notable is the moral machine experiment conducted at MIT, in which millions of participants displayed their own moral code when faced hypothetical moral quandaries (Awad et al., 2018). The moral machine experiment found dramatic differences in moral preference for people based on age, geography, sex, and more showing how complicated AVAI questions are. However, the use of results from the moral machine experiment may not be entirely accurate, as some research argues using data collected in this manner, or big data in general, is inherently flawed (Etienne, 2020; Barns, 2021). The moral machine experiment particularly drew critique in that it uses normative ends, its inadequacy in supporting ethical and juridical discussions to determine the moral settings for autonomous vehicles, and the inner fallacy behind computational social choice methods when applied to ethical decision-making (Etienne, 2021).

Nonetheless, as the first government in the world, Germany, undeterred by this complexity, has created a twenty-point code of conduct for how AVs should behave (Luetge, 2017). The German code notes "The protection of individuals takes precedence over all other utilitarian considerations" (Luetge, 2017, p. 549). Other studies confirm that utilitarian ethics may be what guides AVAI in the future (Faulhaber et al., 2019). It is likely that other countries will adopt similar codes, though how those codes will differ remains to be seen; if the moral machine's observation bleeds into reality, then these codes are likely to be extremely different. Concerns and arguments over which moral or ethical code an AVAI adopts may also seriously slow the technologies spread as well (Mordue et al., 2020).

Sentiment Toward AVs: Risk-Aversion, Trust, and Familiarity

AVs are slated to enter our surroundings as preeminent smart AIs that will make decisions impacting our fate as mobility users. For example, an AVAI may be responsible for analyzing road conditions, plotting courses, or recognizing a user; but an AVAI may also be responsible for more critical functions like when to brake or swerve to avoid hitting another vehicle or pedestrian (Hengstler et al., 2016; Etzioni and Etzioni, 2017). Trust in technology to make life and death decisions is intertwined with predictability and dependability, though perceptions are not always rational. One might expect teams of programmers, ethicists, and engineers to work together to imagine and plan for atypical scenarios such that an AVAI may make instant and informed decisions based on accurate data, learned rules, and known outcomes. In practice, there are an infinite number of scenarios, and AVAIs must operate on imperfect information fed into probabilistic models. Rather than designing a system to determine with certainty who lives and who dies, development teams instead make estimates from imperfect information and develop models to operate safely with a high probability in all known and unknown scenarios. It is failures to act appropriately, rather than deliberate action, that result in harm to passengers or bystanders. Algorithms do not choose to kill; rather, inadequate data, improper logic, or poor modeling cause unexpected behavior. Yet, consumers perseverate on "intent"—and struggle to understand how an automated system could bring humans to harm, as AVs are held to a higher standard than human drivers (Ackerman, 2016).

Although AVs will likely improve road safety, there will remain an element of risk at play, and AI-human interactions themselves may also result in injury (Major and Harriott, 2020). In general, more risk-averse people are less likely to adopt new technology, regardless of how benign or beneficial it is (Smith and Ulu, 2017; Kaur and Rampersad, 2018; Schleich et al., 2019). The perception of risk appears to be a major factor in a person's willingness to adopt AVs (Wang and Zhao, 2019). Though, perception of risk is situational, and in some cases, people may perceive risk differently when interacting with new technology. For example, people are more willing to allow an AVAI to harm a pedestrian than they would be willing to harm one themselves, were they driving the vehicle (Gill, 2018). Notably, those that have experienced automobile accidents in their past are more likely to adopt an AV, indicating that they view traditional driving as riskier given their history (Bansal and Kockelman, 2018). The perception of risk is likely correlated with trust, increasing trust may in turn reduce the perception of risk.

The main AV concerns impacting trust is safety (Haboucha et al., 2017; Rezaei and Caulfield, 2020). Trust in automotive companies, manufacturers, and regulatory agencies increases a person's willingness to adopt AVs, and the same is true for perceived usefulness and the perception that one can regain control (Choi and Ji, 2015; Wen et al., 2018; Dixon et al., 2020). In particular safety concerns, such as crashes, accidents, or non-recognizing human and animal life, are the primary reasons why people distrust AVs (Kassens-Noor et al., 2020, 2021b). In general, older people and females are less trusting of AVs than are other demographics (Bansal et al., 2016). Geography impacts trust as well, even in culturally similar places such as the U.S. and U.K. (Schoettle and Sivak, 2014). Given familiarity' with AVs except as depicted in the media is rare, trust in other technology, like smart phones, can be used as a proxy until wide-scale deployment increases familiarity. One of the most effective means to increase trust may be for individuals to interact with the technology on a personal basis: studies have found that after individuals interact with AVs, their opinions change for the positive; they are able to better conceptualize the benefits of the technology, and more willing to ride in an AV (Pakusch and Bossauer, 2017; Wicki and Bernauer, 2018; Salonen and Haavisto, 2019). Just as trust influences the perception of risk, familiarity appears to positively influence trust.

In general, familiarity with technology appears to impact willingness to adopt said technology, this is true for AVs as well, as a person's familiarity increases, so too does their willingness to adopt (Haboucha et al., 2017; Liljamo et al., 2018; Gkartzonikas and Gkritza, 2019). Particularly Gkartzonikas and Gkritza (2019) summarizes the many studies conducted on AVs, focusing on the likelihood of AV adoption and identifying different factors that may affect behavioral intention to ride in AVs. These factors include the level of awareness of AVs, consumer innovativeness, safety, trust of strangers, environmental concerns, relative advantage, compatibility, and complexity, subjective norms, self-efficacy, and driving-related seeking scale (Gkartzonikas and Gkritza, 2019, p. 335). Moreover, attitudes with and familiarity regarding technology often have a greater influence on willingness to adopt than do other demographic factors (Zmud et al., 2016). Though interestingly, in regard to AVs, familiarity was not found to increase willingness to pay, at least in one study (Bansal and Kockelman, 2018). As AVs continue to proliferate throughout all levels of society, and as the likeliness of individuals interacting with them grows, on average, familiarity with AVs is likely to increase. This in turn may foster trust and reduce the perception of risk, further increasing the chances that AVs will become a standard part of the modern world (**Figure 1**).

Morals and Ethics in Society and as Drivers

Demographics, too, may play a role in whether a person values ethics over their own morals or vice versa. The moral machine experiment found that women and men often approach ethical and moral situations differently (Awad et al., 2018). In other examples women were found to generally make the same moral decisions as men when presented with dilemmas, except in situations where a person must actively choose to harm one person to save many people (Capraro and Sippel, 2017). The same study also suggests that emotional elements to ethical or moral dilemmas have a greater impact on women. Another study, this time in nurses, also found that women may be more impacted by moral dilemmas and as such may be more negatively affected by them (O'Connell, 2015). There is no consensus, however, as other research asserts that women make moral decisions based on deontological outcomes, whereas men were found to have more utilitarian ethics, and that these differences are significant (Friesdorf et al., 2015). Finally, women may have stronger moral identities and thus are more inflexible when presented with dilemmas (Kennedy et al., 2017).

Based on the literature, demographics, sentiments, experiences, and design among many other factors influence a person's willingness to adopt autonomous vehicles. Our work addresses an important question on the relationship between people's ethical and moral perceptions and their willingness to accept and adopt Autonomous Vehicles' Artificial Intelligence(s), their decision-making, and implications. Given that connected AVs are intended to optimize city functions and autonomous mobility across society, we test two hypotheses related to a state of mind variable about governing society to measure willingness to adopt AVS based on ethics and morals while controlling for factors that have proven to enhance adoption. Thus, we test:

- whether a person who prefers ethics over morals is more likely to be comfortable with AVs,
- whether those people share similar characteristics.

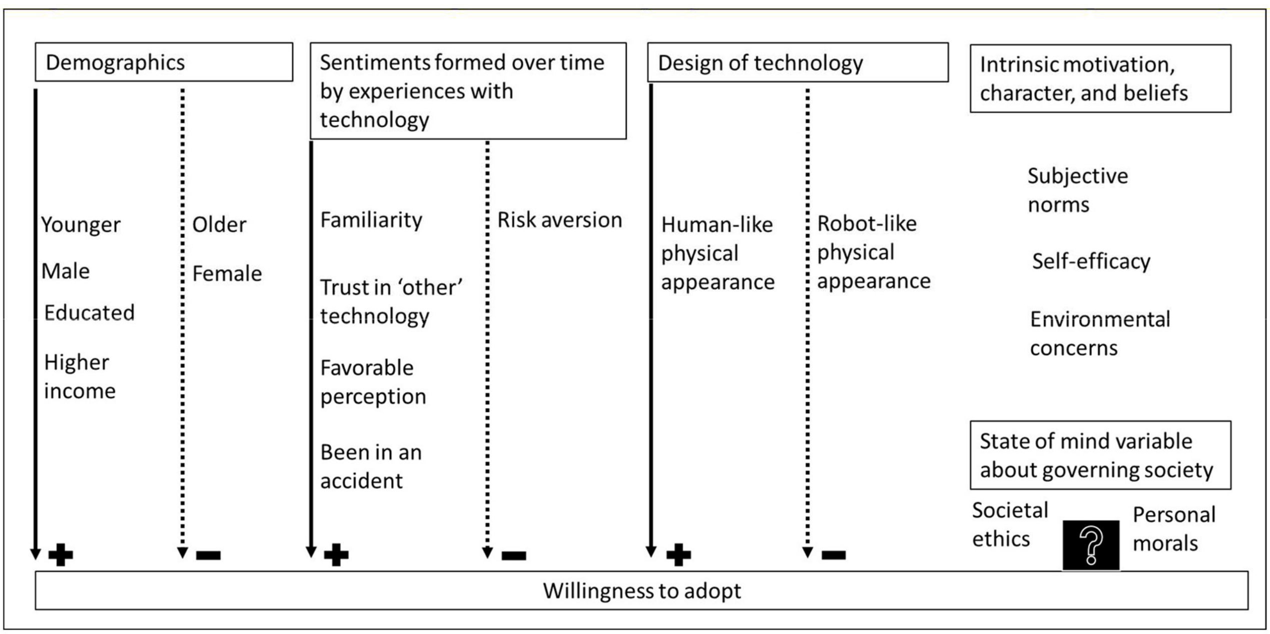

FIGURE 1 | State of mind variables integrated into exemplary framework on influences AV adoption willingness. *Source: for an expanded framework on influences see Gkartzonikas and Gkritza (2019)*.

TABLE 1 | Sample characteristics ($N = 1473$).

Characteristic	Count	Percent
Role		
Faculty	226	15.3%
Staff	482	32.7%
Student	765	51.9%
Gender		
Female	963	65.4%
Male	510	34.6%
Age		
18 to 24	640	43.4%
25 to 34	285	19.3%
35 to 54	389	26.4%
55 to 64	126	8.6%
65 to 74	31	2.1%
75 and over	2	0.1%
Race		
White	1,285	87.2%
Asian	104	7.1%
Multiracial	40	2.7%
African American	38	2.6%
Native American	4	0.3%
Hawaiian	2	0.1%
Ethnicity		
Hispanic	44	3%

METHODS

Data Collection

During the spring of 2019, the human resources department of a large public Midwestern university emailed a link to an online Qualtrics survey to all faculty, staff, and students. Responses to the survey aimed to elicit respondents' sentiment toward autonomous vehicles and artificial intelligence.

Sample

A total of 3,370 respondents started the survey, but here we focus on an analytic sample of the 1,473 students, staff, and faculty who provided complete responses to the items described below (see **Table 1**). This represents a convenience sample that is not necessarily representative of the university's or state's population, so the analyses reported below should be viewed as exploratory and descriptive, rather than as confirmatory tests of hypotheses. A majority of the sample were students (51.9%), with smaller numbers of staff (32.7%) and faculty (15.3%). The majority of respondents were female (65.4%) and white (87.2%), and under the age of 55 (89.2%).

Dependent Variable, Willingness to Adopt

Respondents were asked "I would ride in an autonomous/self-driving ___" for nine modes of AV: shuttle, bus, light rail, subway, train, car, pod, bike, scooter, and motorcycle. Responses were recorded on a 5-point Likert scale ranging from strongly agree to strongly disagree. Respondents' willingness to adopt AVAIs was measured using their mean response across these nine modes, yielding a willingness to adopt scale with high reliability ($\alpha = 0.9062$).

Independent Variables

In addition to measuring respondents' sex (male = 1), race (white = 1, non-white = 0), and age (six categories), we also measured their familiarity with and perception of AVs, and their preference for AVAI to rely on society's ethics or their own morals. Familiarity with AVs was measured using their agreement, on a 5-point Likert scale ranging from strongly agree to strongly disagree, with the statement: "I would say I am familiar with autonomous/self-driving vehicles." Perception of AVs was measured using their agreement, on a 5-point Likert scale ranging from strongly agree to strongly disagree, with the statement: "I would say my perception about autonomous/self-driving vehicles is positive." Finally, preference for AVAI's reliance on ethics or morals was measured by asking: "Would you want autonomous technology to learn your morals or shall it adopt society's ethics as governed by law or chosen by hundreds of thousands?" These questions were pilot-tested with five faculty members and 17 students.

RESULTS

Table 2 reports the mean and standard deviation of each variable for the full sample, and separately for subgroups who indicated that autonomous technology should "learn your morals" or "adopt society's ethics." We find that respondents reported moderate willingness to adopt AVs ($M = 3.01$), familiarity with AVs ($M = 3.32$) and perceptions of AVs (3.30). They were nearly evenly split between whether AVs should learn my morals (54%) or adopt society's ethics (46%). However, those believing that AVs should adopt society's ethics were statistically significantly more willing to adopt AVs (3.12 vs. 2.92, $p < 0.001$), more familiar with AVs (3.34 vs. 3.26, $p = 0.027$), and had more favorable perceptions of AVs (3.45 vs. 3.17, $p < 0.001$). Those favoring ethics over morals for AVs were also significantly more likely to be men (38% vs. 32%, $p = 0.07$), but did not differ in terms of race or age.

To understand the factors that are associated with an individual's willingness to adopt AVs, we estimated an OLS regression (see **Table 3**). We find that individuals who are younger, male, do not identify as white, and who have favorable perceptions of AVs express a statistically significantly greater willingness to adopt. Interestingly, controlling for these factors, we find that individuals' familiarity with AVs and their beliefs about whether AVAIs should rely on ethics or morals are *not* statistically significantly associated with their willingness to adopt AVs.

DISCUSSION

Governments around the world must determine how and to what extent they will allow AI to make decisions for the good of society. As the technology and its choice-making algorithms will play a major role in the future autonomous

TABLE 2 | Full sample and subsample comparison.

Variable	Full Sample ($N = 1473$)	Learn my morals ($N = 801$)	Adopt society's ethics ($N = 672$)	*T*-test of mean difference
Willingness	3.01 (0.93)	2.92 (0.95)	3.12 (0.88)	$p < 0.001$
Familiarity	3.32 (1.14)	3.26 (1.14)	3.34 (1.14)	$p = 0.027$
Perception	3.30 (1.04)	3.17 (1.07)	3.45 (0.98)	$p < 0.001$
Male	0.34 (0.48)	0.32 (0.47)	0.38 (0.49)	$p = 0.007$
White	0.87 (0.33)	0.88 (0.33)	0.87 (0.34)	$p = 0.727$
Age	2.07 (1.12)	2.07 (1.13)	2.07 (1.09)	$p = 0.943$
Learn my morals	0.54 (0.50)	–	–	–

TABLE 3 | Predicting willingness to adopt AV.

Variable	Estimate	Standard Error	P	Beta
Familiarity	−0.002	0.018	0.891	−0.003
Perception	0.557	0.019	0.000	0.626
Learn my morals	−0.030	0.037	0.412	−0.016
Male	0.183	0.040	0.000	0.094
White	−0.139	0.054	0.011	−0.050
Age	−0.047	0.017	0.005	−0.056
Intercept	1.352	0.093	0.000	–

N, 1,473; R^2, 0.443.

city (Allam, 2020; Cugurullo, 2020), it can keep us safe from disasters (Yigitcanlar et al., 2020a,b), help reduce contributions to climate change (Allam, 2020; Acheampong et al., 2021), limit crashes (Major and Harriott, 2020) and more; but, will we also allow it to make life or death decisions that has traditionally been in the power of an individual? Even if a majority of people agree as to an answer, the datasets used to create an AVAI may also be flawed and may also provoke a myriad of ethical dilemmas (Barns, 2021). Even more, not only can these questions create policy bottlenecks (Gkartzonikas and Gkritza, 2019; Acheampong et al., 2021), they can also pose challenges for manufacturers.

If AVs and AI are to become widespread, manufacturers of AVs and AIs may have to adapt their products to specific cultures, including the process by which an AI makes its decisions (Applin, 2017). In this instance, choosing the ethics of society as millions of drivers' making choices on the road, or learning from an individual driver is a fundamental difference in how AVAIs can be programmed. Morals, ethics, and philosophy have long been considered in relationship to AI, with recent advances making such discussions relevant to self-driving. However, manufacturers and suppliers may lack ethics teams (Baram, 2019) and consider ethics and morals only once a system is completed or a problem has been encountered (Webster, 2017). This presents a problem in that if society is to maximize the potential benefits of AVs, then we must ensure that their implementation is conducted in a meaningful, equitable, and deliberate fashion—a way that considers the preferences and opinions of all members of society. Given our survey showed an almost even preference split, our state of mind variable is signaling an implementation problem in governing cities and in ensuring widespread adoption and understanding of AVAIs. If we as a group cannot decide how we want these machines to behave, then their introduction will surely cause strife and disagreement. Public policy essentially will provide the regulations that will shape how AVs operate, embedding moral principles and ethics into algorithms. Thus, while individuals will not have the "power" in reality to ensure that their own moral principles, other than that of society will prevail in choosing AVs, they will have a choice on whether to purchase an AVs or ride in particular AV depending on how they are programmed. Thus, a better understanding of people sentiment, preferences, and expectations can help lead to a more amenable and efficient adoption.

Researchers have explored the role for and implementation of morals and ethics in AVs, often with the Trolley Problem formulation that a vehicle knows its state and that of its environment perfectly, and thus that the outcomes are definite. Utilitarianism is a typical starting point and posits that minimizing total harm—even if bystanders or vehicle occupants are put at risk by an AVAI's decision—is optimal. While individuals claim to support this approach, they may not buy vehicles ascribing to this philosophy as personal harm may result (Awad et al., 2018; Kaur and Rampersad, 2018). Potential passengers may find it easier to ascribe to Kant's "duty bound" deontological philosophy, wherein AVAI's may be operated according to invariant rules, even if those rules are only *optimal* in most cases. Google's self-driving vehicles did this, striving to hit the smallest object detected when a collision is deemed unavoidable, no matter the object type (Smith, 2019). Other AVAIs *may* make distinction among objects—for example, that it's better to hit a traffic cone than a car, or a car vs. a person—whether through explicit rules or learned outcomes. Some manufacturers may follow the principle of "first, do no harm"—preferring injury through inaction rather than deliberate decision. AV companies have programmed in logical "safety nets" such that if a human were to stand in front of the vehicle, it will wait indefinitely rather than risk injuring that pedestrian by creeping forward—perhaps even when an approaching ambulance would need the AV to clear a path to the hospital. Rather than addressing morals and ethics explicitly, Tesla mimics human behavior (Smith, 2019) though it might be argued that with sufficient training data, moral and ethical philosophy may be learned implicitly. Outside of these examples, the authors have discussed with employees of automotive manufacturers and suppliers solutions ranging from user-configurable preferences, to preserving the vehicle purchaser (or licensee) at all costs, to rolling "digital dice" as a means of determining behavior. The state of morals and ethics in self-driving implementation is evolving rapidly, though today it takes a back seat to more immediate technical challenges.

AI and other autonomous technologies are slated to begin making decisions in our daily lives, for better or worse (Allam, 2020; Cugurullo, 2020). How people prefer these machines behave, however, is understudied. By introducing the concept of state of mind, which are variables related to a person's intrinsic motivation, we analyze whether society's ethics or personal morals are determinants in choosing AVs. In essence, we found that the ethics/morals variable is correlated with familiarity, perception, and gender with some caveats. Respondents were almost evenly split in preferring whether an AVAI should rely on society's ethics or the driver's own morals when making choices. Especially those who believe that AVs should adopt society's ethics were statistically significantly more willing to adopt AVs, more familiar with AVs, had more favorable perceptions of AVs. However, controlling for these factors, we find that individuals' familiarity with AVs and their beliefs about whether AVAIs should rely on ethics or morals are not statistically significantly associated with their willingness to adopt AVs. However, other studies have found that familiarity *does* positively influence willingness to ride in or adopt AVs (Haboucha et al., 2017; Liljamo et al., 2018; Gkartzonikas and Gkritza, 2019). Further, attitudes have proven to wield more influence on technology adoption than demographic variables (Zmud et al., 2016).

We also find that individuals who are younger, male, not white, and who have favorable perceptions of AVs express a statistically significantly greater willingness to adopt. This finding largely aligns with most studies which identify males (Liang and Lee, 2017; Dos Santos et al., 2019) and younger people (Bansal et al., 2016) are more likely to accept the new technology. Because the sample was racially homogeneous, we are cautious to interpret the finding that non-white respondents are more willing to adopt; future research should examine whether this replicates in more racially heterogenous samples.

Using the example of autonomous mobility, we introduced a variable (ethics vs morals) that may help governments decide over how to direct development of AIs and their power over governing future cities. However, in our study we simply tested for a binary variable, instead of expanding the survey to include other powerful and potential sources of values for AVs that are introduced by different car manufacturers and their programmers. In future studies the state of mind variables including not only a broader set of the general population, but also targeted focus groups with manufacturers would allow a broader perception and reasoning of how AVs can and should be programmed. As comparatively little attention has been paid to decision over how these new technologies proliferate our everyday lives, governments need a better understanding on how we as a society would want these machines to behave, especially in critical situations.

CONCLUSIONS

This study asks a simple question: do potential AVAI users believe morals or ethics guide AVAIs? Survey findings from a university campus suggest that people are divided on which should guide AVAIs' choices, but that those who believe AVAIs should be guided by ethics are more willing to adopt AVAIs than those who believe they should be guided by morals. However, after controlling for individuals' familiarity with AVAIs, perceptions of AVAIs, and demographic characteristics, this apparent effect disappears. That is, beliefs about whether AVAIs should be guided by morals or ethics appear to be unassociated with willingness to adopt AVAIs. This may help explain engineers' decision to postpone the problem, arguing that whether we instill or program ethics or morals into our vehicles is inconsequential.

This study has several limitations: conducted on a university campus, the survey only included people associated with the university, and thus the sample was biased toward both younger people and those with more education. It could be that within the demographic scope of this research, which was primarily a highly educated and relatively advantaged group, familiarity was simply a secondary consideration, or people associated with higher education may already be familiar with the technology beyond the point that it can influence their opinions. A similar survey of the general population may reveal different patterns because of this. Additionally, many of the constructs of interest (e.g. familiarity, morality) are likely multidimensional, but here were measured using single items, which reduces their reliability and their ability to fully capture these constructs. Future studies should consider using or developing multi-item scales to assess these constructs. Nonetheless, this study represents a preliminary exploratory and descriptive study of a large university sample, and provides a starting point for related future work on states of mind in AV programming. Lastly, this survey forced respondent to choose between morals and ethics, whereby these may not have to be distinctly different.

The core topic within this paper, whether and to what extent people's state of mind matters in the adoption of AVAIs, however, remains relevant and deserves further study given the limited nature of our sample. While our theoretical moral vs. ethics question may appear simple, the reality of implementation is extremely complex: the technology sector, car manufacturers, and the internet providers are rapidly developing technology for the future of mobility without engaging with the human state of mind variables, such as familiarity, willingness to adopt, and our newly introduced one in this paper: the preference whether morals or ethics should guide AVAIs. Given respondents' preferences show an almost 50/50 moral/ethics split, further exploration to the future of AI-enabled choice-making is necessary. In contrast, the AV industry is plowing down a path that may differ significantly from reality. These state of minds, which may not be comprehensive, combined ultimately determine AVAIs adoption into society. Future work should be focused on identifying further state of mind variables and test them via perception studies on representative populations to help identify their influence over the embracing the idea of AVAIs in the future of mobility.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Internal Review Board, Michigan State University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

EK-N and JS: study conception and design. EK-N: data collection. EK-N and JS: analysis and interpretation of results. EK-N, JS, and TD: draft manuscript preparation. All authors reviewed the results and approved the final version of the manuscript.

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Methods for Uncovering Discourses That Shape the Urban Imaginary in Helsinki's Smart City

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In modern urban environments the technologies that are basic to everyday life have become further embedded in that life. Smart cities are one example of the acceleration of technological change in order to engage with urban sustainability challenges, with Artificial Intelligence (AI) tools as one mode of engagement. However, the discourses through which cities engage with smart city growth and management can have long-term consequences for diverse knowledge held within the imaginaries of situated smart urbanism. As the city of Helsinki increasingly focuses on sustainable smart city initiatives, concurrent research suggests that smart urbanism is at a crossroads, where developers must decide how smart cities choose to engage with its residents' knowledge. This research sets out to ask, how are top-down smart city interventions communicated on Twitter (de)legitimizing diverse knowledge in situated smart urbanism? We draw from Foucaudian theory to identify which discourses are elevated, through statements posted on the social media platform Twitter. By answering this question, our goal in this paper is to examine how Foucault's methods can be used to highlight unseen assumptions about smart urbanism in Helsinki. Our objective is to identify overarching narratives and potential contested conceptualizations of smart urbanism in Helsinki. With our methods, we contribute a novel angle to surfacing power relations that are becoming evident in the development of AI-governed smart cities.

Keywords: smart cities, urban imaginaries, discourse analysis, subjectivities, Twitter discourse, Foucault

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INTRODUCTION

Observing the slow pace of international efforts to forestall the impacts of climate change, the Intergovernmental Panel on Climate Change (IPCC) has recommended further research on the impacts of climate change in urban areas, and an increased focus on adaptation and resilience strategies for cities (Revi et al., 2014; Masson-Delmotte et al., 2021). With the United Nations projecting two-thirds of the global population to live in urban regions by 2030, a range of adaptation strategies have come to the fore, focusing on frameworks including and intertwining smart growth, nature-based solutions, zero and low-impact technological solutions, and social justice in urban sustainability (Artmann et al., 2019; Kremer et al., 2019; Anguelovski et al., 2020; Cousins, 2021). Critically, the potential for conflicts and synergies between AI-guided economic growth and standards of livability (Allam and Dhunny, 2019) has emerged as a field for future research in smart urban governance. Competing interests in smart city development often lead to an overemphasis on innovative technological solutions, while obscuring infrastructure and social needs that are at once less glamorous and basic to daily urban life (March and Ribera-Fumaz, 2016; Irazábal and Jirón, 2021).

Left unaddressed, the complexities of interacting urban, national, and international governance strategies, combined with individual- and community-level efforts and discourses to combat climate change often result in the depoliticization of urban spaces and power mismatches that threaten socio-ecological justice on the ground (Kitchin et al., 2016; Rossi, 2016; Norman, 2018; Safransky, 2020), emphasizing the political tensions inherent to sustainable urban development (Bulkeley and Betsill, 2005; Martin et al., 2018; Yigitcanlar and Cugurullo, 2020). As will be discussed below, power exists within louder discourses focusing on economic growth and technocentric solutions to sustainability, which mediate urban imaginaries, and thus discredit quieter narratives and limit the potential for socially just urban sustainability (May and Perry, 2017; Dunn, 2018; March, 2018). City planners, who often hold power over expert knowledge production, have also paid less attention to the diverse territorial knowledges in contested spaces that can constitute forms of situated urbanism (Jirón et al., 2021). These discourse producers in turn feed neoliberal trends in city growth that have been problematized throughout the urban planning literature (Weber, 2002; Tochterman, 2012; Grossi and Pianezzi, 2017; Cardullo and Kitchin, 2019b; Burns and Andrucki, 2021).

The Autonomous Smart City

The lack of a coherent definition for smart cities has been noted repeatedly in sustainable urban planning literature (Mora et al., 2017; Cugurullo, 2020; Burns et al., 2021). However, it is usually understood as a proliferation of information and communication (ICT) technologies, and technocratic and market- driven solutions to urban governance, underpinned by a trust in the pragmatism of smart technologies (Kitchin et al., 2015; Cugurullo, 2020). Networked devices collecting data in all urban spaces and at any time have contributed to new fields of research on situated urbanism and the "real-time city" (Barns, 2012; Jirón et al., 2021). However, critiques of smart urbanization have pointed to contrasting ideas about dominant narratives in *what* makes a city smart ("science" and "efficiency"), and the practical social end environmental implications for *how* a city could be made smart (Buiani, 2020; Cugurullo, 2020; Irazábal and Jirón, 2021). For example, recent scholarship has highlighted the altered social relations developed in the neoliberal conception of the smart city (Kitchin et al., 2019). It has also been questioned how much resilience strategies reliant upon smart urbanization alleviate socio-environmental inequalities and promote justice (Kaika, 2017; Kitchin et al., 2019; Kremer et al., 2019; Safransky, 2020). In the case of smart cities, economic growth often becomes a primary goal through technological innovation and efficiency, while simultaneously undertaking to improve quality of life (Artmann et al., 2019; Cardullo and Kitchin, 2019b). However, scholars have noted threats to justice as a result of AI-led smart governance, including an increased focus on the wellbeing of affluent communities, marginalization and loss of empowerment, elevation of consumerist cultures, and promotion of neoliberal economic growth, all while in fact neglecting environmental protection (Zuboff, 2015; Martin et al., 2018; Yigitcanlar and Cugurullo, 2020).

For example, while the provision of digital solutions through urban green infrastructure (UGI) has been promoted as a way to accelerate co-benefits for people and nature, automated UGI solutions can come with trade-offs associated with reduced empowerment and representation in urban landscapes (Gulsrud et al., 2018). Social impacts were found in the case of Dublin, where residents were encouraged to take a more passive role in their relationship with the urban environment, with a focus on consumption choice rather than civil rights (Cardullo and Kitchin, 2019a). Further research in Dublin suggests that Living Labs, meant to foster digital innovation through co-production, may compromise autonomy *via* civic paternalism over community ownership of solutions to urban problems (Cardullo et al., 2018). In her 2019 book, Zuboff highlights more abstract risks to individual rights: those of the "*right to the future tense* and the *right to sanctuary*" (Zuboff, 2019, p. 54). Additionally, a recent survey of expert stakeholders in research, policymaking, and management found that despite the weight placed on the perceived benefits of robotics and autonomous systems (RAS) in environmental monitoring, efficiency of infrastructure, etc., there is less understanding about and focus upon the potential threats posed by these technologies to socio-ecological-technological systems including but not limited to loss and over-intensive management of green spaces and biodiversity, reduced complexity in human-environment interactions, and changes in how individuals value ecosystem services (Goddard et al., 2021). In order to draw these complex lines of inquiry together, we chose to examine more closely the discourses that are developed within the case study of smart urbanization in Helsinki. For this reason, we have utilized urban imaginaries as the theoretical platform on which to politicize questions about discourse in Helsinki's smart city, further detailed below.

The Smart Urban Imaginary

Despite the risks outlined above, discussions about the future of AI-governed smart cities remain limited without also engaging with human imagination and the ongoing quest for the smart utopia (Söderström et al., 2014; Datta, 2015; Grossi and Pianezzi, 2017). The role that imagination plays in developing the city (an inherently creative effort), must not be overlooked when considering how sustainability is conceptualized in urban regions (Lindner and Meissner, 2018). As a critical theoretical framework for understanding urban spaces, Lindner and Meissner refer to the urban imaginary as a concept which acknowledges how space is "*simultaneously* material, conceptual, experienced, and practiced" (Lindner and Meissner, 2018, p. 2), building upon a general conceptualization of imaginaries that "at once describe attainable futures and prescribe futures that states believe ought to be attained" (Jasanoff and Kim, 2009, p. 120). Imaginaries about what the (smart) city is and what it can become in the future are reproduced and legitimized in multiple sites and by multiple authors (Wiig, 2016; Glass, 2018; Zukin, 2020). As Jasanoff crucially hints toward, the interrelationships between urban imaginaries and entities of power are an important entry point for examining how spaces and discourses mediate behavior (Jasanoff and Kim, 2009; Lindner and Meissner, 2018).

Analyzing Discourses About Urban Planning on Social Media

There has been much written on theoretical and case study-based critiques regarding smart city growth which examines the economic, environmental, and social effects of such projects (Colding et al., 2019; Artyushina, 2020; Irazábal and Jirón, 2021). A developing line of inquiry is *how* city governments are able to legitimize certain discourses [disciplinary sites "which (constrain *and enable*) writing, speaking, thinking"] (McHoul and Grace, 1993; Hook, 2001) over others, through discourses on social media platforms. Common terms used in Twitter discourses have been analyzed in previous studies examining, for example, how the COVID-19 pandemic should be handled in policy spheres (Wicke and Bolognesi, 2020), and the legitimization of discourses surrounding the UK's handling of its refugee crisis (Bennett, 2018). In the case of urban planning, these discourses shape an implicit understanding of good and desirable futures, and further entrench the urban imaginary (Jasanoff and Kim, 2009). However, here we acknowledge research complementing the development of urban ontologies, which notes that politics should not be considered as a background force, controlling human behavior; human agency is also a factor (Magnussen, 2011).

Discourse analyses on bodies of Twitter data have been used in multiple urban and environmental planning contexts; for example, past research has identified alternative stories about the smart city as told by creative skilled migrants (Monachesi, 2020), assessed public engagement in the management of protected areas (Bhatt and Pickering, 2021), and analyzed the psychological benefits of urban green space use (Plunz et al., 2019). Additionally, recent literature has begun to use Twitter discourse analyses to ascertain how discourses in urban planning and natural resource management are constructed between planners and the public (Williamson and Ruming, 2017; Boyer et al., 2021). Twitter has also been used to gather public perceptions on the relevance of automation, robotics, and AI-managed urban planning for their community (Yigitcanlar et al., 2020). Outside of explicit studies on discourse, past research has also examined human behavior and spatio-temporal activity on Twitter for the purpose of informing urban planning (Resch et al., 2016; Garcia-Palomares et al., 2018).

Helsinki and Its Smart City Interventions

As of 2021, Finland's capital Helsinki had a population of 658,595 people (Tilastokeskus, 2021). Urban planning decisions are handled by the city council, an 85-member body chosen in municipal elections held every 4 years (City of Helsinki, 2021). The City of Helsinki currently pursues sustainable urban development by focusing on smart initiatives which develop upon economic, environmental, and social capital (Region). The Helsinki City Strategy has been linked to the UN Sustainable Development Goals, and is using smart city initiatives in areas of action including Decent Work and Economic Growth (SDG 8) and Climate Action (SDG 13) (Jaakola et al., 2019). The city of Helsinki's living lab company Forum Virium supports the development of smart technologies and organizes innovation competitions and funding (Hielkema and Hongisto, 2013). In particular, the company places a heavy emphasis on its Agile Piloting Programme, which aims to fast track the development of tech solutions through active experimentation for the benefit of Helsinki residents (Spilling et al., 2019). The city of Helsinki is also a member of the Six-City Strategy (abbreviated as 6Aika), a national effort between the six largest cities in Finland to develop urban areas sustainably, organized by Forum Virium. The strategy operates on the goals of "open innovation platforms, open data and interfaces, and open participation and customership" (Anttiroiko, 2016, p. 10).

Overall, Helsinki has been recognized internationally for its efforts in smart city construction (Mora et al., 2019). However, while it has been frequently acknowledged that there is no "one size fits all" approach to smart city development and its services (Kitchin, 2015; Allam, 2018), international metrics may miss certain social nuances. Past research has found in Santiago, Chile that urban planning interventions involving the smart city are often little more than placebos for cities to participate in worlding exercises, while minimally addressing urban problems (Jirón et al., 2021). Jirón et al. (2021) work upon the concept of *situated urbanism*, wherein local knowledges, and by extension narratives, are linked to spaces of being and thinking, and are necessarily "multiple, incomplete, and strongly attached to place" (Jirón et al., 2021, p. 615). In using this concept, they find that certain knowledges, narratives, and ways of thinking can be discarded by these smart urban interventions (Jirón et al., 2021). Normative assumptions about smart urbanization often lead to an unbalanced focus on economic growth and efficiency (Grossi and Pianezzi, 2017; Irazábal and Jirón, 2021). Further, city-level aspirations for worlding, or the integration of local economies in global capital flows, especially through smart city interventions, has the potential to create tensions with provicializing trends which can promote alternative urbanization narratives (Baker and Ruming, 2015; Burns et al., 2021; Irazábal and Jirón, 2021).

Yet, while these studies have acknowledged the role that Twitter plays in (dis)empowering public discourses in urban planning, what is less emphasized in the wider urban planning and sustainability transformations literature is how power is exercised by city governments to (de)legitimize certain narratives through Twitter, therefore influencing urban imaginaries and situated urbanism. While plans for urban development and redevelopment have been recognized as sites for urban planners to exercise power in capital accumulation and value extraction (Weber, 2002), Foucauldian methods have not yet been utilized to uncover their effects on situated urbanism.

Given calls for further research into how smart city discourses are being negotiated on the ground (Evans et al., 2019), it remains important to challenge the assumptions about Helsinki's techno-centric approaches to urban dilemmas. The technologies of smart urbanization are simultaneously social and political (Jasanoff and Kim, 2009), and the sharp contrast between a perceived lack of individual autonomy and a more general perception of autonomous and neutral smart technologies signals a need to further explore the consequences of this dichotomy (Hernández-Ramírez, 2017). As the City of Helsinki proceeds with smart urbanism, its power as an institution in part shapes how city residents talk about and perceive themselves within the smart city. In response to the above research gap, this study sets out to ask, how are top-down smart city interventions communicated on Twitter (de)legitimizing situated smart urbanism?

By answering this question, our goal in this paper is to examine how Foucault's methods can be used to highlight unseen assumptions about smart urbanism in Helsinki, which circumscribe the potential for what Jiang et al. (2020) refer to as "smart urban governance," in which the social context of urban problems are identified as a precursor to technological solutions (Jiang et al., 2020). Our objective is to identify overarching narratives for smart urbanism in Helsinki, and potential contested spaces encapsulated by the concept of situated smart urbanism. With our research, we contribute a novel case study that contributes to evidence of power relations that are becoming evident in the development of AI-governed smart cities.

METHODS

Foucault in Urban Planning

From a Foucauldian perspective, certain "regimes of truth" are promoted over others when taken in the context of wider "conflicts over meaning that are linked to power" (Jacobs, 2006, p. 44). We contend that Michel Foucault's theories on truth and power are particularly relevant in the context of AI-governance, theories which posited that the concept of an autonomous individual is not possible under the pressures of social structures and discourses (Bevir, 1999). But while power and knowledge are inherently related for Foucault, power does not necessarily lead to relations of dominance and submissiveness; rather, power structures are horizontally networked, producing a system through which an individual becomes known, and is thus placed under a system of power (Mashhadi Moghadam and Rafieian, 2019).

Foucauldian conceptualizations of discourse analyses span a broad range of methods, yet there is agreement that this perspective is interested in knowledge production and the shaping of reality, rather than a strict focus on linguistics (Feindt and Oels, 2005; Sam, 2019). This approach to discourse analysis therefore rests on a foundation of social-constructivist and post-positivist interpretations of meaning (Leipold et al., 2019). This research uses Hajer and Versteeg's definition of discourse as "an ensemble of ideas, concepts and categorizations through which meaning is given to physical and social realities, and which is produced and reproduced through an identifiable set of practices" (Hajer and Versteeg, 2005, p. 175).

In this sense, Foucauldian perspectives have been applied to past urban planning literature, including assessments on the reformulation of collectivist forms of urban governance (Stenson and Watt, 1999), analyses on the relationships between discourses on social reform and urban planning efforts (Mele, 2000), and inquiries into how different understandings of urban realities shape policies governing ethnic diversity (Hoekstra, 2018). Foucauldian theory has also been used to analyze discourses produced by experts in the smart urban planning field (Wang, 2017). However, as noted above, Foucauldian methods have not yet been used to research how regimes of smart urban planning impact situated urbanism. Thus, the novelty of this research rests in an approach to discourse analysis derived from Foucault's theories on *archaeology* performed on Twitter statements produced by accounts related to Helsinki's smart urban planning regime.

Desk Research

In order to illustrate the context of the research setting, it is necessary to begin by problematizing and conducting background research on urbanism in Helsinki (Hajer, 2006; Arribas-Ayllon and Walkerdine, 2008; Wiig, 2016; Sam, 2019). The advantage of this is to repoliticize the (smart) city by acknowledging the normative values of diverse interests, and the imaginaries which overwhelm alternative narratives for urban futures (Bunders and Varro, 2019; Schuilenburg and Pali, 2020). The purpose of this section is not to provide a comprehensive historical account of Helsinki's urban history, nor is it to imply a strictly causal relationship between institutionalized urban planning of the past and present. Rather, by acknowledging that discourses are produced and reproduced in multiple sites (Wiig, 2016; Glass, 2018), we aim to draw together diverse perspectives to paint one possible picture of Helsinki as a city. This possible picture amounts to a step in "diagnosing" the present of Helsinki's urban planning (Kendall and Wickham, 1999a). We focused our research on a review of urban planning articles, insights from critical literary and cinema arts, and documentation on Helsinki's smart city initiatives.

Problematizing Helsinki's Urban History

Since the 1860's, Helsinki's history as an industrial hub has grown, starting as a natural harbor connected by railway to the core of Finland and St. Petersburg (Kervanto Nevanlinna, 2016). This trend accelerated with the 1915 Munkkiniemi-Haaga Plan and the 1918 Greater Helsinki Plan, through which city planners Bertel Jung and Eliel Saarinen played leading roles in detailing Helsinki's expansion (Kolbe, 2016). These plans aimed to solidify Helsinki's position "as a city that belongs within the Western European cultural sphere" (Niemi, 2016, p. 54), detailing "a clear vision of an administrative, commercial and industrial capital city of Finland" (Kolbe, 2016, p. 148). This initiative grew following independence in 1917, and Helsinki's prominence as an industrial core increased, with employment in industrial sectors increasing through the postwar years until the mid-1960's (Niemi, 2016). However, artistic expressions of the period indicate how poverty was woven into Helsinki's urban memory of the early twentieth century; urban literature from this period explores the sensory world of working class environments, cultural representations that are no longer visually present in the city, but persist in writing (Laine, 2019). Yet, efforts to display a modern image for the 1952 Olympic Games became central to Helsinki's outward identity during this period, with modern transportation and sports facilities linking stable values to future ideals (Niemi, 2016).

From the 1980's, centrally located sites for seaports and factories became desirable areas for cultural centers and habitation, spurring waves of gentrification that continue today (Kervanto Nevanlinna, 2016). Following a period of economic growth in the 1980's, the Finnish mark was tied to the European Currency Unit, driving up unemployment rates—concurrently, filmmaker Aki Kaurismaki was directing films including *Calamari Union* and *Drifting Clouds*, melancholy depictions of the living conditions of ordinary people in Helsinki (Bacon, 2016). In particular, *Calamari Union* serves to portray the stark contrast between the working-class lifestyle in the Kallio neighborhood, compared to that of affluent dwellers of Punavuori (Seppälä, 2017). Following the restructuring of industrialism, factories that were once used as promotional material for Helsinki are less relevant, as European cities looked toward new forms of urbanism (Kervanto Nevanlinna, 2016).

Present-day Helsinki has set itself with the task of becoming "the most functional city in the world," and city planners now are making efforts to collaborate internationally in search of digital tools to make residents' lives easier (City of Helsinki). This is concurrent with an increase in residents of international backgrounds, with 13.5% speaking a language other than Finnish or Swedish in 2015 (Helminen, 2016). Yet there is a degree of tension acknowledged by research on Helsinki's urbanization, which points to a paradigm shift in the way that Helsinki understands urbanity; namely, a to a more dense, cultural hub, which also strives to mitigate segregation (Lilius, 2021).

The city's digital innovation company Forum Virium places emphasis on Agile Piloting, through which tech startups can collaborate with residents and urban planners to "co-create" new sustainability technologies (Spilling et al., 2019; Spilling and Rinne, 2020). Yet, while the public-private partnerships formed through Helsinki's smart city development can foster collaboration and participatory governance over urban planning, increased digitalization in Helsinki has been critiqued for eroding job security (Lönnqvist and Salorinne, 2020). Meanwhile, representations of urban Helsinki in modern literary culture by Mikko Rimminen explore the simultaneous unfolding of reality and imaginary; his trilogy narrating the development of a post-apocalyptic version of Helsinki, testing the reader's understanding of the urban environment and its development (Ameel, 2020). These counter-discourses serve in opposition to, for example, discourses produced by Hannu Mäkelä's book *HyvaJatka*, commissioned by the City of Helsinki to celebrate the development of smart Jätkäsaari neighborhood and distributed to all residents moving into the area (Ameel, 2020). In effect, the development of these contrasting perspectives between the imaginaries of Helsinki's urban planners and working class serves to illustrate a contested urban space.

Corpus of Statements

An archive in its colloquial sense can denote a collection of documents kept physically or online, organized but not logically connected. Yet for Foucault, the archive is a site of the production of knowledge, determining not only what can be said, but also what cannot be said; as he and Jacques Derrida note, it is therefore an essential tool for political power (Manoff, 2004). The archivization process and its technologies also have the power to determine what is archived, and consequently, what knowledge is considered legitimate (Manoff, 2004).

We decided to develop our corpus by mining Twitter as a source of statements, as it has become evident that Twitter can be used as a tool for users to shape modern political discourse (Masroor et al., 2019; Pond and Lewis, 2019; Breeze, 2020), and consequently, a tool to shape individual subjectivities (Persson, 2017; Boler and Davis, 2018). While the analysis of discourse using Foucault's methods has been accomplished (if not under an established set of guidelines), the acknowledgment of Twitter as an archive of knowledge is a relatively new method [see for example Sam (2019)]. The use of Twitter as a corpus of statements is appropriate for many reasons, primary among them addressing what is perceived to be one of Foucault's core questions: "Who are we today?" (McHoul and Grace, 1993), but also to acknowledge Twitter's potential as a "form of social control and social possibility" (McHoul and Grace, 1993, p. 26).

We applied for a license to use Twitter's Application Programming Interface (API) for researchers in March 2021. Using Twitter's Developer License and the Tweetsearcher tool developed by the University of Helsinki's Digital Geography lab, we were able to retrieve an original dataset of ∼23,000 Tweets and Retweet *via* Python (Väisänen et al., 2021). We decided to source these Tweets from accounts directly linked to the City of Helsinki's smart urbanization agendas (**Table 1**). Our purpose behind this decision was 2-fold; firstly, while we acknowledge that Foucault's theory of power and knowledge structures power relations as horizontally networked rather than constructed as a vertical hierarchy, we assert that the city's power as an urban planning institution has partial responsibility for shaping not only discourses but the physical spaces they discuss (Mashhadi Moghadam and Rafieian, 2019). Thus, the city has a unique hold over imagined and constructed spaces in Helsinki that merits further analysis. The second reason is practical in nature. When mining Twitter data, deliberate choices must be made in order to limit what can become an endless stream of information (Sam, 2019). Thus, while this dataset excludes accounts held by individuals, public organizations, and the city of Helsinki's other Twitter accounts discussing sustainability in general terms, we are able to center on a specific perspective about the city of Helsinki's smart urbanization agenda. All posts by the accounts were pulled from their join dates until May 25th, 2021.

TABLE 1 | Body of Twitter statements derived from the above accounts.

Corpus of statements derived from		
Account handle	**Account name**	**Join date**
@FiksuKalasatama	Fiksu Kalasatama	April 2015
@ForumVirium	Forum Virium Helsinki	November 2009
@HBH HQ	Helsinki Business Hub	April 2013
@HELilmasto	Helsingin Ilmastoteot	April 2014
@HelsinkiSmart	Helsinki Smart Region	May 2016
@SmartClean FI	Smart and Clean	June 2016

Analysis

Using Foucault's approach requires an understanding of how his theory could be viewed as a toolbox of instruments to be applied to certain lines of inquiry. From here, the application of the theory is not the goal in itself, but rather its use as a means of understanding a specific problematique (Garland, 2014). While we have stated that there is not a single set of requirements for applying Foucault's theory in discourse analysis, past researchers have suggested methods for accomplishing this (Kendall and Wickham, 1999b; Arribas-Ayllon and Walkerdine, 2008; Bourke and Lidstone, 2015). This research draws from methods used by Sam (2019), in which the context of the case study drives analysis (Sam, 2019).

Archaeology

Once the corpus of statements was finalized, we used Python to execute the first round of analysis, based on Foucault's archaeology (Foucault, 2013). The code can be found in the public repository (https://github.com/hcorinna/smartHEL). The purpose of archaeology is to "look for relationships between and among different statements", in order to look for changes, mutations, and (in)consistencies (Sam, 2019, p. 343). In this phase, we took care to maintain that our analysis was noninterpretive and non-anthropological, terms used by Kendall and Wickham to mean that the Tweets were analyzed only on the basis of their content, rather than authorship or time context (Kendall and Wickham, 1999b).

We began by dividing the corpus into sets of original Tweets and Retweets. We then created a list of the top 50 most common terms in Tweets and Retweets. In order to clean the results, we removed stop words, or commonly used words in English and Finnish, as well as punctuation and numbers (see **Supplementary Material** for coded list of stop words). Using a grounded theoretical approach, we used open coding methodology to categorize these most common terms based on discernible themes (Bryman, 2016; Kennedy and Thornberg, 2018). The most common terms were divided into the functional categories shown in **Table 2**. Following Hyland, we also developed subgroups of text strings composed of the top 50 most frequent strings of four words (fourgrams) of Tweets, as these are more common than five-word strings, and offer more structural and functional clarity than three-word strings (Hyland, 2008). The most common terms and fourgrams included references to other accounts (mentions) in order to maintain contextual clarity, and excluded hashtags. This method is also referred to as composing lexical bundles, or "words which follow each other more frequently than expected by chance, helping to shape text meanings and contributing to our sense of distinctiveness in a register" (Hyland, 2008, p. 5). In academic writing, lexical bundles and keyword frequencies have been found to communicate the identity of the speaker and establish certain truths about the content at hand (Hyland, 2010). The most frequent fourgrams in the corpus were divided into the functional categories derived from Hyland (2008): subject-oriented, text-oriented, and participant-oriented (**Table 3**). In addition, we examined the number of followers for each account, and an iterative analytical process that utilized the conceptual groupings of common terms, fourgrams, and hashtags in Retweets.

Previous studies on Twitter discourse have established the linguistic and cultural importance of hashtags in communicating social movements and identities (Konnelly, 2015; Reyes-Menendez et al., 2020), as well as the role of the hashtag in what (Zappavigna, 2012) refers to as "searchable talk," or signals toward the performative nature of social movements (Brock, 2012). Because of this, we decided to analyze groups of hashtags separately from Tweet statements themselves, using the same iterative coding process as for the dataset of most common terms. We decided to preserve instances of the same word in Finnish

TABLE 2 | Iterative categories of most common terms and hashtags for Tweets and Retweets.

Cities, regions, and neighborhoods	References to neighborhoods, cities, regions, etc. which imply action at a particular geographic scale
Future, time	References to time scales which imply action at a particular time scale in the present or future
Transportation	References to mobility needs and action items
Accounts	References to other accounts (or "mentions")
Communications, transparency	References to events or notifications implying a sense of transparency about smart city initiatives
Smart	References to the smart city and data capabilities
Intent, action	References to projects or events for community participation
Business, jobs	References to business or job growth and development
Focus words	References to Helsinki's position as global smart city

TABLE 3 | Iterative categories of most common fourgrams for Tweets and Retweets.

Subject-oriented	Explanations of activities and experiences in the real world, including location, procedure, quantification, description, topic
Text-oriented	Regarding the organization of the Tweet content and its meaning as a message or argument, including transition, resultative, structuring, and framing signals
Participant-oriented	Clarifying focus on reader or writer of the Tweet, including stance and engagement features

TABLE 4 | Discourses in Tweets and Retweets as reflected by top 50 most common terms.

Dominant discourses—common terms				
Categories of common terms	**Tweet frequency**	**Tweet frequency in %**	**Retweet frequency**	**Retweet frequency in %**
Cities, regions, and neighborhoods	5,424	42.07	3,413	30.13
Future/time	775	6.01	642	5.67
Transportation	223	1.73	308	2.72
Accounts	708	5.50	3,751	33.12
Communications, transparency	1,358	10.53	0	0
Smart	1,950	15.12	939	8.29
Intent/action	1,152	8.84	1,187	10.48
Business	843	6.54	415	3.66
Focus word/superlative	460	3.57	671	5.92
Total	12,893	100	11,326	100

Categories of common terms were defined through inductive coding.

TABLE 5 | Discourses in Tweets and Retweets as reflected by top 50 most common hashtags.

Dominant discourses—hashtags				
Categories of hashtags	**Tweet frequency**	**Tweet frequency in %**	**Retweet frequency**	**Retweet frequency in %**
Cities, regions, and neighborhoods	2,864	42.22	1,752	36.85
Transportation	496	7.31	178	3.74
Smart	2,311	34.07	2,266	47.66
Climate and Health	641	9.45	316	6.65
Jobs	471	6.94	243	5.11
Total	6,783	100	4,755	100

Categories of common hashtags were defined through inductive coding.

and English recorded twice in the same list (for example, the hashtags "avoindata" in Finnish and its translation "opendata" in English were counted 176 and 129 times, respectively). Following a similar iterative approach to coding common terms, we then divided the list of hashtags to into common conceptual groupings (Bryman, 2016; Kennedy and Thornberg, 2018).

RESULTS

Consistency

Narrative consistency about smart city development took shape in Tweets and Retweets through the use of common terms, fourgrams, and hashtags. **Table 4** displays how original Tweets that referred to specific cities, regions, and neighborhoods were the most common theme (42%). Within this category, the majority of these geographic scales of place referred to Helsinki or Finland (63%), and with relatively few terms referring to international regions or the world overall (10%).

TABLE 6 | Functions of fourgrams in Tweets and Retweets.

Text functions—fourgrams				
Functions of fourgrams	**Tweet frequency**	**Tweet frequency in %**	**Retweet frequency**	**Retweet frequency in %**
Topic-oriented	590	63.30	209	62.20
Text-oriented	116	12.45	45	13.40
Participant-oriented	226	24.25	82	24.40
Total	932	100	336	100

Function categories were derived from Hyland (2008).

Under Retweets, the most common terms were mentions to other Twitter accounts, including those of politicians and pilot projects (33%). Most of these mentions referred to @ForumVirium; however, excluding this account, other mentions predominantly focused on individuals related to smart Helsinki and politicians in support of these plans. Similarly to original Tweets, cities, regions, and neighborhoods were a common theme (30%) that emerged from the discourse (**Table 4**).

The common discourses in original Tweet hashtags were found in geographic scales (42%) and references to smart technology (34%). The neighborhoods most commonly referenced in the corpus were Jaätkäsaari and Kalasatama, two test-bed neighborhoods which are the sites for Forum Virium's Agile Piloting Programme. While the category of geographic scales held the majority in terms of frequent discourses, the Smart category held more varied hashtags (22 separate instances). Hashtags in Retweets followed a similar pattern, with references to smart technology occuring most frequently (47%), and hashtags of cities, regions, and neighborhoods occurring at 37% frequency (**Table 5**).

Functions of fourgram phrases in Tweets and Retweets were commonly oriented toward "subjects," or explanations of activities in the real world (63 and 62%, respectively) (**Table 6**). Similar patterns of fourgram functions were seen overall when comparing across Tweets and Retweets, which were less likely to be focused on participant engagement or transitions within text (**Figures 5**, **6**).

Mutations and Change

In the years following the release of the Helsinki City Strategy 2017–2021, Tweets and Retweets about smart city initiatives in Helinki increased (**Figures 1**, **2**). Following the release of this strategy, Retweet discourses surrounding the City of Helsinki's innovation company, Forum Virium, also gained a foothold. These discussions also emerged at a similar time to hashtags "avoindata" and "iot" (**Figures 3**, **4**), popular search terms and hashtags that imply the linkage between smart city development and technological innovation. Over time, original

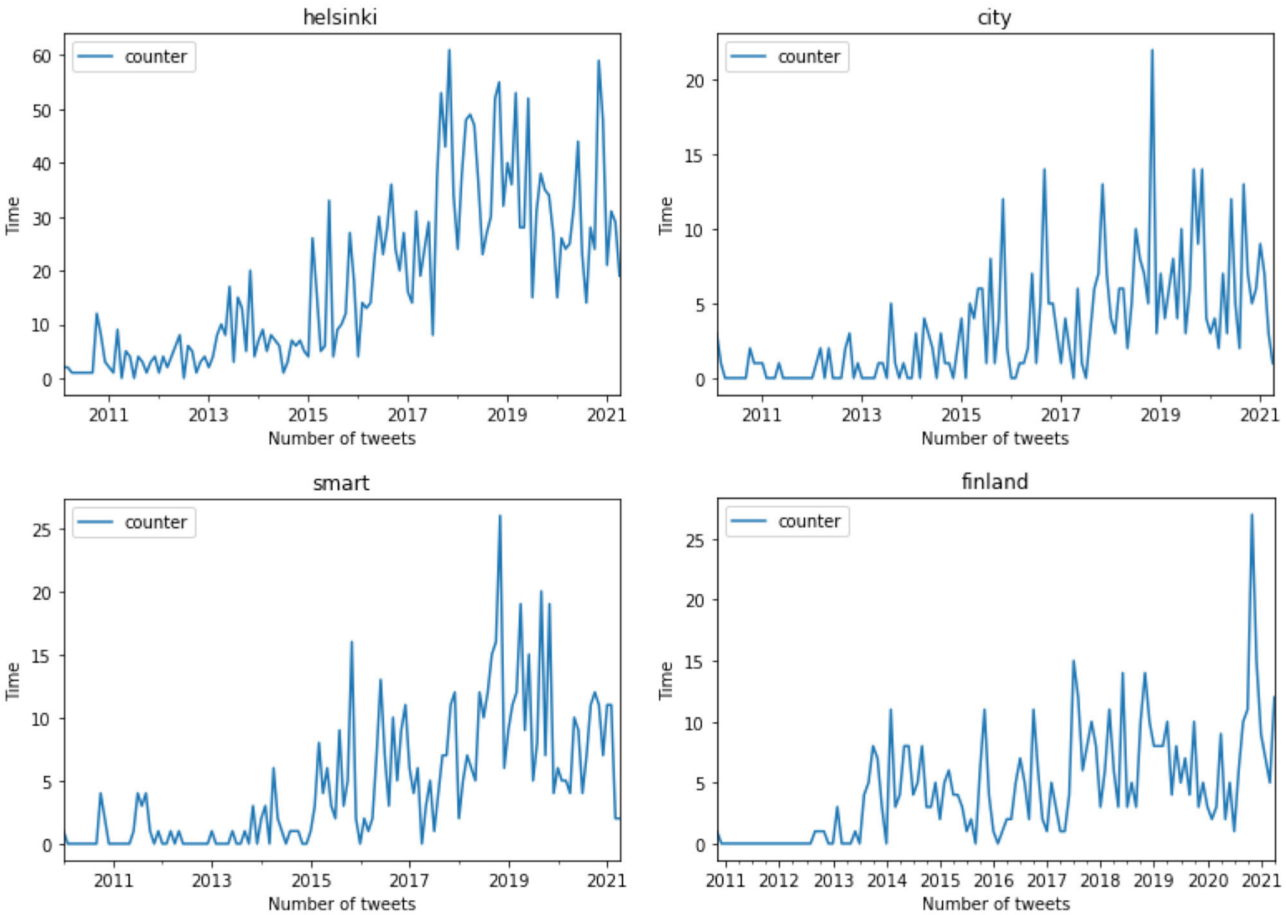

FIGURE 1 | Timelines of top four most common terms in original Tweets within corpus of statements. Timelines begin from the first instance that the term is mentioned in the corpus.

Tweets discourses have become more Helsinki-centric, and lean heavily on its smart city initiatives. However, discourses derived from Retweets tended to peak on the topic of Helsinki and the smart city in about 2016–2017, after which discussions tend to focus more on projects associated with this goal.

Contradictions

There were little or no indications of contradictory statements to be found within or across sets of Tweets and Retweets. The lists of most common terms, fourgrams, and hashtags all followed a similarly consistent narrative and change over time, which focused on technological solutions and innovation capacity to find solutions to urban problems, including carbon emissions, public transportation, and climate change adaptation.

Authority and Legitimacy

In terms of overall original Tweets, @ForumVirum is the oldest account (**Table 1**), has the largest amount of followers (over 4,800), and has control over narratives related to smart city growth, and projects related to finding solutions for climate change adaptation and mobility. In contrast, @HelsinkiBusinessForum had more control over narratives related to corporations invested in solutions to climate change. This pattern was similar in the set of Retweets. However, @ForumViriumH and @FiksuKalasatama more frequently elevated the narratives of Twitter accounts held by individuals related to the management of Forum Virium and Smart Kalasatama. The relationship between knowledge and power is exercised here by promoting circular discourses, or strategically retweeting accounts with a confirmatory bias.

DISCUSSION

This study set out to uncover potential discourses that are elevated or delegitimized by the City of Helsinki's Twitter accounts regarding the use of artificial intelligence in smart urban development, its contribution to situated smart urbanism in this corpus. Our methods, derived from Foucauldian theories on discourse, allowed for an iterative approach to analyzing our corpus of statements. While the purpose of this paper is not to identify each narrative thread taking place within the corpus, we were able to highlight some of the louder discourses occuring on Twitter through the application of *archaeology*.

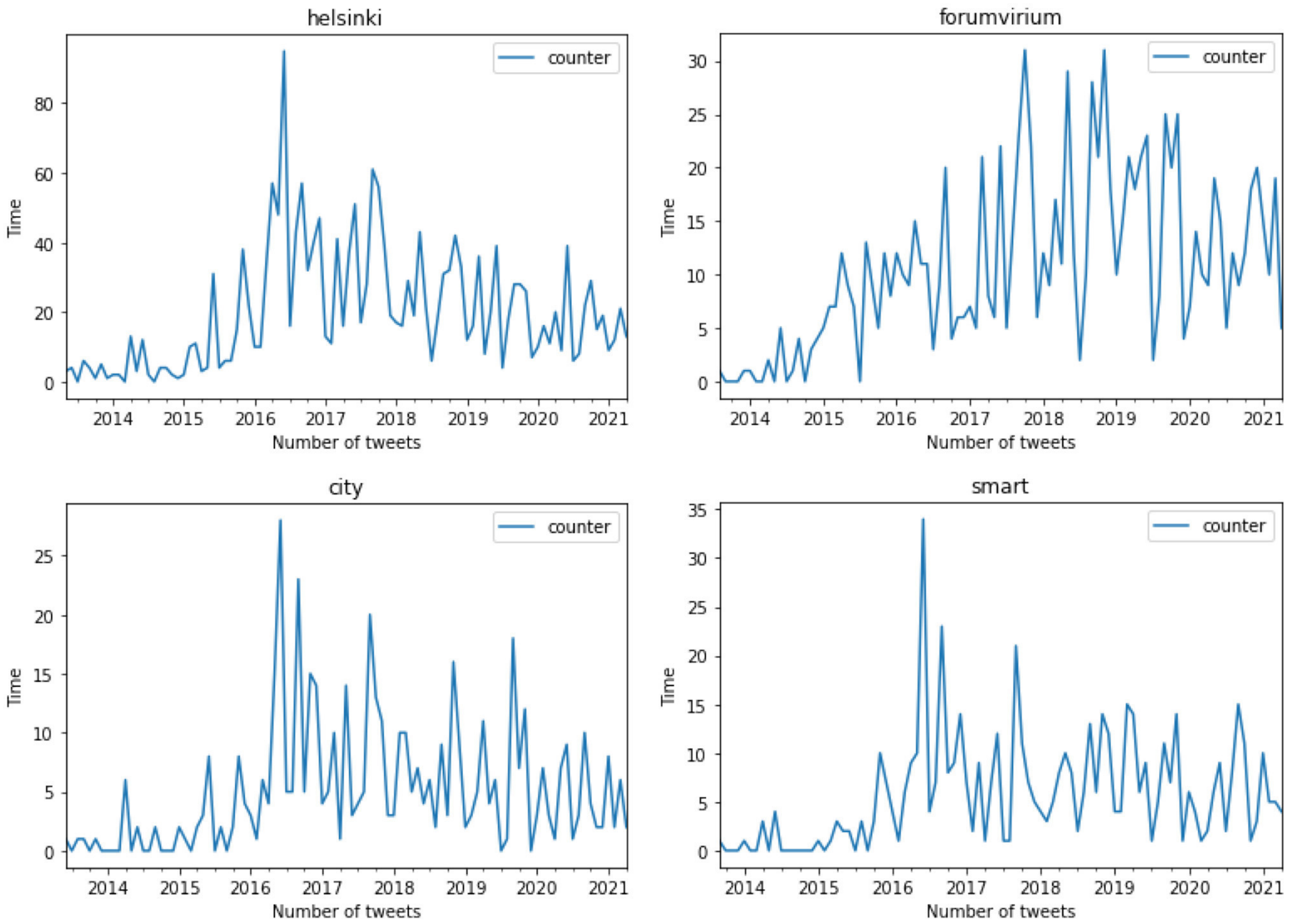

FIGURE 2 | Timelines of top four most common terms in Retweets within corpus of statements. Timelines begin from the first instance that the term is mentioned in the corpus.

Our study found that the narratives presented by the city of Helsinki were consistent over time, and followed a pattern consistent with the progress of Forum Virium and the development of the Kalasatama and Jätkäsaari neighborhoods. Our corpus gave no indication of contradictory statements within Helsinki's smart goals, which is likely a reflection of a focused agenda with more or less intentional outcomes. However, while there was no indication of contradictory statements in lists of common terms, fourgrams, and hashtags, this does not mean that the corpus as a whole did not contain contradictions. Rather, it is indicative that the louder narrative surrounding Twitter statements from the City of Helsinki is one centered upon technological innovation.

Urban Competition

Our analysis of dominant discourses in common terms suggests a strong focus on smart urbanism in Helsinki specifically, and its effects on Finland as a whole. While it is to be expected that the City of Helsinki's Twitter accounts would center discourse on the development of its own urban region, it is telling that there is little discourse related to the cooperative or collaborative impact of smart development in Helsinki on other cities in Helsinki and around the world. While 6Aika is a frequent hashtag in our corpus of statements, the city of Helsinki does not frequently refer to other Finnish cities in terms of common words, fourgrams, or hashtags. The lack of collaborative discourses implies a desire on the part of the City of Helsinki to make the region more competitive nationally and globally, despite public efforts to create a nationally unified smart city goal. Overall, this follows patterns discussed in previous smart city literature, in which the smart agenda is seen as conducive toward a corporate-driven competitiveness on an international stage (Herrschel, 2013; Hollands, 2015b).

In a narrower geographic scale, our analysis on discourses involving hashtags also suggests that the City of Helsinki's focus on smart growth leans heavily on pilot neighborhoods (Kalasatama and Jatkasaari), for testing solutions to urban problems including public transportation and energy use. These neighborhoods are also the focus sites for Forum Virium's Agile Piloting Programme, which aims to increase

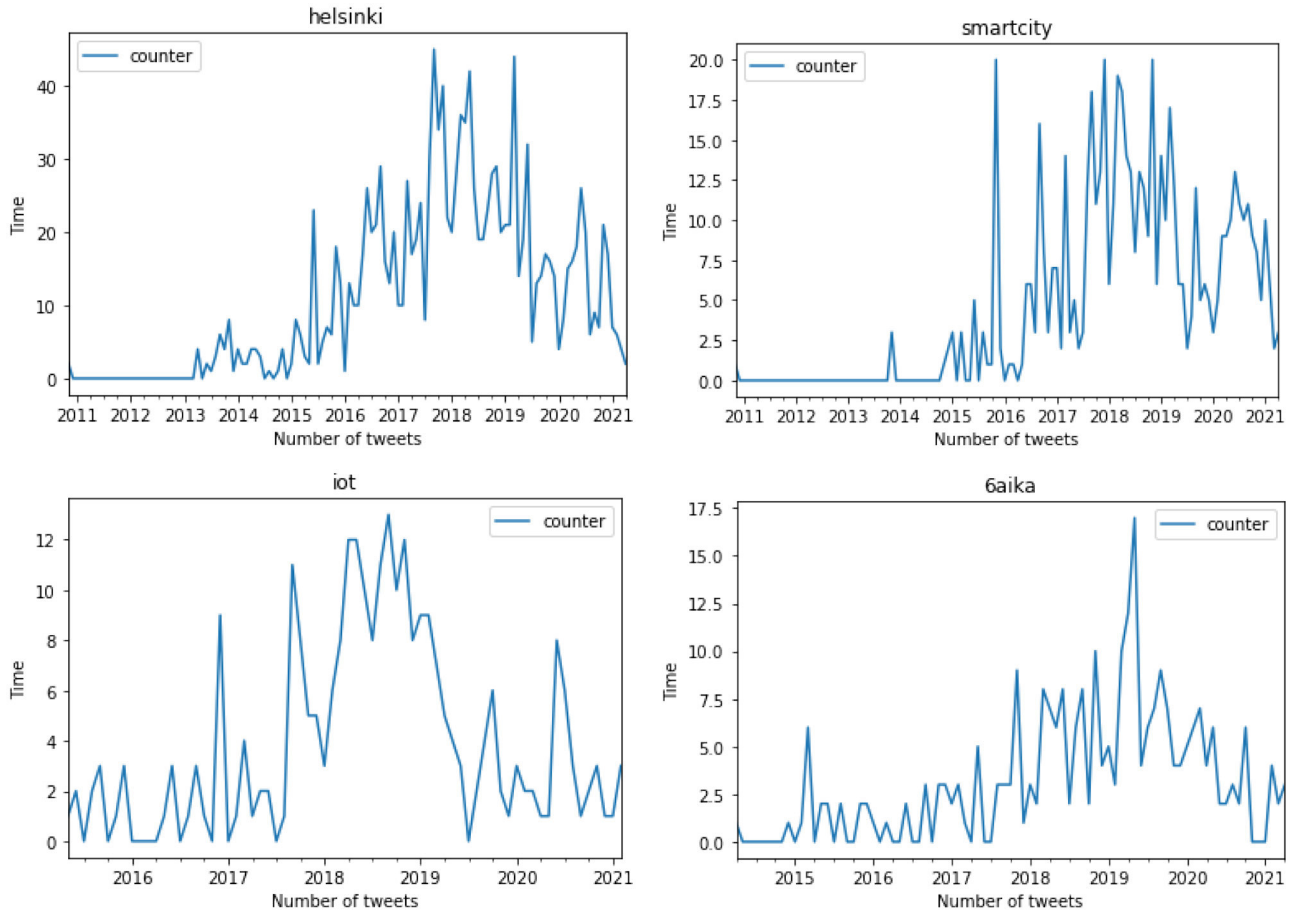

FIGURE 3 | Timelines of top four most common hashtags in original Tweets in corpus of statements. Timelines begin from the first instance that the hashtag is mentioned in the corpus.

the competitiveness and experimental nature of Helsinki's tech startups (Hämäläinen, 2020). Indeed, past studies researching frameworks for smart city design in Helsinki observe a high degree of focus on the development and experimentation of digital technologies, including artificially intelligent city services (Hämäläinen, 2020). However, it is unclear whose knowledge is used to defined the urgency of these urban problems. For example, collaborative efforts have been made to develop a more streamlined healthcare system for the Kalasatama neighborhood through community workshops, and make public city decision- making documentation through the OpenAhjo app; however, these bottom-up, collaborative approaches are not central to this study's corpus. Additionally, it is not transparent who was invited to participate in these collaborations, and whose needs are prioritized in smart innovations that, while contributing to open data platforms for Helsinki, are not necessarily a priority for average residents.

In this sense, our results confirm past research on the coded (in)visibilities of the smart city, and highlights again critical questions about who participates in vision-making and practical implementation of the smart city (Burns and Andrucki, 2021). These findings also return us to the assertion of our desk research, in which the imaginaries and knowledges of the working class are not necessarily the visions which direct the development of the smart city. With current research highlighting the right to the (sustainable) smart city and the potential for bottom-up approaches to smart governance (Cardullo et al., 2019; Heitlinger et al., 2019; Kitchin et al., 2019), it is becoming increasingly imperative that these issues are addressed by urban planners.

No Looking Back

There is also little if any reference to the past of Helsinki's urban development, and how current plans for the smart city relate to lessons that have been learned in the past. The initial, and indeed logical, interpretation of this may be in part due to the nature of Twitter as a site for content production for current events. However, while future-oriented projects spur innovation and break boundaries in technological growth, the lack of recognition of Helsinki's urban past, and critically, *urban problems of the present*, risks denying history in favor of louder desirable futures.

This pattern is observable in our analysis of fourgrams, which use a tone advertising the future of smart growth

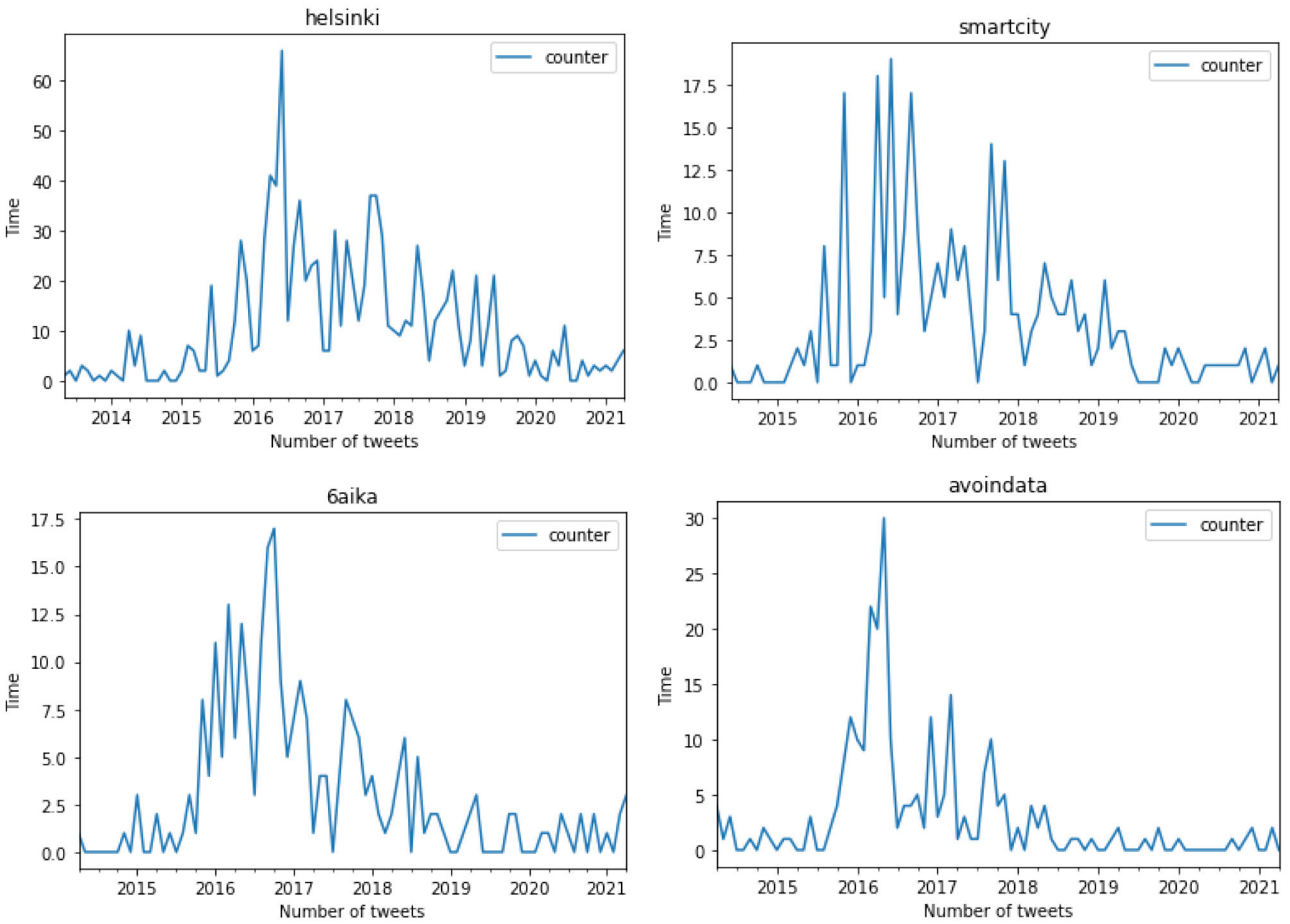

FIGURE 4 | Timelines of top four most common hashtags in Retweets within corpus of statements. Timelines begin from the first instance that the hashtag is mentioned in the corpus.

in Helsinki. These fourgrams correlate to past studies pointing to the role of urban rankings in pacesetting the conceptualization and construction of smart cities globally (de Almeida, 2019). While cities may rank highly in terms of the development of internet-based technologies, or sustainable development indicators, these rankings may ignore other urban problems, including mobility and social stratification (ibid.). Minimal acknowledgment of Helsinki's past urban issues and the diverse knowledges that contribute to an understanding of its contested spaces continues a trend of path dependency and lock-in (Olsson et al., 2014; Mäkinen et al., 2015).

It is useful to consider this result from the perspective commonly held in Finland that residents are part of a "classless society," and that Helsinki places a great emphasis on the development of the so-called "creative class" (Kantola and Kuusela, 2019; Lilius, 2021). This perception persists despite a wealth of Finnish cultural depictions focused on class struggle, and the downward trajectories of marginalized groups in Helsinki referred to in our desk research (Ameel, 2014; Bacon, 2016). And yet, a Lefebvrian viewpoint would insist that (urban) spaces do not occur spontaneously, without the context of social practices and histories (Zieleniec, 2018). The development of these imaginations of space throughout Helsinki's history points to a need for greater emphasis on how its past indeed influences its future. In order for residents and urban planners in Helsinki to engage critically with smart urbanism, they must do this while simultaneously interrogating the disconnect between social perceptions of egalitarianism and social stratification.

Marketable Catchphrases

It is evident that the development of Helsinki's smart city is advertised widely over its Twitter discourses. This marketing leans heavily on certain phrases and projects that are easily memorized, but often not explained or justified as to what urban problems are being solved by these initiatives. Although it is implied that a smart Helsinki is progressive and an inherent improvement upon past urban planning design, it is less clear how or if the City of Helsinki uses Twitter to critically engage with shortcomings in smart urbanism overall.

Analysis through the use of fourgrams and hashtags was helpful for identifying certain catchphrases used to promote

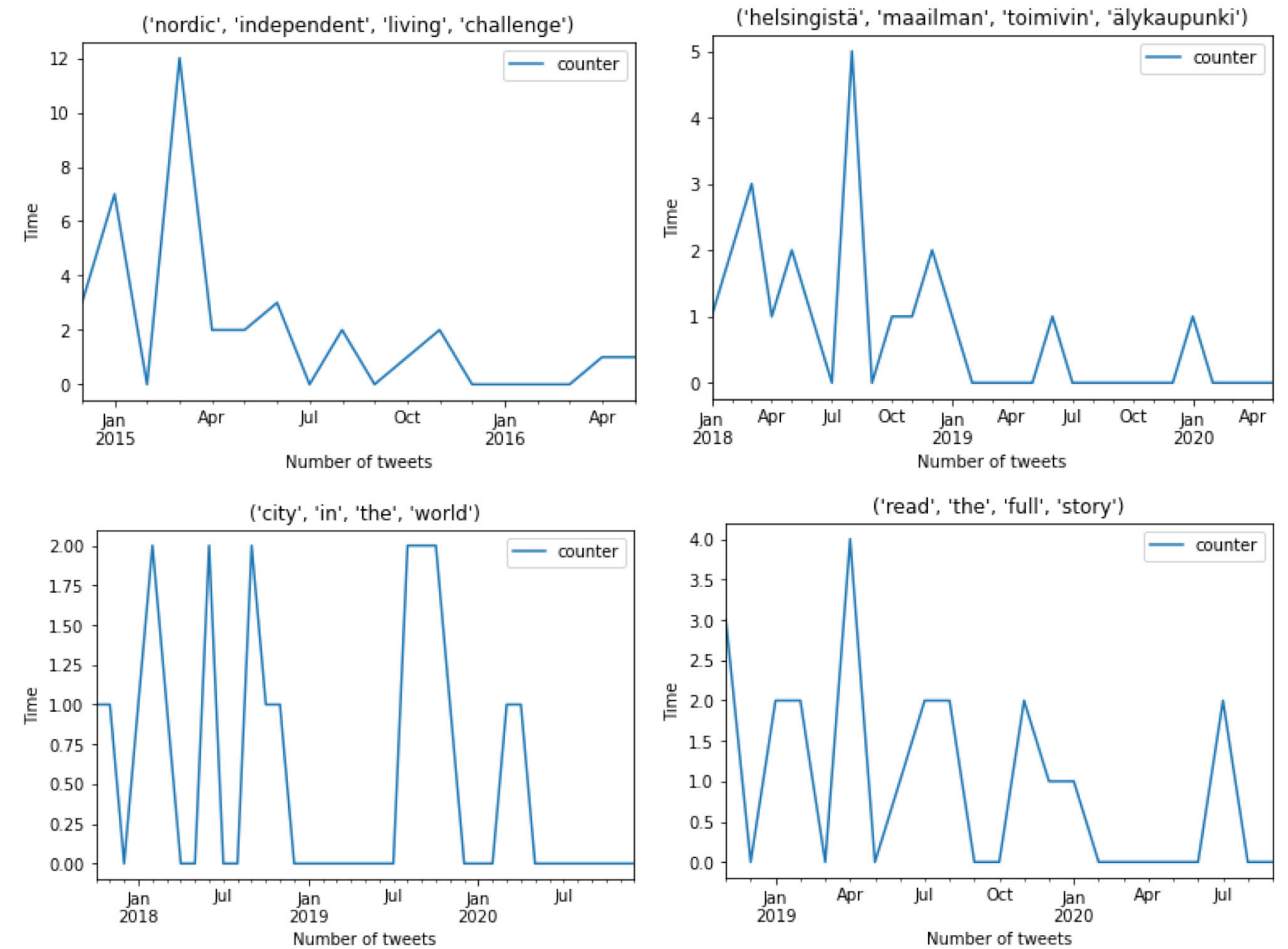

FIGURE 5 | Timelines of top four most common fourgrams in original Tweets within corpus of statements. Timelines begin from the first instance that the hashtag is mentioned in the corpus.

Helsinki's smart city development. These catchphrases were typically parts of highly ranked fourgrams; for example, "Helsinki is the most functional city in the world" (corresponding Finnish phrase "Helsingista maailman toivimin alykaupinki"). Similarly, hashtags were often phrases that advertised Helsinki's role in and action in developing its smart city. Related to urban rankings limiting discussion about urban problems is the trade-off for a focus on branding and the development of a global image (de Almeida, 2019). While there is a high degree of focus on the improved functionality of urban space in Helsinki, there is little indication of a willingness to contextualize artificially intelligent governance to the needs of residents, or need for reflexivity in ongoing smart city development (Jean and Daniel, 2016). Especially acknowledging that smart city development and governance is assembled piecemeal, a marketing focus on becoming the "best city in the world" circumscribes conversations about how smart Helsinki occurs in practice (Shelton et al., 2015).

Understanding the City of Helsinki's role in the ownership, and thus in the conceptualization of Helsinki's urban space, urban planners must also look toward the political values shaping this contested space (Zieleniec, 2018). Helsinki has not been constructed neutrally, and the dominance of this fourgram within a catchphrase marketed to Helsinki residents implies a lack of recognition about the social issues relevant to the city.

Implications for Smart Helsinki

The future of discourse production from the City of Helsinki must take into consideration the needs of its community. It is telling that there is little to no reference to the potential for a smart city that is built on themes of cooperation and increased feelings of community. Rather, the overriding narrative is based on a need to build not only the competitiveness of tech startups, neighborhoods, and Helsinki overall. A corporate-driven smart city poses limitations for a wider understanding of how "smartness" and "sustainability" work for the benefit of

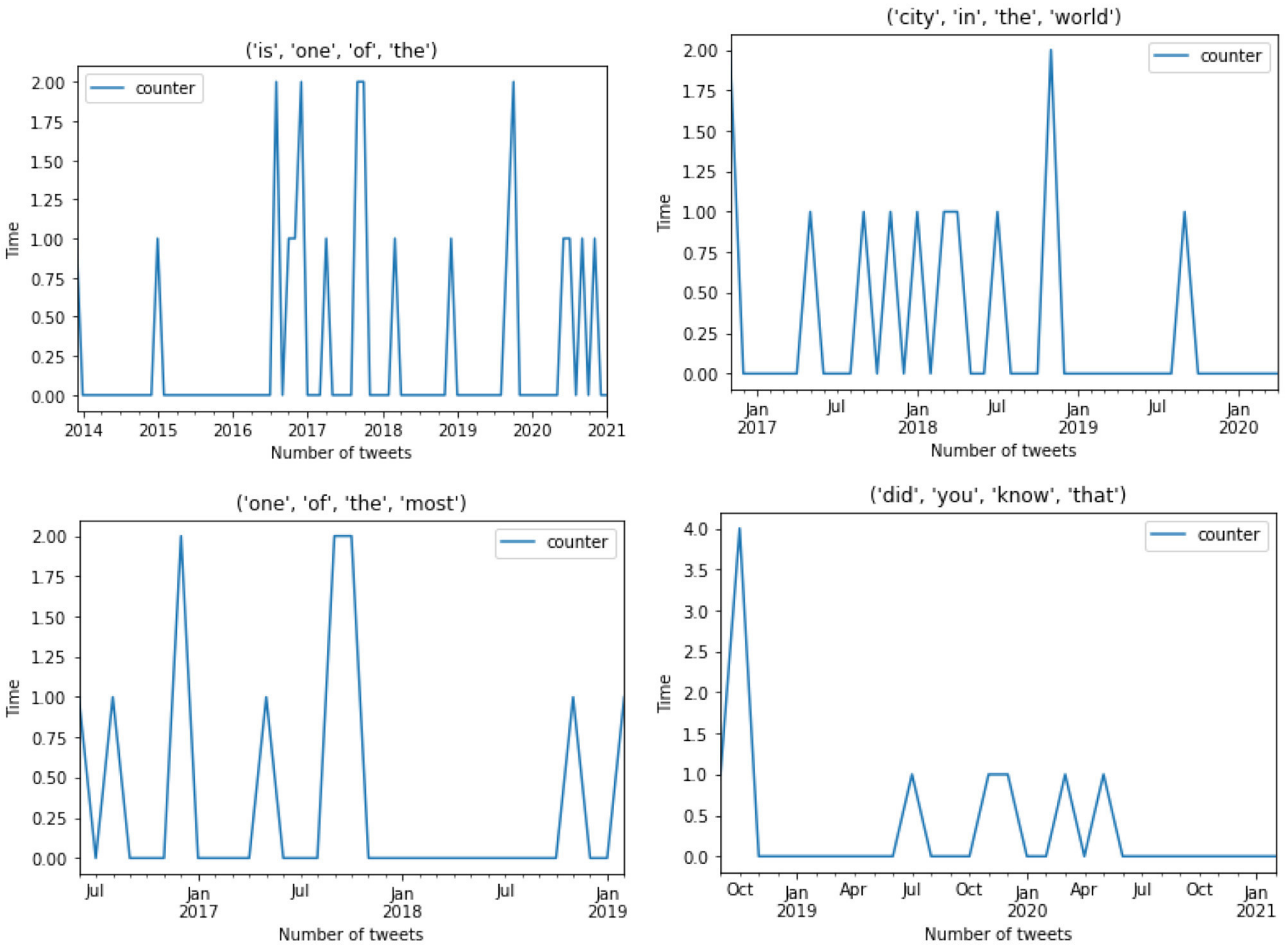

FIGURE 6 | Timelines of top four most common fourgrams in Retweets within corpus of statements. Timelines begin from the first instance that the hashtag is mentioned in the corpus.

residents, and restricts the smart urban imaginary to visions promoted by corporate entities and urban planners (Hollands, 2015a; Sadowski and Bendor, 2019). Potential remedies for this top-down approach may indeed rest upon a *community-driven* definition of the smart city, in which residents decide the most urgent agenda that the smart city can resolve, thereby softening the effects of "corporate storytelling" (Söderström et al., 2014). The elevation of these alternative imaginaries of the smart city will allow urban planners to engage more thoughtfully about for whom is the smart city (Luque-Ayala and Marvin, 2019).

The lack of reference to the past of Helsinki's urban history was striking, though not surprising, given the narrative trend of fast-tracking new technologies and the focus on newly-developed neighborhoods in Helsinki. However, increased reference to the sometimes shared, sometimes disparate histories of Helsinki residents can have an empowering effect on the desire to maintain and share urban culture (Sandoval, 2018). Especially when regarded in the face of increasing gentrification (Lilius, 2021), the erasure of culture from space could be slowed, and goals for a more inclusive urban space could be met, by acknowledging the diversity of how Helsinki residents know and remember their surroundings. This is particularly relevant for the ongoing development of the urban imaginary, in which knowledges of an urban past and present are contested and shaped in a contemporary setting (Bloomfield, 2006).

Limitations and Future Directions

This study undertook to identify dominant discourses found in a corpus of Tweets collected from the City of Helsinki's accounts on smart urban planning. This study did not examine discourses of Helsinki residents with regard to the smart city, but instead decided to focus on the top-down discourses produced by the City of Helsinki. we also focused on Tweets specifically related to smart urbanism, rather than sustainability in Helsinki as a whole. While this method for examining discourses was able to identify some prominent themes in smart Helsinki's social media presence, we cannot claim that these discourses are "dominant" in discussions about urban planning. Additionally, we do not yet understand how these discourses are perceived by residents (work that has been done in past research (Yigitcanlar et al., 2021). Future research on the ongoing development of the smart urban imaginary should examine discourses produced on other forums, and by other (possibly interacting) groups. Possible avenues for research also include bottom-up approaches to how community discourses on artificial intelligence and the smart city are created, and further legitimized.

Overall, we assert that, while we did not analyze counter-discourses in this study, those produced by the City of Helsinki on Twitter are underpinned by capitalist understandings of the perceived need for growth, which must be questioned and reworked in order to produce sustainable futures (Asara et al., 2015; Albert, 2020; McPhearson et al., 2021). McPhearson et al. and others in the sustainability transformations literature highlight the urgent need to acknowledge and act upon the dissonance contained in the "pro- growth within environmental limits and societal benefits" ideology (Lang and Rothenberg, 2017; Albert, 2020; McPhearson et al., 2021). AI-managed smart cities have so far managed to fit neatly into this narrative of efficiently managed green growth in cities, allowing urban planners to navigate masses of complex, living data (Nigon et al., 2016; Allam and Dhunny, 2019). Suggestions for challenging this narrative in future research and practice in urban planning include how smart urban imaginaries can engage with theories on degrowth for a more critical dialogue with social justice (March, 2018). Additionally, building collective agendas for provincialization and local goal-setting can help limit influences of consumer behavior and corporate interests (Evans et al., 2019; Irazábal and Jirón, 2021). Previous work has noted that encouraging issue-based citizen participation may have the potential to elevate the lived experiences of urban residents, and promote *substanive* forms of citizenship (Häkli et al., 2020). However, urban planners should consider this goal thoughtfully to manage the risks we have discussed in allowing companies to engender or otherwise define citizenship through smart technology. In sum, we find that a more relational understanding of smart city interactions at a global scale can help illuminate tensions between geopolitical contexts and multi-layered sustainability governance (Burns et al., 2021).

CONCLUSION

Through discourse analysis methods derived from Foucault, this research was able to identify some of the overriding discourses that are produced by the City of Helsinki on smart urbanism and AI governance. The initial finding of our research was unsurprising, in that the city of Helsinki focuses on technocratic management of urban problems, and keeping Helsinki competitive on a global stage. However, we assert that the discourses frequently observed in our corpus contribute to an understanding of situated smart urbanism that legitimizes corporate strategies for smart urbanism, while sacrificing resolutions to urban problems that could be defined by Helsinki residents.

With this research, we find that the use of discourse analyses which surface power relations can be useful for the future of urban planning and governance strategies which strive to resolve urban socio-environmental problems, both inside and outside of the smart city context. By uncovering these unseen assumptions about the city of Helsinki's goals for smart city development, community discussions are better able to redirect focus on "smart urban governance" through diverse forms of situated knowledges and developing just solutions to urban problems, with the aid of smart technology.

DATA AVAILABILITY STATEMENT

The data analyzed in this study is subject to the following licenses/restrictions: this dataset is restricted by the terms of the Twitter Developer Agreement. Requests to access these datasets should be directed to sara.zaman@helsinki.fi.

AUTHOR CONTRIBUTIONS

SZ was primarily responsible for development of the research question, interpretation of data, and writing the original draft of the submitted manuscript. CH was responsible for data analysis using programming *via* Python. SZ and CH were responsible for data collection and editing the submitted manuscript for critical content revisions. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frsc.2022.796469/full#supplementary-material

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Justice and the Pandemic City: How the Pandemic Has Revealed Social, Urban, and Data Injustices, and How a Narrative Approach Can Unlock Them

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The global COVID-19 pandemic has exacerbated infrastructural, societal, and resource inequalities along racial and socioeconomic lines. Many countries have struggled to provide adequate COVID testing and healthcare. Denmark has been exceptional in its investment in a hyper-efficient and ever-present infrastructure, with testing tents distributed across the country. In this article we ask: What is the impact of this infrastructure in terms of the (urban) culture that is built around testing? And what does that mean in terms of data management and mass surveillance? As a public good, the COVID-19 testing infrastructure has costs and benefits, but these are not always clear. They concern future urban life and data management, and our ability to draw a boundary around ourselves—that is, biopolitics. At the time of writing, with the Omicron variant on the rise, we are hovering on the threshold between new restrictions and a post-COVID urban reality. Now is the time to take stock of the COVID infrastructure's spatial, temporal, and political dimensions, and of what they mean for urban decision-making, governance, justice, and democracy. To do so, and following philosopher and legal scholar Martha Nussbaum, we suggest the deployment of a narrative approach for the education of democratic citizenship and, indeed, for justice.

Keywords: white tents, COVID-19 testing, hyper-infrastructure, surveillance, biobank, justice, urban governance, narrative approach

INTRODUCTION

I literally haven't gone beyond my own front yard in 2 weeks. I speak to my neighbors through the windows. One of them has the virus. We help him by organizing bags of groceries, which we leave on the sidewalk outside his house. A couple of children play a game called "virus" in the street. They yell to each other: "The stick has corona, watch out!" "The car has corona, don't touch it!" "You touched it, now you have corona!" They run up and down the street, yelling, and laughing (Steiner and Veel, 2021, p. 1).

A few months before my friend died from cancer, she said that she wasn't fighting anything. She just took the drugs and underwent strange-sounding treatments, like getting her brain "zapped." Or at least, she went for any treatment she was offered while she wasn't considered too statistically close to death for the treatment costs to potentially "pay off." In the meantime, her 37 year-old body withered, one damaged cell at a time. Anne Boyer speaks to the complexities of the gendered politics of cancer when she writes that "the work of care and the work of data exist in a kind of paradoxical simultaneity: what both hold in common is that they are done so often by women, and like all that has historically been identified as women's work, it is work that can go by unnoticed. It is often noted only when absent." In light of a potentially deadly or crippling illness such as COVID-19, intersections between care, data, and death become visible in new ways that affect larger institutional and social structures—and indeed, these intersections become particularly visible when absent because they are damaged, abused, repressed, or left uncared for (Steiner and Veel, 2021, p. 55).

There has been much discussion regarding the unequal distribution of resources and societal infrastructure throughout the COVID-19 pandemic, and how existing societal inequities have been exacerbated along racial and socioeconomic lines. Many have had limited access to healthcare, testing facilities, or vaccines. Others have been skeptical of public health campaigns and reluctant to seek or accept healthcare due to a variety of factors, including historical discrimination in the healthcare system (Bambra et al., 2020).

Denmark is a rich country with comparatively high living standards and levels of economic equality. While some of the issues listed above have arisen here, this country has fared better during the pandemic than many others, including developed countries such as the United States and United Kingdom, where death rates have been far higher. Nonetheless, traditionally marginalized neighborhoods in Copenhagen, for example, have been disproportionately impacted by COVID-19. In these neighborhoods, residents are more likely to work in the service or health sectors, where employees are at higher risk of COVID exposure; large families live in close proximity; and vaccination rates are comparatively low (Krusaa, 2020). Other socioeconomic factors, such as the house price boom and the unequal distribution of wealth in Danish society in general, have also helped to make COVID into more than a health crisis: the pandemic's political handling raises questions of justice and what makes a society equitable.

While other countries have struggled to provide adequate testing and healthcare during the pandemic, Denmark has been exceptional in that it has built a hyper-efficient and ever-present infrastructure. This infrastructure is most visible in the numerous white testing tents that have sprung up across the country. But there is also the underlying digital and technological infrastructure for epidemic surveillance—statistical analysis, genetic sequencing, and biobanks of biological material—as well as a corresponding set of (more or less forcefully imposed) new cultural and social practices, norms, and ethics (Busk et al., 2021).

At the time of writing, with the Omicron variant on the rise, we are hovering on the threshold between new restrictions and a post-corona urban reality. Now is the time to take stock of the COVID infrastructure's spatial, temporal, and political dimensions, and of what they mean for urban decision-making, governance, justice, and democracy. To do so, we call for the deployment of a narrative approach, exemplified in the two quotations above. As philosopher and legal scholar Nussbaum (1998) suggests, a narrative approach can offer a vehicle for democratic citizenship education and thus, indeed, for questions of justice. What is the impact of Denmark's COVID testing infrastructure in terms of the cities of the future? What does this mean for urban decision-making and governance going forward, specifically in terms of justice and democracy?

DENMARK'S COVID TESTING PROGRAM AS INFRASTRUCTURE AND CULTURE

Denmark has established mass testing as a free nationwide healthcare infrastructure to control the spread of COVID-19. In April 2020, white tents sprang up to host government-run polymerase chain reaction tests. As infection numbers rose during winter, facilities multiplied with rapid testing options, and much of this expanded infrastructure was transferred to private companies. In December 2020, ∼2,900 people per 100,000 were tested daily; the numbers peaked in May 2021, with 12,167 tests per 100,000 inhabitants per day. The testing program was briefly suspended between September 10 and November 11, 2021, when COVID-19 was officially deemed to no longer be an emergency in Denmark (Regeringen, 2021). It was then reintroduced, albeit with differentiations regarding vaccinated and unvaccinated people.

The scale and rapid implementation of Denmark's testing scheme is unique, certainly in Europe. Yet recent research suggests that mass testing does not impact hospitalization numbers. One factor is that with rapid (antigen) tests, people infected with COVID-19 are not "tested early in their infection where the risk of transmission is highest," and indeed testing "increases risk-behavior of the tested persons and … a high fraction of false negatives at low Covid-19 prevalence combined with increased risk-behavior outweighs beneficial effects of mass testing" (Busk et al., 2021). Thus, although Denmark's government presented mass testing as a key healthcare measure (Krogh et al., 2021), it may have been relatively unsuccessful in controlling the epidemic. But as we will shortly argue, it was successful in helping to establish a particular culture around COVID-19. Proof of vaccination, a negative test result, or natural immunization from infection became compulsory for people to access basic public amenities such as school, work, sports and leisure facilities, and restaurants. Indeed, not only did a negative antigen test give access to these basic societal functions, but it also became normal to get tested before attending private gatherings.

Thus, before the advent of mass vaccination, and subsequently for people who are unwilling or ineligible to be vaccinated (e.g., children), testing was and is key in order for individuals to participate in everyday activities, like dining out, going to work or school. Nevertheless, testing is voluntary, and except in cases of contact-tracing, it is largely left to the individual to decide whether a test is necessary. This means that the mass testing has been unsystematic and uneven. As of August 2021, 10% of the population had never been tested for COVID-19, although roughly 80 million tests had been conducted, of which 340,567 were positive (Statens Serum Institut, n.d.). Evidently, since Denmark's population is only six million, large groups of people have been tested very frequently, while others have been tested sporadically or not at all.

Denmark's COVID infrastructure is not only architectural and spatial; it is also a data infrastructure. Only a few weeks into the pandemic, on April 3, 2020, a national biobank for COVID-19 test swabs was established (Ministry of Foreign Affairs of Denmark, 2020). At first, all test swabs were collected and stored, although this was later restricted to positive test swabs only. This has made it possible to trace the distribution of specific viral strains in Denmark, where around 20% of all positive tests have been sequenced (Bech, 2020). Citizens can opt out of the biobank, but doing so requires action on their part (Coronaprøver, 2020). This digital culture around Denmark's mass testing has helped to produce big COVID data on a scale that is unique worldwide—data that is ripe for future analysis and mining.

A *culture* is a set of norms and practices. We contend that a culture has been built around mass testing in Denmark. This culture hinges on an infrastructure where bodies, human biological material, digital communication, data collection, public services, for-profit private enterprise, urban and architectural planning, and construction have come together. The result is a set of practices that constitute a significant aspect of the pandemic experience in Denmark. The culture rests on the surveillance of the population through digital data, enforced testing and/or vaccination, and biological and big-data collection and storage, as well as a high degree of transparency, knowledge, and openness about COVID-19. It also encompasses a set of practices the Danish public quickly embraced, whether because they had no choice or because it was communicated as the sensible thing to do (Steiner and Veel, 2021, p. 35–54): those 80 million tests involved real individuals traveling to a testing site and having biological material swabbed from their throats or nostrils. There is also a set of norms and feelings about what it means to live a good life in the pandemic: the research finding that people who have had a negative test result are more likely to engage in "risky behavior"—e.g., physical contact or proximity to others—suggests that testing is seen as a ticket to a more normal life. Clearly, this culture comprises spatial, affective, and political components.

But what trade-offs does this culture entail? Every time I get tested—for free, and at my discretion—I give away behavioral and biological data. If the test is positive, I also give biological material. What form of transaction is this? Does it have a price, and when will that price by paid? If my data is stored now and not used until later, what futurity is involved here? What does it do to the (potentially sick) body that is both a vehicle for the spread of the virus and an instrument to monitor the disease? Is my body a distributed object, parceled out and preserved for the future in data flows and biobanks, even though it may itself be eradicated by the virus? What happens to the boundary between common sense and emergency laws when cultural practices change with changing rules and are steeped in moralistic notions about the protection of common goods such as healthcare? What questions arise about justice and injustice on that ontological and epistemological boundary? These issues lie at the intersections of infrastructural, urban, and data justice and injustice, now and in the future. Going forward, urban decision-making and governance must respond to a context where not only deep political injustices have been exacerbated by the pandemic, but where everyone, voluntarily or not, simply by virtue of having a body that is vulnerable to COVID, has participated in creating a huge repository of data, and in creating new practices about that body as an object of desire for the virus—a form of dehumanization (Steiner and Veel, 2021, p. 55–74). The prevailing reduction of social justice to distributive justice presents itself here as a dilemma, and the COVID-19 crisis speaks to that dilemma. The belief that the infrastructure is a neutral framework that contributes to the common good, health, and wellbeing eclipses critical questions around ethics, practice and politics as well as surveillance and data-tracking, and is based on highly normative standards regarding what it is to be an acting human.

A NARRATIVE APPROACH TO JUSTICE IN THE PANDEMIC CITY

To grapple with these questions, we suggest an approach to basic, normative values or "capabilities" that draws on the work of philosopher Nussbaum (2000). According to her, the ability to preserve one's bodily integrity and sense of self is a key marker of quality of life, and hence is one of the goals of the good life. We might say it is part of what it takes to build a just society. To begin to understand the full complexity of our post-pandemic predicament—for example, to assess the effects of mass testing in Denmark—we contend that we need to deploy multiple academic angles and disciplines, ranging from statistics to epidemiology, sociology, urban planning, cultural studies, philosophy, and more. Such a complex, large-scale, interdisciplinary study is not possible in this short paper, but it suggests a way forward. Future research on the effects of the pandemic should focus not only on central societal institutions and experiences, but on categories pertaining to individual and social bodies, common sense, justice, and infrastructure—in short, the basis of the just and democratic city. While it is not unreasonable to outsource such issues to institutions, the COVID-19 emergency has often seen big political decisions being taken overnight in the name of a good and safe future (Douglas, 1986; Steiner and Veel, 2021, p. 73–74). We would welcome reflections on the consequences of this from politicians, artists, and scientists alike. We therefore end this paper by suggesting a methodological way forward: the narrative approach, of which we provided examples in the epigraph.

In her work on the philosophy of justice, Iris Marion (Young, 1990, p. 6) writes:

Each social reality presents its own unrealized possibilities, experienced as lacks and desires. Norms and ideals arise from the yearning that is an expression of freedom; it does not have to be this way, it could be otherwise. Imagination is the faculty of transforming the experience of what is into a projection of what could be, the faculty that frees thought to form ideals and norms.

In what sounds like a response to Young, (Nussbaum, 2000, p. 15) defines a narrative approach "with its implicit emphasis on the political importance of the imagination and the emotions" as a vehicle for democratic citizenship education and thus, indeed, as a problem of justice (Nussbaum, 1998). In the current transitional situation toward a post-pandemic reality (living with the virus, as many experts and politicians say), we may see the pandemic as a crisis on a par with other current cultural, ecological, and cultural crises. In this light, we advocate for joining scholars like Young and Nussbaum as well as contemporary feminist and ecocritical theorists who insist that we need to imagine alternative futures. For academics, this entails writing academic texts differently—for example, by learning from situated experience (Haraway, 1988; Lykke, 2014; Steiner and Veel, 2020) and to include other voices, other stories also in academic arguments as we have done in the epigraph to this paper. However, beyond the academy, narratives are vehicles that allow us to acknowledge that this moment's crisis is also a crisis of the imagination—for what kind of future can we hope for and support in shaping? The first step is to inquire into the changing cultural and urban life-forms that we are now living through, by telling stories about the kinds of experiences, emotions, and interactions with other people and places which have been impacted by the political and human response to the pandemic. Heeding these calls, we advocate for a narrative approach, engaging with our own experience as particular and situated material, as well as drawing on studies and reports pertaining to the specifics of the situation, and combining them with theoretical frameworks from cultural studies, criticism, and philosophy. Moreover, it is possible to use a range of news media stories and scholarship from various fields to explore the spatial, affective, infrastructural, and political dimensions of the response to the pandemic. We see these dimensions as intertwined, and we suggest that a situated, narrative approach to that intertwining—in research, teaching, and public scholarship—can unlock an overview of the pandemic's social, urban, and data injustices.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Discovering Urban Governance Parameters for Online Learning in Saudi Arabia During COVID-19 Using Topic Modeling of Twitter Data

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Smart cities are a relatively recent phenomenon that has rapidly grown in the last decade due to several political, economic, environmental, and technological factors. Data-driven artificial intelligence is becoming so fundamentally ingrained in these developments that smart cities have been called artificially intelligent cities and autonomous cities. The COVID-19 pandemic has increased the physical isolation of people and consequently escalated the pace of human migration to digital and virtual spaces. This paper investigates the use of AI in urban governance as to how AI could help governments learn about urban governance parameters on various subject matters for the governments to develop better governance instruments. To this end, we develop a case study on online learning in Saudi Arabia. We discover ten urban governance parameters using unsupervised machine learning and Twitter data in Arabic. We group these ten governance parameters into four governance macro-parameters namely Strategies and Success Factors, Economic Sustainability, Accountability, and Challenges. The case study shows that the use of data-driven AI can help the government autonomously learn about public feedback and reactions on government matters, the success or failure of government programs, the challenges people are facing in adapting to the government measures, new economic, social, and other opportunities arising out of the situation, and more. The study shows that the use of AI does not have to necessarily replace humans in urban governance, rather governments can use AI, under human supervision, to monitor, learn and improve decision-making processes using continuous feedback from the public and other stakeholders. Challenges are part of life and we believe that the challenges humanity is facing during the COVID-19 pandemic will create new economic, social, and other opportunities nationally and internationally.

Keywords: urban governance, online learning, machine learning, topic modeling, latent dirichlet allocation (LDA) algorithm, social media, natural language processing (NLP)

INTRODUCTION

Smart cities and societies are characterized by our desire for innovation and advancements, and our aim to achieve environmental, social, and economic sustainability. The "smartness" in these environments is realized through engaging with these environments at fine-grained levels, in both space and time, analyzing these environments, and making informed decisions under sustainability constraints, all in a timely manner (Alotaibi et al., 2020; Yigitcanlar et al., 2020a). We engage with these environments through various physical and virtual sensors such as the Internet of Things (IoT), smartphones, and social media. These devices produce "big data" that is characterized by four Vs, Volume, Velocity, Variety, and Veracity (Chen et al., 2014). The data is analyzed using mathematical and computational methods that provide artificial intelligence (AI) for the city brains (Cugurullo, 2020; Yigitcanlar et al., 2020a, 2021a). Various physical and virtual devices provide the actuation ability for the smart environments using edge and fog computing (Janbi et al., 2020; Khan et al., 2020; Wang et al., 2020).

A key to this "smartness" is data-driven artificial intelligence that is becoming so fundamentally ingrained in these developments that smart cities have been called artificially intelligent cities (Yigitcanlar et al., 2020a,b), autonomous cities (Cugurullo, 2020), etc. Most applications, systems, and platforms we use today, non-stop, are powered by AI; Alexa, Cortana, Siri, Google Maps, and the list goes on. AI is helping us increasingly in everything we do, or, we may say, it is making decisions for us in many spheres of our life. It tells us what toothbrush to buy. It defines health and fitness for us, and how to achieve those health and fitness goals. It selectively brings information to us about our beliefs, culture, and values. It is our teacher, and spiritual leader, it tells us what is good knowledge, what to believe in through YouTube, news websites, and other information media. AI helps us even in finding the "true love" of our life and select the "significant other" (Janbi et al., 2020).

The COVID-19 pandemic has shown us that a tiny virus can gravely affect our lives, societies, economies, and planet (Alam et al., 2021). As of 24th July 2021, nearly 200 million people have been infected by the SARS-CoV-2 virus causing over 4.14 million deaths worldwide (Johns Hopkins University, 2020). Governments have used physical distancing as a measure to prevent the spread of infection among people. This has increased the physical isolation of people and consequently furthered the pace of human migration to digital and virtual spaces. One of the most important public issues and economic sectors affected due to this physical distancing is the education sector. In many parts of the world, countries have made transitions from in-class, in-person, or face-to-face learning to distance or online teaching and learning (we use the term online learning from hereon).

Social media has emerged over the last decade as the key "engagement" platform between people and service providers, be it businesses or governments (Kemp, 2019). Twitter is among the most popular social media due to it providing microblogs, called tweets, that are brief messages used for sharing product and service information, news, events, government decisions and news, personal status, and more (Lin, 2019). With 330 million active users every month and a 5.79 average tweets every second (Lin, 2019), Twitter is a lifeblood of urban life and could provide key information about public and other matters. With Saudi Arabia among the top counties in terms of Twitter users in the world, Twitter data provides a fertile and important source of information on research and practice in smart societies.

This paper investigates the use of AI in urban governance as to how AI could help governments learn about urban governance parameters on various subject matters including the public reactions, concerns, and preferences, for the governments to develop better governance policies, strategies, programs, and procedures. To this end—considering the significance of the education sector in general, and during the COVID-19 pandemic, in particular—we develop a case study on online learning in Saudi Arabia. Specifically, using Twitter data in the Arabic language, we discover 10 urban governance parameters for online learning in Saudi Arabia as seen during the COVID-19 pandemic using unsupervised machine learning. These governance parameters represent the most discussed topics by the Saudi society, including their needs and concerns, the government's measures to combat the pandemic-induced challenges, as well as their efforts to make the education process successful.

We group these ten governance parameters into four governance macro-parameters namely **Strategies and Success Factors, Economic Sustainability, Accountability**, and **Challenges**. The first macro-parameter touches upon strategies and success factors including developing social sustainability and enhancing educational performance through supporting families, students, teachers, and other stakeholders. The second macro-parameter reports on new economic opportunities enabled by individuals and SMEs in providing services to fill the service gaps created through the rapid transition of in-class learning to online learning. The third macro-parameter touches on governance accountability and provides evidence for the government to have successfully managed the pandemic-induced emergency for transitioning the whole national education delivery system from in-class to online learning. The fourth macro-parameter touches upon the challenges that the people faced during the online learning period and the government's strategies to manage those challenges.

The process of discovering these parameters involves the automatic detection of 20 most discussed topics using LDA-based topic modeling of Twitter data. Subsequently, we merge some of these 20 topics into topic clusters based on their relationships to others and call them urban governance parameters. The terms topic cluster, cluster, and governance parameter are used interchangeably in the paper. These ten governance parameters are then grouped into four governance macro-parameters based on their relationship to the macro themes.

We have developed a software tool from scratch for this work. The tool implements a complete machine learning pipeline including data collection, pre-processing, clustering, validation, and visualization components. The dataset contains 128,805 tweets related to online learning in the Arabic language collected for the period beginning October 1st to December 6th, 2020. The translation of the keywords and other Arabic content (sample tweets, etc.) given in this paper is deliberately made contextual to allow English readers to understand the contextual use of the keywords.

Many works have been reported on modeling COVID-19 related issues using natural language processing (NLP) methods. Some of these works are related to government measures and public matters such as a study on detecting symptoms of stress due to COVID-19 in the US (Li et al., 2020) and a study on detecting government measures and public concerns in Saudi Arabia (Alomari et al., 2021a). Both these works used Twitter data, the first work analyzes tweets in English and the second work in Arabic. The works using NLP with a focus on education during COVID-19 are not many. For example, Duong et al. have investigated the differences in responses to the COVID-19 pandemic between university students and the general public in the US (Duong et al., 2020a). Their focus and findings are very different from our work. They focused on comparing responses of students and the general public on seven topics about discussions on politics, national and international news, racism against Chinese related to COVID-19, physical distancing, and closures of colleges. In the Arabic language, we did not find any work that has focused on online learning. The only work remotely related to our paper is a sentiment analysis study of closures of seven types of public and private facilities to manage the pandemic in Saudi Arabia (Alhajji et al., 2020). One of these seven types of facilities was schools and universities. The focus of the paper was to find sentiment polarities whether the people were happy or unhappy about the closure of these seven types of facilities. Further description of these works and other related works is provided in Section Literature Review. In short, the study developed in this paper differs from the existing works in several ways including the context, focus, time period, geography, data, language, design, and findings of the study. Moreover, the particular perspective on the use of AI in urban governance that we have presented in this paper would be a trendsetter for many more works to come in the future and significantly impact research and practice in this field.

The case study in this paper shows that the use of AI does not have to necessarily replace humans in urban governance, rather governments can use AI, under human supervision, to monitor, learn and improve decision-making processes using continuous feedback from the public and other stakeholders.

The rest of the paper is organized as follows. Section Literature Review reviews the related works. Section Methodology and Design describes the methodology and design. Section 4 explains the results. Section Results and Findings provides a discussion of results including potential utilization of the research. We conclude in Section Discussion and present directions for future work.

LITERATURE REVIEW

This section provides a literature review on the topics related to this research study. Section Twitter Data Analytics (General Literature) reviews general literature (not specific to COVID-19) on analytics of Twitter data in the Arabic language (because Arabic is the focus of this paper). In Section Twitter Data Analytics and COVID-19, we review the works on Twitter data analytics that focus on COVID-19 (because COVID-19 is a focus of our paper). Section Twitter Data Analytics in Teaching and Learning reviews the works on Twitter data analytics that focus on teaching and learning (because this is the focus of our paper). Section Twitter Data Analytics Using Topic Modeling reviews the literature related to topic modeling of Twitter data (because this is the method we have used in this paper). Section AI and Online Learning presents the studies related to the use of AI in online learning. Section Research Gap highlights the research gap.

Twitter Data Analytics (General Literature)

Sentiment analysis of text in Arabic is one of the research areas that has recently gained increasing attention from the research community (Alotaibi et al., 2020; Alomari et al., 2021a). Sentiment analysis is known as the process of extracting phrases or words that refer to polarity of a specific topic. It reveals whether a phrase is positive, negative, or neutral. The objective behind sentiment analysis is to discover the polarity in reviews and comments of people. It is very important where valuable information can be obtained about a particular idea, product, or topic (Oueslati et al., 2020). It is useful for organizations, institutions, and companies where it can be used for evaluating the provided services or products (Duwairi and Qarqaz, 2016). It can also be used by governments to understand peoples' opinions about certain matters including government policies and procedures or detect events such as in transportation (Alomari et al., 2020a).

A number of works have reported Twitter data analytics using machine learning methods. Duwairi and Qarqaz (2016) developed a framework for detecting sentiments and the polarity of user's Arabic reviews on Twitter and Facebook. The researchers focus on preparing a suitable dataset for sentiment analysis by collecting and labeling the data. The dataset that was obtained consists of 2,591 tweets/comments. Crowdsourcing technology was employed for the labeling and annotating of the dataset. Furthermore, they investigate how various functions or techniques of term weighting could affect the model accuracy. Moreover, they investigate the accuracy of various classifiers including support vector machines (SVM), k-nearest neighbors (KNN), and Naïve Bayes (NB) textual analysis, and detecting the polarity of the comments. The authors conducted the study using the RapidMiner tool. The obtained results indicate that NB and SVM performed better compared to KNN. The results also showed that varying between the weighting schemes BM, TF, and TFIDF will affect the classification results. The results also showed that using a classifier with different weighting schemes will have different results. For example, the best results of KNN were obtained when it was used with BM, while SVM provided its best results when used with the TFIDF scheme. For NB, the best results were achieved when it was used with TF. The best accuracy over all the algorithms they achieved was 69.97%, which was for the NB algorithm combined with TF.

Altawaier and Tiun (2016) studied the performance of machine learning-based sentiment analysis of Twitter data in Arabic including Decision Trees (DT), NB, and SVM. They used

Arabic stemming and simple features including TF-IDF (Term Frequency-Inverse Document Frequency). The experiments were conducted on a Modern Arabic Corpus dataset obtained from the UCI repository containing 2,000 annotated tweets (50% positive and negative each) with different tweets in politics and arts. The experiments were carried out using the Weka machine learning tool. The evaluation of the classification performance was based on three metrics including F-measure, recall, and precision. Their experiments suggested that DT (with 78% for F-measure) provided better results than the other techniques. Therefore, sentiment analysis on Arabic texts with two classes of opinions, DT will perform better than SVM and NB techniques. Baker et al. (2020) proposed an approach for detecting Influenza from Arabic tweets in Arab countries. The research was conducted using machine learning techniques. The dataset was prepared for this study with many steps including collecting Arabic tweets related to influenza, labeling, and finally filtering. For analysis purposes, various classifiers were used including SVM, NB, KNN, and DT. The experimental results reveal that the highest accuracy obtained was 89.06%, for the Naive Bayes classifier, and 86.43% for K-Nearest Neighbor.

Among the few works that have used deep learning for Arabic sentiment analysis includes the study by Gwad et al. (2020) on classifying sentiment reviews in Arabic collected from Twitter using LSTM, a type of deep learning Recurrent Neural Networks (RNNs). The experimental results showed that LSTM provides higher accuracy, requires less calculation, and a shorter period for working compared to traditional recognition techniques. They obtained 89.8% accuracy on average.

The literature on corpus-based sentiment analysis of Arabic tweets includes a method that combined stemming, TF-IDF, DMNB (Discriminative multinomial Naïve Bayes), and 4-grams tokenizer (Alsalman, 2020). The experiments were conducted on a Twitter corpus dataset, with 2000 Arabic tweets already labeled as negative or positive. WEKA machine learning software was used as the analysis tool. Their approach obtained 0.3% higher accuracy compared to other works.

Some works have used the SAP HANA in-memory platform for Twitter data analytics. In Alsulami and Mehmood (2018), the authors proposed a model for sentiment analysis of Arabic tweets. The research goal was to detect the opinions of users about the Ministry of Education services in Saudi Arabia. The study focused on finding what the users think about the new university system in Saudi Arabia. They used the in-memory platform SAP HANA for processing and analyzing Arabic Tweets. Alomari et al. (2020b) proposed an approach for classifying the feelings and emotions of car drivers using Arabic sentiment analysis. The proposed sentiment analysis mechanism was based on a lexicon approach. The study also provides analysis for Saudi dialect comments on Twitter about the conditions of road traffic. The dataset was collected for the Jeddah and Makkah cities, two large cities, during Ramadan. The data storage and analysis were performed using the SAP HANA platform. The obtained results were validated using data from news media.

A recent survey on sentiment analysis of Twitter data in Arabic can be found in Oueslati et al. (2020). It provides a review of sentiment analysis research focussing on approaches, resources, and open challenges. The authors divide the approaches for classifying the texts into corpus-based, lexicon-based, and hybrid approaches. The hybrid and corpus-based approaches have primarily used machine learning. NB and SVM are the most used algorithms for Arabic sentiment analysis. Deep learning approaches are scarcely explored. The authors state that the performance of sentiment analysis depends on the quality of data. The data available for sentiment analysis is not good due to Arabic dialectical content that is difficult to process. However, for data in other languages, findings are promising albeit challenges.

Some other works related to the analysis of Twitter data in the Arabic language are reviewed in Alomari et al. (2020a) and Alotaibi et al. (2020).

Twitter Data Analytics and COVID-19

This section reviews the works on Twitter data analytics that focus on COVID-19. First, we discuss works that use Twitter posts in any language other than Arabic. Subsequently, in Section Twitter Data Analytics and COVID-19 (The Arabic Language), we review the works on Twitter data analytics that focus on COVID-19 in the Arabic language.

Twitter Data Analytics and COVID-19 (Any Language)

Recently, COVID-19 has become one of the hot research fields. Twitter is one of the widely available and most useful resources. With the huge increase in social media usage such as Twitter during the pandemic, numerous opportunities are provided for the research community. Different fields are utilizing the data obtained from Twitter including health, education, and policy. We provide in this subsection a review of the most notable works related to COVID-19 that use Twitter data.

A number of works have looked into thematic analysis of Twitter data. For example, Samuel et al. (2020a) investigated the sentiment associated with COVID-19 pandemic from Twitter data. Coronavirus related Twitter posts were analyzed using the sentiment analysis packages of R statistical software and the NB and LR (Logistic Regression) algorithms. A comparison between the algorithms was conducted with varying lengths of tweets. The experimental results demonstrated that both algorithms have relatively weaker accuracy with longer tweets as compared to shorter tweets. NB and LR provided 91 and 74% accuracy on shorter tweets. They extended their earlier work in Samuel et al. (2020b) and analyzed the sentiment on Twitter posts to find the dominant trends related to the debate on reopening the US economy during COVID-19. They implemented an innovative and useful approach for sentiment polarity. The approach could handle data from different social media sources and perform analysis beyond COVID-19. It was designed based on public sentiment scenarios (PSS). The study employed Twitter API and well-known packages in R such as rTweet and Syuzhet for classifying the tweets. The results revealed an overall trend with positive sentiment where fear and sadness have lower levels of sentiment as compared to trust and anticipation sentiments.

Duong et al., 2020a,b investigated the implications of COVID-19 on society by sentiment analysis of Twitter data. They utilized topic modeling methods to find the topical patterns on Twitter. Latent Dirichlet Allocation (LDA) was used for topical analysis of COVID-19 tweets. RoBERTa model was used for topic-based sentiment analysis, the transformers library by Hugging Face for training and evaluation, with SemEval-2017 Task 4A dataset evaluation. They found seven topics related to the concerns of college students and general society about the pandemic. These topics related to discussions on politics, national and international news, racism against Chinese related to COVID-19, physical distancing, and closures of colleges. Their results revealed that the response of college students to COVID-19 was more negative than the general population. Abdulaziz et al. (2021) provided a model for analysis of COVID-19 tweets in which it extracts the most popular topics related to COVID-19 and then it provides an analysis for the sentiment of the extracted topics. LDA was utilized for finding the important topics and lexicon-based approaches were used for sentiment analysis.

Abd-Alrazaq et al. (2020) reported sentiment analysis of tweets to identify major topics related to coronavirus disease (COVID-19). The authors used Twitter's search API, PostgreSQL database, and Python libraries including Tweepy. The analysis was performed using LDA and recurrences of words (unigrams and bigrams). The interaction for each topic is obtained by extracting the average number of retweets, likes, and followers. As a result of the analysis, 12 topics were identified and grouped into four classes: the virus origin, sources, the effect of the virus on countries, the economy, and the people, the ways to reduce and control the spread of the infection. The results also revealed that the overall sentiment was positive in which it was positive for 10 topics and for the remaining 2 (deaths and racism) it was negative.

Other studies that reported thematic analysis of COVID-19 related tweets include (Das and Dutta, 2020; Jimenez-Sotomayor et al., 2020). Some other COVID-19 related works on social media data analysis including Twitter were reviewed in Alomari et al. (2021a).

Twitter Data Analytics and COVID-19 (The Arabic Language)

The existing research studies related to COVID-19 based on the data analytics using social media in the Arabic language are limited. Most of the current research studies using social media in the Arabic language have used Twitter as a data source since it is one of the most active social media and highly rich with COVID-19 related data.

Several studies have focused on studying various topics related to COVID-19. Essam and Abdo (2021) investigated the reactions of Arab communities on Twitter against the pandemic of COVID-19. The authors study the linguistic expressions used to reveal the feelings on the pandemic using Twitter data. The objectives were to perform thematic analysis to find the dominant COVID-19 related topics and to explore the effects of these topics from the psychological aspect and find how these implications and the causes of the pandemic are related. The analysis was lexicon-based, and it was conducted using corpus tools, R language's stylo, and LIWC. The results showed that 30.6% of the community discussions on Twitter were around news about the epidemic in general in addition to the number of people who got infected. 6.8% of the discussions were about the signs and symptoms of Coronavirus, and 6% were around Economy. The experimental results also show the causes of the pandemic from the perspective of Arab tweeters. Alsudias and Rayson (2020) reported an analysis of COVID-19 related Arabic tweets with a focus on rumor detection. The study aimed to provide analysis results aimed at Arab World governments, as well as Public Health Organizations. Multiple machine learning algorithms including k-means algorithm, Support Vector Classification, NB, and LR were utilized in the study to identify the topics of the discussions related to COVID-19 on Twitter, to perform rumor detection, and to predict the class the source of tweets about COVID-19. They found that the rumor was correctly identified with an accuracy of 84% by Logistic Regression, when used with count vector, and Support Vector Classification, when used with TF-IDF. The results also indicate that around 60% of the tweets that were detected with incorrect information were written in a language style of academics and health specialists. Alanazi et al. (2020) presented a study on the Arabic tweets to recognize the most common syndromes associated with COVID-19 cases and the order with their appearance. The Twitter data used in the study was for the period March to May 2020. The experimental results demonstrate that 66% of the users have experienced some symptoms and provided sequential order of their appearance. The results showed that fever, headache, and anosmia were the top three symptoms experienced by patients.

Some researchers have also looked at government measures and public concerns related to COVID-19 using Twitter data in Arabic. Alhajji et al. (2020) presented a sentiment analysis study of closures of seven types of public and private facilities to contain the virus in Saudi Arabia. These seven types of facilities included Grand Mosque, universities, schools, and shopping malls. They extracted tweets related to the sentiments over the closure of these seven types of public and private facilities from various hashtags. They used the Naïve Bayes machine learning model. Their results show the overall positivity regarding the preventive measures in the Saudi community except for shopping malls closure. Alomari et al. (2021a) presented a study reporting an analysis of Arabic Twitter data to detect concerns of the public and the pandemic measures of the Saudi Arabia government during the COVID-19 pandemic. They collected a dataset of Arabic tweets from Saudi Arabia for the period February to June 2020. They developed a software tool consisting of the LDA topic modeling algorithm, visualization and spatio-temporal techniques, and other natural language processing (NLP) techniques. Various technologies were utilized such as Apache Spark, Spark ML, Spark SQL, Parquet, and MongoDB. The paper provides data analysis from the information-structural perspective, temporal perspective, and spatio-temporal perspective. The experimental results revealed 15 government pandemic measures and public concerns in which they were grouped into six macro-concerns including daily livelihood, and economic, social, and environmental sustainability.

A review of other COVID-19 related studies that use Twitter data in the Arabic language is given in Alomari et al. (2021a).

Twitter Data Analytics in Teaching and Learning

We review here the works related to online learning where social media is used for machine learning-based data analytics. First, we review works that are not related to COVID-19 and subsequently, in Section Twitter Data Analytics in Teaching and Learning (COVID-19), we will review works on online learning during COVID-19.

Verma et al. (2016) provided a survey on analyzing students' learning by utilizing social media data. They stated that analyzing social media data that is related to students' learning experience could provide transparent results (such as emotions and opinions) which could be valuable for organizations and educational administration. According to their survey, Naive Bayes algorithms need less time for computation and a smaller amount of pre-defined data (Clark et al., 2008) and they provide the best performance with most of the feature extraction techniques. It also indicates that the Support Vector Machine algorithm has some limitations in terms of complexity, speed, and size (Go et al., 2009). Lande and Dalal (2016) provided an analysis for Twitter data under certain hashtags related to engineering students. The aim was to explore the issues that affect the learning process of students and help improve the educational system. Naïve Bayes Multi-label classifier was used in the study. The experimental results classified the tweets into six main categories including the heavy load of study, diversity issues, lack of social engagement, sleep problems, negative emotions, and others.

Other studies on utilizing social media applications such as Twitter and Facebook for improving the learning process include (Kechaou et al., 2011; Chen et al., 2014; Verma et al., 2016).

Twitter Data Analytics in Teaching and Learning (COVID-19)

Researchers have focused on various issues related to education during COVID-19. Some have focused on studying students and their attitudes while others have focused on teachers and other stakeholders. Adnan and Anwar (2020) developed a study to find the attitudes of higher education students about online education in Pakistan during the pandemic. They used an online survey for collecting data from 126 higher education students (with a two-third of them females). The results demonstrated that online learning cannot provide the required results in Pakistan due to various issues including technical and monetary issues of Internet access. The study also highlighted some challenges and obstacles related to distance learning such as the absence of face-to-face interaction and lack of classroom socialization. Bestiantono et al. (2020) presented an exploratory study to discover high school students' perspectives and viewpoints toward online learning in Indonesia during the pandemic. The data was collected with online surveys including 180 Indonesian secondary school students (90 female, 90 male). The results showed that online learning cannot provide the expected outcomes where a large number of students cannot get Internet access due to financial issues. The results also highlighted various issues related to online learning including the absence of eye contact of instructor and the usual schoolroom socialization.

Rasmitadila et al. (2020) presented a case study about the perceptions of online learning during COVID-19 from primary school teachers' perspectives. The data collected from surveys and interviews. They used inductive and thematic analytics. The results demonstrated four major themes, specifically, instructional strategies, teachers' motivation, challenges, and support. They found that the success of online learning was determined by the collaboration and support of teachers, schools, parents, the government, and the community. Harron and Liu (2020) studied Twitter posts of K-12 teachers in the English language during the pandemic of COVID-19. They analyzed the posts related to online learning. The results show that most of the teacher's tweets were on the actions of political leaders, transition to online learning, and sharing free advice and resources. Carpenter et al. (2020) provided an analysis study for education-related hashtags on Twitter. The study included 2.6 million tweets in English posted on 16 different hashtags during a 13-month period. They explored the trends among the 16 hashtags, the similarities, and the differences. They found significant differences in the traffic related to the hashtags.

Twitter Data Analytics Using Topic Modeling

We review in this section the studies related to Twitter data analytics using topic modeling with a focus on the Latent Dirichlet Allocation (LDA) topic modeling algorithm.

Zahra (2020) developed a topic modeling algorithm for focused analysis to obtain semantic relations on a targeted aspect from COVID-19 related Twitter data. Data collection was performed in two phases with the use of a list of stop words that are frequently occurring and the geo-labels. Text pre-processing, as well as lemmatization, were performed using hand-crafted rules due to the lack of text processing resources for Levantine Arabic. The model learns topics from Twitter data expressed in various dialects of Levantine Arabic. The experimental results demonstrated the model's capability of capturing topics within the required scope. The results were compared to a baseline model as well as another targeted topic model that is designed to serve the same purpose. Korshunova et al. (2019) propose a supervised learning model used for classification or regression. The proposed model can also provide unsupervised learning by exploiting the structure in the data. It can be used with groups of images, in addition to, arbitrary text embeddings. Alomari et al. (2021a) used the LDA topic modeling algorithm for analyzing Arabic Tweets related to COVID-19 with the aim to detect public concerns and government measures.

Elaraby and Abdul-Mageed (2018) developed various classifiers to identify the dialect using a dataset for online comments in Arabic. The classifiers are based on neural networks including CNNs, LSTM, RNN, and gated recurrent unit (GRU). The results indicated that attention-based BiLSTMs achieved the best accuracy on dialect identification, if it is used with a large dialect-specific model for word embeddings.

Magatti et al. (2009) proposed an algorithm to provide automatic labeling for topics based on a hierarchy obtained through a tree. The best label is selected by utilizing a set of labeling rules. The rules for labeling are created to get the labels that are best agreed among the topic and the hierarchy. The results indicated the effectiveness of the proposed algorithm in mapping the extracted topic to topics labels associated with a topic hierarchy. Onan et al. (2016) presented an empirical study on the performance of the Latent Dirichlet Allocation (LDA) algorithm with sentiment classification. They examined the performance of various classification algorithms when LDA-based representation is used. Based on the analysis, they found that SVM, KNN, NB are used as the weak learners, while other algorithms such as AdaBoost, Voting, and Stacking, and Bagging are used as the ensemble learning methods. A review of other studies related to topic modeling using LDA can be found in Alomari et al. (2021a).

AI and Online Learning

Artificial intelligence technologies are important tools in the education industry to improve and reform the educational systems. It helps in understanding the stakeholders' needs and issues. For example, it helps educators in understanding the details of students' needs which helps making targeted adjustments to the content, cater to learners' individual learning styles and content needs, and teach students based on their aptitude (Hou et al., 2021). AI has accelerated distance education's modernization due to its rapid development (Gao et al., 2021). We review here in this the studies related to the use of AI in online learning. The works on social media analysis using AI for online learning are reviewed in Section Twitter Data Analytics in Teaching and Learning. Online learning is an active area of research. Utilizing artificial intelligence approaches in the learning domain has also gained researchers attention (Gao et al., 2021).

Some works have looked into recommendation systems in online learning using machine and deep learning methods. For example, Ai et al. (2019) introduce a system for online learning that provides personalized recommendations to students on specific exercise they should attempt. The system aims to improve the efficiency of the online learning experience. An online self-directed learning system (IPS) was used to analyze 5th grade students' interactions in the math curriculum. The proposed recommendation algorithm utilizes deep reinforcement learning techniques. The experimental findings indicate that the proposed system achieves better performance than existing policies in terms of optimizing the knowledge level of students. A recent review of recommendation systems in online learning and the utilization of AI technologies can be found in Khanal et al. (2019).

Other works have focused on understanding users' experiences about online learning. Ai and Laffey (2007) presented an experiment with pattern classification as a means of predicting the performance of students in the WebCT learning system. They aim to investigate whether data can be used to predict students' achievements in online learning, and examine how Web mining can be applied to online learning. The paper finds that Web mining is a useful approach for building knowledge about online learning and that it can improve learning performance in the long run. Mehmood et al. (2017) proposed a teaching and learning big data framework to improve lifelong learning in smart societies. They used eleven widely used datasets to evaluate various functions of the proposed framework. The ML techniques they used included DLANNs, Random Forests, and Naive Bayes classifier.

Research Gap

The literature review presented in this paper has clearly established the research gap and novelty of our work. The study developed in this paper differs from the existing works in several ways including the context, focus, time period, geography, data, language, design, and findings of the study. Moreover, the particular perspective on the use of AI in urban governance that we have presented in this paper would be a trendsetter for many more works to come in the future and significantly impact research and practice in this field.

METHODOLOGY AND DESIGN

The architecture of the proposed system is shown in **Figure 1**. It consists of five phases including data collection, pre-processing, governance parameters discovery, results validation, and visualization. The dataset has been collected using Twitter REST API.

Research Design and System Overview

We built the system using Twitter data analytics in the Arabic language. The architecture of the proposed system consists of five phases: data collection, pre-processing, parameters discovery, validation, and visualization. First, we collected the Arabic tweets related to online learning using Twitter REST API and the Tweepy library. The tweets extracted from the Twitter API were in the JSON (JavaScript Object Notation) format. Subsequently, we converted and saved the collected JSON file to XLXS format using a parser algorithm that we implemented in python. In the Pre-Processing phase, the collected data are cleaned and preprocessed to make it ready for the analysis stage. For stop-words removal, we used the Natural Language Toolkit (NLTK) library with an additional list of dialectical Arabic stop-words to remove from text. Then, we used the scikit-learn Python library to build the discovery module using Latent Dirichlet Allocation (LDA). Then, we provide visualizations of the discovered parameters using inter-topic distance map and term frequency diagrams. We have used the Python pyLDAvis library (Sievert and Shirley, 2014; Mabey, 2015) for computing and plotting the map and the term frequency diagrams. The inter-topic distances and the scaling for the set of inter-topic distances are computed using the default options Jensen-Shannon divergence and Principal Components, respectively. The term frequency diagrams show the corpus-wide and topic-specific frequencies represented by the widths of the blue and maroon bars, respectively. Finally, we validated the results using both internal and external validation. Internal validation was done by finding tweets that support the discovered urban governance parameters and findings. For example, in

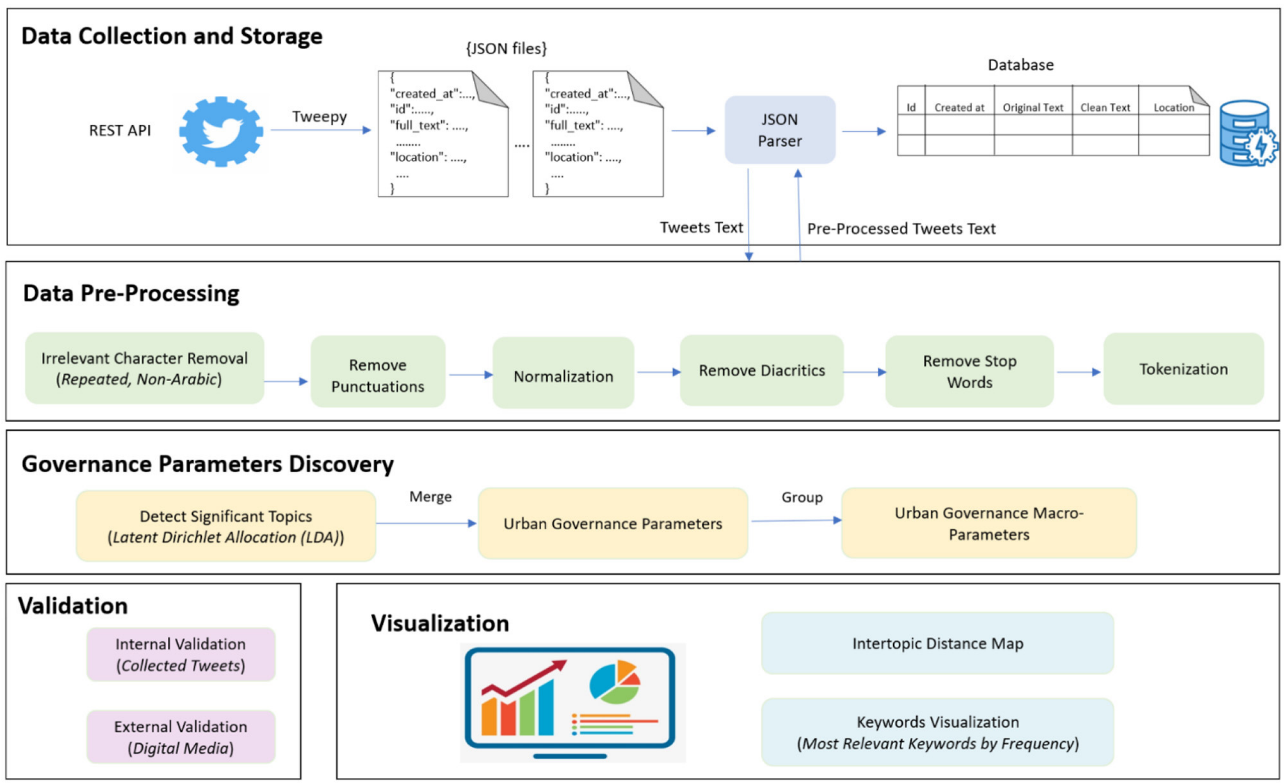

Figure 1 | The system architecture.

Section Results and Findings, New Economic Opportunities parameter was validated internally by many tweets, found by our tool, providing information about various educational services offered by individuals and small businesses for students and other stakeholders. For external validation, the parameters are validated by finding external online sources such as online newspapers and reports. For instance, Evaluation governance parameter was validated by two different studies conducted by six international organizations including Harvard University, UNESCO, and IITE (See Section Results and Findings).

Table 1 | The list of twitter hashtags used for the data collection.

	Hashtags	English translation
H1	#التعليم_حضوري	In-Class learning or face-to-face learning
H2	#التعليم_عن_بعد	Distance learning or online learning
H3	#التعليم_الالكتروني	E-Learning
H4	#مانفهم_عن_بعد	We don't understand online learning
H5	#نطالب_بالدراسة_حضوري	We request in-class learning

The Dataset

We collected the Arabic tweets related to online learning using Twitter REST API and the Tweepy library which is a python library that provides easy access to Twitter API (Roesslein, 2022b). The data was extracted during the period from October 1st to December 6th, 2020. The total number of collected tweets is around 128,805 tweets.

Firstly, we download tweets using a set of predefined parameters such as the "Arabic" language, the "extended" mode for extracting the entire text of the Tweet without truncation, and a set of search hashtags related to online learning in Saudi Arabia. For example, we used the hashtags #التعليم_حضوري (in-class education or face-to-face education), #التعليم_عن_بعد (online education). The list of the hashtags used for our data collection is listed in **Table 1**. For simplicity, we refer to Twitter hashtags as H. H1 hashtag was used to discuss in-class learning. H2 and H3 hashtags were used for discussing online learning. H4 and H5 hashtags were used by people who were requesting in-class learning and were not supportive of online learning.

The tweets extracted from the Twitter API were in the JSON (JavaScript Object Notation) format which is the default Twitter API response format. Each tweet is retrieved with several attributes (Twitter, 2022) such as "id" which reflects a unique id for each tweet, "created_at" which represents the time of posting the tweet, "text" which provides the actual tweet message, and other attributes related to the geographical location including "place," "geo," and "coordinates." Furthermore, "entities" attribute encapsulates a number of attributes e.g., "media," "links," "hashtags," and "user_mentions." The user_mentions attribute refers to other tweeters mentioned

```
{
"created_at": "Sat Oct 17 18:48:27 +0000 2020",
"id": 0000000000000000000,
"full_text": "@XYZ!مخفي",
"truncated": false,
"entities": {
   "hashtags": [],
   "symbols": [],
   "user_mentions": [{ "screen_name": "XYZ",
                       "name": "مخفي", }],
   "urls": []},
"metadata": { "iso_language_code": "ar", },
"user": {
   "id": 000000000,
   "id_str": "000000000",
   "name": "مخفي",
   "screen_name": "ABC",
   "location": "",
   "description": "",
   "url": null,     },
"geo": null,
"coordinates": null,
"place": null,
}}
```


Figure 2 | Example of a tweet object (JSON format).

in the Tweet's text. An example of a tweet object is shown in **Figure 2**. The "full_text" field contains the complete untruncated text of the tweet [the explanation of the "full_text" field can be found in Roesslein (2022a)]. Note that the full_text attribute is returned instead of the text attribute because we used the extended mode. Note that all personal information in the figure has been replaced with "XYZ" or "ABC" letters for English text and "مخفي" for Arabic text which means "hidden," and that is for preserving privacy. We also replaced the fields that have integers with an equal number of "0" digits.

Managing tweets in the JSON format involves certain programming and computational challenges. Therefore, we created a parser algorithm in python to iterate over all the tweets and extract the important attributes e.g., tweet id, date, time, and text from JSON format, get clean text by invoking pre-processing module (see **Figure 1**), and finally store the results in the XLSX format. Duplicate tweets were removed based on Tweet "Id" using Panda package. An example of the output of JSON parser is shown in **Table 2**. The JSON parser algorithm is shown in **Algorithm 1**.

Data Pre-processing

Data pre-processing is a very important step for data analytics. It involves employing various techniques on the obtained data to clean data, remove noise, enhance the quality, and accordingly, improve the accuracy of data analysis. There are some libraries

Algorithm 1 | The JSON parser algorithm.

Input: json_files[]
Output: xls_file

Function: process_json (json_files[])
create xls file with the following columns: id, created_at, text, clean_text, location
For tweet **in** json_file do
id ← tweet["id_str"]
created_at ← tweet["created_at"]
text ← tweet["full_text"]
clean_text ← tweet_cleaner.clean_tweet (text) // *Invoke text pre-processing module*
location ← tweet["user"]["location"]
End For
// *Remove duplicate Tweets*
df = pd.read_excel (xls_file)
df = df.drop_duplicates (subset="id")
Return xls_file

for pre-processing of textual data such as Natural Language Toolkit (NLTK) library. Data pre-processing includes various tasks including tokenization, removal of irrelevant words and characters, normalization (letter replacement), and stemming.

After converting the extracted tweets from the JSON format to excel format, we started pre-processing by removal of irrelevant words and characters including hashtags, mentions, URLs, numbers, whitespaces, smiley faces, and emojis. Emoji faces used in tweets could hold some meaning. Some studies are replacing it with a suitable word describing the emotion behind using it. However, in this paper, we removed them. Furthermore, we replaced the new line and the colon symbol (:) with whitespace for readability. Removing the repeating characters was also performed for readability.

Moreover, we removed all punctuations such as mathematical notations (÷, ×, −, +, %), different types of brackets {}, [], (), colons and semi-colons (: ؛ ;), question marks (? ؟), slashes, ad symbols such as *, &, ∧, $, >>, <<, |, ∼. Furthermore, we removed the non-Arabic letters and kept only the Arabic letters.

Normalization is another pre-processing task. PyArabic is one of Python libraries that can help with the normalization task. It provides support for the Arabic language, and it offers various functions for letters and texts detecting characters, removing diacritics. It also involves Tashphyne library for the normalization task (Harron and Liu, 2020). We removed all the forms of diacritics including Tashdid (ّ), Fatha (َ), Tanwin Fath (ً), Damma (ُ) Tanwin Damm (ٌ), Tanwin Kasr (ٍ) Sukun (ْ) are removed. Furthermore, we normalized the letters in the words into consistent form. For example, "Taa marbutah" (ة) was replaced with "haa maftohah" (ه), Alif" with three shapes (أ، إ، آ) to "bare Alif" "Yaa" (ي) to "dotless Yaa" (ى).

For text mining, stop-words are not significant, and removing them will reduce the volume of the feature set. The Natural Language Toolkit (NLTK) library was used with some

Table 2 | The output of JSON parser.

Id	Created at	Original text	Clean text	Location
1311800269257200000	01-10-2020	@News_Ejazah حضوري او تأجيل الدراسه كلياً… In class studying or postponing studying altogether...	حضورى تاجبل الدراسه كلىا … In class studying postponing studying altogether...	Jeddah City
1314314042652000000	08-10-2020	#شكرا_وزير_التعليم و ياريت لو كمان تخلي... Thank you, Minister of Education, and I wish if you also make…	ىاربت كمان تخلى … I wish you also make…	Medina City

modifications that suit the needs. For example, the stop-word list provided by NLTK is for modern standard Arabic (Alomari et al., 2021b), and accordingly a list of words in the dialectical Arabic is needed. After manual observation of the tweets, we added a new list for stop words which are usually used in dialectical Arabic such as in the following list "علي، الي، شى، وش، ليش، ايش، لاكن، لكن، علا، مو، احنا، اللى، اللهم، والله، الله، اللي". The original list was extended with the list provided in Alrefaie and Bazine (2019), which contains 750 stop words.

Tokenization is important in the pre-processing phase. It aims to split the text into a sequence of words (tokens) separated by punctuation characters or whitespaces. Split () is an available method in python ad it was utilized for this task.

Governance Parameters Discovery

We report here the process of discovering urban governance parameters using topic modeling of Twitter data. Modeling of topics is an AI approach that is frequently used for topics discovery and data analysis. It consists of a set of algorithmic methods that seek to identify structural patterns within a corpus of documents, producing clusters of word terms that identify the central themes of the documents (Mortenson and Vidgen, 2016). Latent Dirichlet Allocation algorithm (LDA) is an unsupervised machine learning technique, a commonly used algorithm for topic modeling. It is a statistical approach that is used to find the most common topics in a collection of documents. It helps in finding clusters in a collection of documents. LDA can be used to map a given set of documents (such as tweets in our case) to a set of topics or clusters and each document in the set is associated with a topic by a certain probability.

We used the scikit-learn Python library to build the discovery module using Latent Dirichlet Allocation (LDA).

Modeling the distributions required determining the number of topics. We ran LDA multiple times to explore different cluster sizes e.g., 10 15, 20, and other numbers, and we found that 20 topics provided the best results for identifying important urban governance parameters. Subsequent to the extraction of clusters, we manually assigned names to the clusters based on the keywords, tweets, and the domain knowledge. We first looked at the key terms of each cluster and then we gave a name. When the key terms were not clear, we then looked at the context of the tweets. This was an iterative process. The clusters' names are a reasonable representation of the LDA keywords and the tweets in the cluster. Then, we removed the clusters that are not related, and we merged some of these 20 topics into 10 topic clusters that we call urban governance parameters. The merging of topics was based on their relationships to other topics. We further group these ten governance parameters into four governance macro-parameters based on their relationship to the macro themes. The macro-parameters are higher (broader) level parameters. This whole process created a set of 10 parameters and 4 macro-parameters.

For example, we found that the keywords and the tweets for both topics 5, 10, and 14 refer to the nature of exams during COVID-19 and the concerns of attending in-class exams due to the fear of COVID-19 infection. Some of the keywords are "Exams," "Physical Attendance," "Infection," "Health," and "Physical Distancing." For this reason, we merged the three topics and named them as the Exam Procedures. Since conducting exams during COVID-19 whether online or in-class has many challenges, these three topics were listed under the fourth macro-parameter, Challenges.

Evaluation and Validation

For validating the discovered parameters obtained from the extracted topics using the LDA model, two methods were used, following the approach used by Alomari et al. (2021a). The first method provides external validation and uses digital media such as online newspapers (e.g., the Okaz and Al Madina newspapers) and other online reports and information to verify the identified parameters. The second method provides internal validation using the collected Twitter data including the tweets posted by the official accounts of schools, universities, or the Ministry of Education.

RESULTS AND FINDINGS

Online learning currently is a key public issue due to the ongoing pandemic requiring physical isolation of people and in turn the migration of many aspects of our life to cyberspaces. Given the importance of this subject, we investigate in this section the use of AI in urban governance as to how AI could help governments learn about various urban governance parameters for online learning in Saudi Arabia. These governance parameters include government policies and strategies on the subject matter as well as the public reactions and concerns. Specifically, we report the process of discovering 10 urban governance parameters using LDA-based topic modeling of Twitter data. The process involved extracting 20 topics from the Twitter data using the LDA algorithm and then merging some of these topics into topic clusters that we call urban governance parameters. We will use the terms topic cluster,

Table 3 | Urban governance parameters (online learning during COVID-19, October–December 2020).

Macro-Parameters	Urban governance parameters	Topics	Keywords (%)	Keywords
Strategies and success factors	Supporting online learning	1	11%	**حضوری، الطلاب، وزاره، استمرار، افضل، قرار** In-Class, Students, Ministry, Continuation, Better, Decision
		12	4.1%	**الفصل، تبقى، الاختبارات، الامر، الجامعي، والتدريب، التقني، سلامه، بصحه** Semester, Remaining, Exams, Order, University, Training, Technical, Safety, Health
	Supporting families	3	8.7%	**التعليم، الالكتروني، الامر، ولي، شارك، الرقميه، عزيزي، جزء، منظومه، الدراسه، مدرستي، وزارة، مسابقة، تجربتک، التربية** Education, Electronic, Matter, Guardian, Participate, Digital, Dear, Part, System, Studying, Madrasati Platform, Ministry, Competitions, Experience, Upbringing
	Competitions and incentives	4	7.4%	**التعليم، مشاركه، مدرستي، الصف، المدرسه، مسابقة، المعلمه، منصه، الابتدائية، الالكتروني، مدرسه، تعزيز، الرقميه، الأستاذ، الطالب** Education, Participation, Madrasati Platform, Class, School, Competition, Teacher, Platform, Elementary (School), Electronic, School, Strengthening, Digital, Lecturer, Student
	Nurturing positive behavior	9	4.6%	**برنامج، الأطفال، الاحد، الاسبوع، المرشده، انطلاق، الموافق، السلوك، العالمي، الصحيه، تفعيل، الإيجابي، العامه، منصه، الارشاد** Program, Children, Sunday, Week, Adviser, Starting, Corresponding, Behavior, International, Health, Activation, Positive, General, Platform, Guidance
	Commending stakeholders	19	2.7%	**التعليم، كورونا، رساله، نتائج، امانه، شكرا، تجربه، نعمل، التحديات، جائحة، مستمر، الالكتروني، الصعوبات، ناجحا، واتقان** Education, Corona, Mission, Results, Honesty, Thanks, Experience, Work, Challenges, Pandemic, Continuous, Electronic, Difficulties, Successful, Excellence
Economic sustainability	New economic opportunities	6	5.8%	**تصميم، جرافيک، فيديو، شعار، موشن** Design, Graphics, Video, Logo, Motion
		15	3.3%	**المشروع، دخل، خاص، الصور، خصم** Project, Income, Private, Photos, Discount
		17	2.8%	**حل، عروض، واجبات، بحوث، الاختبارات** Solution, Presentations, Assignments, Research, Exams
Accountability	Evaluation	2	8.9%	**التعليم، الالكتروني، التعلم، التعليميه، المعلم، الطالب، تجربه، نجاح، شكرا، عمليه، المملكه، التقنية، مستوى، مهارات، جهود** Education, Electronic, Learning, Educational, Teacher, Student, Experience, Success, Thank, Process, Kingdom, Technology, Level, Skills, Efforts
Challenges	Exam procedures	5	6.4%	**الاختبارات، حضوري، الترم، قرار، المرض** Exams, Physical Attendance, Term, Decision, COVID-19
		10	4.3%	**وزارة، الجامعات، المدرارس، النهائية، وزير، نظام** Ministry, Universities, Schools, Final, Minister, System
		14	3.5%	**انتشار، صحه، مطلبنا، تخاطر، بالتباعد** Infection, Health, Request, Risk, Physical Distancing
	School timings	7	5.6%	**الطلاب، وقت، المنصه، الدراسه، المعلم، المدارس، افضل، وزاره، كثير، مشكله، النظر، الابتدائي، المعلومة، الحصه، صعب** Students, Time, Platform, Studying, Teacher, Schools, Better, Ministry, Excessive, Problem, Consider, Elementary, Information, Class, Difficult
	Digital services	8	4.9%	**الطلاب، المدرسه، المعلمين، الانترنت، مدرستي، ضعف، اجهزه، الالكتروني، المنصه، خدمات، عقد، الاسره، التعليم، الاتصالات، العمليه** Students, School, Teachers, Internet, Madrasati Platform, Weakness, Devices, Electronic, Platform, Services, Contract, Family, Education, Telecommunications, Process

cluster, and governance parameter interchangeably. We further group these ten governance parameters into four governance macro-parameters. The methodology of detecting these topics using LDA has already been described in the previous section. The software is developed completely in the Python language.

Table 3 lists the urban governance parameters and related data. The four governance macro-parameters are listed in Column 1 of the table. These are **Strategies and Success Factors, Economic Sustainability, Accountability**, and **Challenges**. Column 2 lists the ten governance parameters that include **Supporting Online-Learning, Supporting Families**, and others. Note that each governance macro-parameter includes one or more governance parameters. For example, the fourth macro-parameter (**Challenges**) includes three governance parameters namely **Exam Procedures, School Timings**, and **Digital Services**. Column 3 lists the topic numbers. As we have mentioned earlier that we extracted 20 topics from the Twitter data using LDA and some of these topics that are related to each other are merged to form governance parameters. An example of this merging is the first governance parameter (**Supporting Online-Learning**) that is formed from merging Topic 1 and Topic 12 (see Column 3, Row 2, and Row 3). Column 4 gives the percentage number of keywords for the topics in the table rows. Topic 1 is the biggest topic and contains 11% of the total number of keywords. Topic 12 contains 4.1% of the total number of keywords. Column 4 in the fourth row gives the total number of keywords for the first governance parameter (**Supporting Online-Learning**). Column 5 in the table lists 15 keywords (in total for all the topics in a cluster) for each governance parameter. Originally, we have collected the top 30 keywords for each topic. These 15 keywords listed in the table are selected manually (using domain expertise) from the initial 30 keywords based on their significance to the topics.

The keywords are listed in Arabic along with their English translation. The translation of these keywords and other Arabic content (sample tweets, etc.) is deliberately contextual to allow English readers to understand the contextual use of the keywords. A literal translation of certain keywords would not convey the contextual meaning of the keywords and may confuse or give a completely different meaning to the reader.

We now digress from explaining **Table 3** and explain the topics using graphical data. **Figure 3** plots the inter-topic distance of the 20 topics using multidimensional scaling. The bottom-left of the figure gives a key to the size of the topics. Note that Topic 1 is represented by the largest circle implying the largest topic in terms of the number of keywords (as mentioned earlier it contains 11% of the total number of keywords, also see **Table 3**). **Figure 4** plots the top 30 most relevant keywords (or key terms) for Topic 1. The keywords are ordered by decreasing frequency of these keywords within Topic 1 (see the maroon bars). The blue bars give the overall term frequency for each keyword. The software (LDAVis tool) analyses Arabic text and creates graphs for Arabic keywords. The keywords are shown in the Arabic language. The English translation for the Arabic keywords in the figure is provided in **Table 4**. Note that the overall frequency of the keyword "التعلم" (Education) is very near to the total frequency which shows that this keyword has significant weight. Furthermore, the keywords "الالكتروني" (Electronic) and "حضوري" (In-Class) have very similar overall item frequency, however, "الالكتروني" has a higher frequency within Topic 1 which is about electronic learning (E-learning or online learning). Now that we have given a general introduction to the table and topic diagrams, we move on to discuss in detail each of the governance parameters along with supporting data from the collected tweets and external sources. During these discussions, we will also elaborate further on the topic diagrams related to the governance parameter.

The first urban governance parameter (see **Table 3**) is **Supporting Online-Learning** and it belongs to the first macro-parameter **Strategies and Success Factors**. We have mentioned earlier that it is a merged parameter and includes Topic 1 and Topic 12. **Figure 4** plots the top 30 most relevant keywords for Topic 1 (we are unable to include these diagrams for all the 20 topics, avoiding an excessive number of figures and conform to the publisher's article guidelines). The selective keywords in Column 5 of Row 2 (Topic 1) and Row 3 (Topic 12) characterize the governance parameter. The parameter relates to the government's decision, strategies, and efforts to continue online learning for all the school and university levels in Saudi Arabia. Before the beginning of the academic year (in August 2020) the Ministry of Education announced that the schools and universities will be online for the first 7 weeks of the first semester (Saudi Ministry of Education, 2020f). People actively discussed during this time this decision to migrate to online learning and whether it should be continued after the seventh week. Later on, due to the continuing COVID-19 pandemic, the government decided to continue online learning (note the keywords, e.g., "Continuation") over the whole semester (Fall Semester, 2020–2021) (Saudi Ministry of Education, 2020d) that created mixed emotions from the people, though the people applauded the government's decision to continue (the keyword "better"). The keywords "Safety" and "Health" show the government's reasoning for the decision and care for citizens. The keywords "Technical," "Training," and "University" represent the type of educational institutions involved in these discussions. The tweets related to this cluster were posted

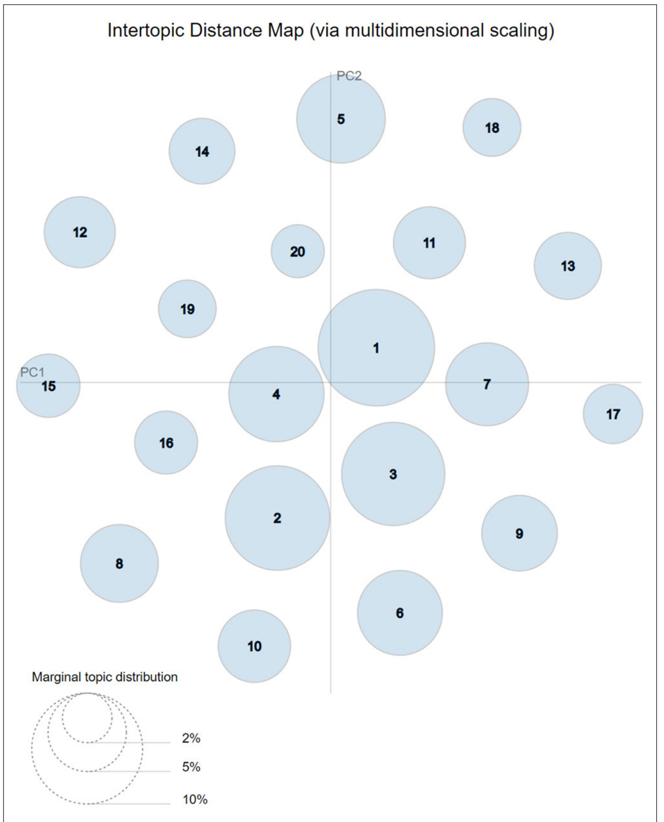

Figure 3 | The intertopic distance map.

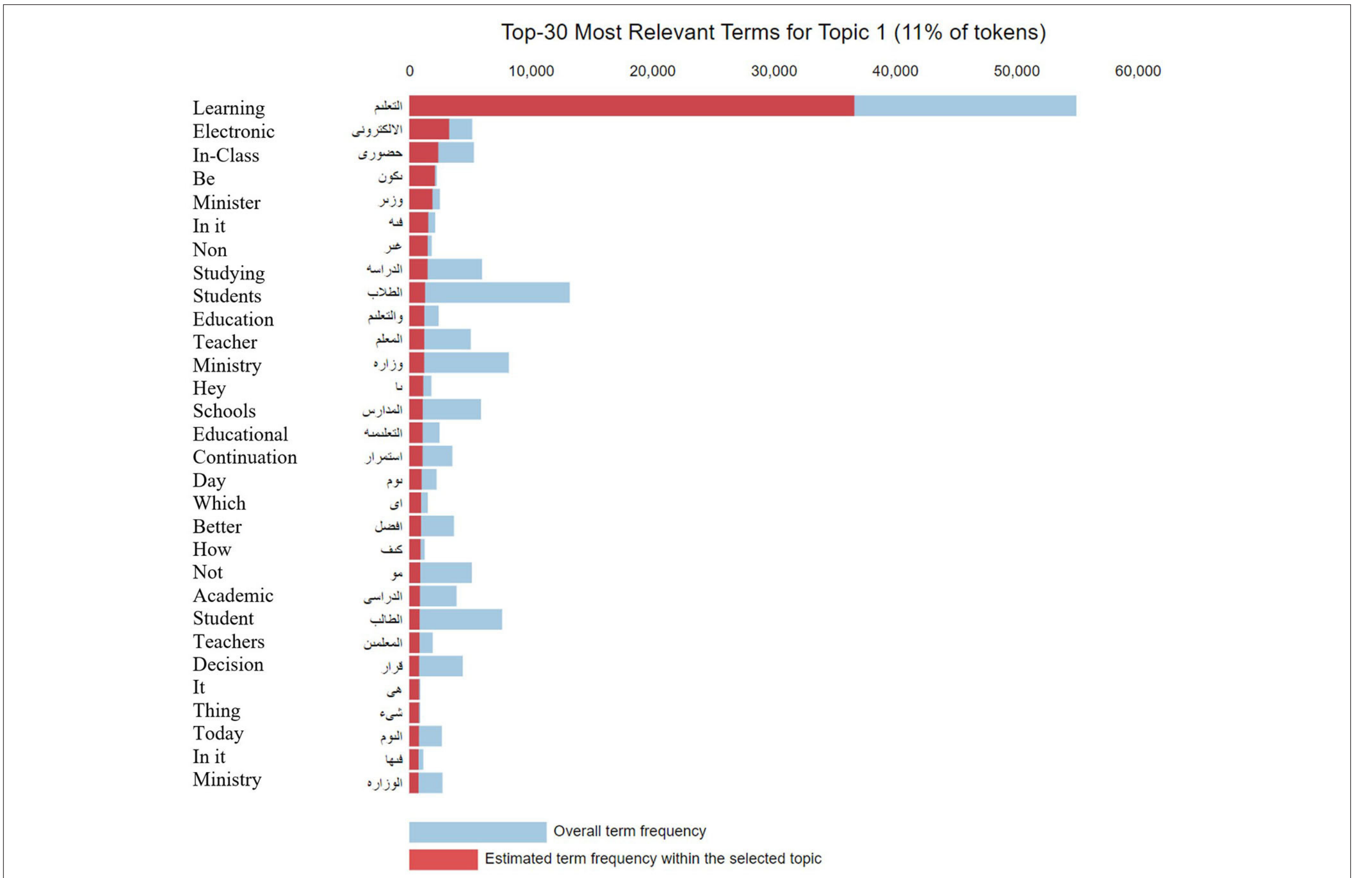

Figure 4 | The top 30 most relevant keywords/key terms by frequency (topic 1).

by official accounts, news accounts, and people. For example, the official account of the Ministry of Education tweeted on October 8, 2020:

"وزارة التعليم تُعلن عن استمرار الدراسة عن بُعد لما تبقى من أسابيع الفصل الدراسي الأول، كما ستوضح آلية الاختبارات خلال الأيام المقبلة."

"The Ministry of Education announces the continuation of online study for the rest of the first semester, ..."

Many universities tweeted accordingly such as the following excerpt of a tweet by Umm Al-Qura University in Makkah city.

"......باستمرار العملية التعليمية عن بُعد لما تبقى من الفصل الدراسي الأول في التعليم العام والجامعي بعكس مدى ... اهتمام القيادة . . . على سلامة وصحة الطلاب والطالبات. #نعود_بحذر"

"... continue the distance learning process for the remainder of the first semester for general and university education ... due to the safety and health of students. #return cautiously"

The second governance parameter is **Supporting Families** (see Row 3, **Table 3**) represented by key terms such as Guardian, Participate, Digital, Part, Madrasati Platform, Experience, and Upbringing. Family participation is very important for the success of online learning. Therefore, one of the strategies used by the Ministry of Education was to strengthen the family involvement in supporting their children for online learning. For this purpose, the ministry arranged some online activities and involved the families in these activities. These activities were organized on the online learning platform "Madrasati" (an Arabic word meaning "My School"). Many schools posted tweets related to this parameter. We found more than 500 tweets in our dataset similar to the following tweet that was posted by a school in Makkah.

"عزيزي ولي الأمر، شارك معنا لأنك جزء من منظومة التعليم الإلكتروني."

"Dear Guardian, participate with us because you are part of the e-learning system."

The Saudi Ministry of Education in August 2020 stressed the importance of parents and families supporting their children

Table 4 | The keywords and their English translation for **Figure 4**.

Keywords	التعليم، الالكترونى حضورى، نكون، وزير، فيه، غير، الدراسه، الطلاب، والتعليم، المعلم، وزاره، يا، المدارس، التعليمية، استمرار، يوم، اى، افضل، كيف، مو، الدراسى، الطالب، المعلمين، قرار، هي، شيء، اليوم، فيها، الوزاره
Translation	Learning, Electronic, Be, In-Class, Minister, In It, Non, Studying, Students, Education, Teacher, Ministry, Schools, Educational, Continuation, Day, Which, Better, How, Not, Academic, Student, Teachers, Decision, It, Thing, Today, In It, Ministry

in transitioning to online learning to make the transition successful (Saudi Ministry of Education, 2020c). Recently, on 27th May 2021, the Minister of Education applauded the parents' involvement and support that enabled the educational process to successfully continue online (Saudi Ministry of Education, 2021a).

"Parents contributed to creating a partnership with the Ministry of Education, and supported the continuation of the educational process online for their children."

The third governance parameter is **Competitions and Incentives** (Row 4, **Table 3**) represented by key terms such as Madrasati Platform, Class, School, Competition, Teacher, Strengthening, and Digital. Developing certain competition exercises among the students was one of the strategies that have been followed by the Ministry of Education to strengthen distance learning. It aimed to encourage students, promote hard work, and reduce laziness among them. Some competitions were on the level of the schools, others were on the level of cities. For example, the "Digital Madrasati Platform Competition" (مسابقة مدرستي الرقمية) was provided by the Saudi Ministry of Education in which every school had its own competition (Alatiq, 2021). It was aimed at highlighting the importance of e-learning and enhancing the participation of the citizens in educational activities. For example, the following tweet found in our dataset was posted on Oct 2, 2020, by a school in Arar city.

"بهدف تعزيز اهمية التعليم الالكتروني والتعليم عن بعد وإثراء المحتوى الرقمي تبدأ إدارة المدرسة في استقبال المشاركات من جميع الفئات المشاركة من معلمين وإداريين وطلاب وأولياء أمور في مسابقة منصة مدرستي"

"With the aim of highlighting the importance of distance learning and improving the digital content, the school administration starts receiving participations on the Madrasati platform from all stakeholders including teachers, administrators, students, and parents."

Another tweet in our dataset, posted on October 11, 2020, is from a school in Taif city. It highlights the use of financial incentives.

"حرصا من إدارة المدرسة على حث الطالبات على دخول منصة مدرستي والاهتمام بالأنشطة والاثراءات واستثمار كل الموارد التي توفرها لضمان سير العملية التعليمية فقد رأت العودة مجددا لمسابقة نجوم رحاب بشروط جديدة وجوائز قيمة شهرية."

"In order to encourage students to enter the Madrasati platform, … to ensure the progress of the educational process online, the school administration will continue the Stars Rehab competition with monthly valuable prizes."

The fourth governance parameter is **Nurturing Positive Behavior** (see Row 5, **Table 3**) represented by key terms such as Program, Children, Sunday, Week, Behavior, Positive, and Guidance. Developing and strengthening good attitudes in students is essential for the success of online learning. This is because with online learning there are a lot of issues including the children's motivation and honesty when the teacher is not present in the physical space to supervise them. Therefore, one of the strategies applied by the Ministry of Education was to strengthen the students' positive behavior. For this objective, the ministry activated the "Schools Promoting Positive Behavior" program. The program was executed by the guidance and counseling departments of schools, and it was for 1 week starting on Sundays (a working day in Saudi Arabia) (Alyaum Newspaper, 2020; Alhadwari, 2021) and this is why "Week" and "Sunday" are the key terms in this cluster. The program, with all its activities and events, aimed to create an institutional environment that stimulates positive behavior to achieve psychological and social compatibility for the student by adopting specialized and attractive methods, emphasizing the strengthening of the relationship between the students, schools, the families, and the local communities. Many schools in the country posted tweets related to this cluster, for example, the following tweet is taken from our dataset that was posted on October 14, 2020, by a secondary school in Jazan city.

"ضمن فعاليات الأسبوع المكثف لبرنامج المدارس المعززة للسلوك الإيجابي نعرض مشاركة الطالبات ومنسوبات المدرسة عبر الحائط الالكتروني؛ بمتابعة المرشدة الطلابية"

"Within the activities of the intensive week of the Schools Promoting Positive Behavior Program, we showcase its results achieved through the participation of students and school staff through Madrasati Platform under the supervision of the student advisor."

The fifth governance parameter is **Commending Stakeholders** (see Row 6, **Table 3**) represented by keywords e.g., Mission, Results, Honesty, Thanks, Experience, Challenges, Pandemic, Continuous, Difficulties, Successful, and Excellence. During the COVID-19 pandemic the teachers' efforts became more evident because the students' families and other stakeholders realized the efforts that the teachers had put into teaching the kids despite the rapidly appearing challenges during the pandemic including migration to online learning. With the efforts of the teachers, online learning became successful. This cluster represents peoples' appreciation for teachers and other stakeholders. Due to this, International Teachers' Day was celebrated more than before. The following

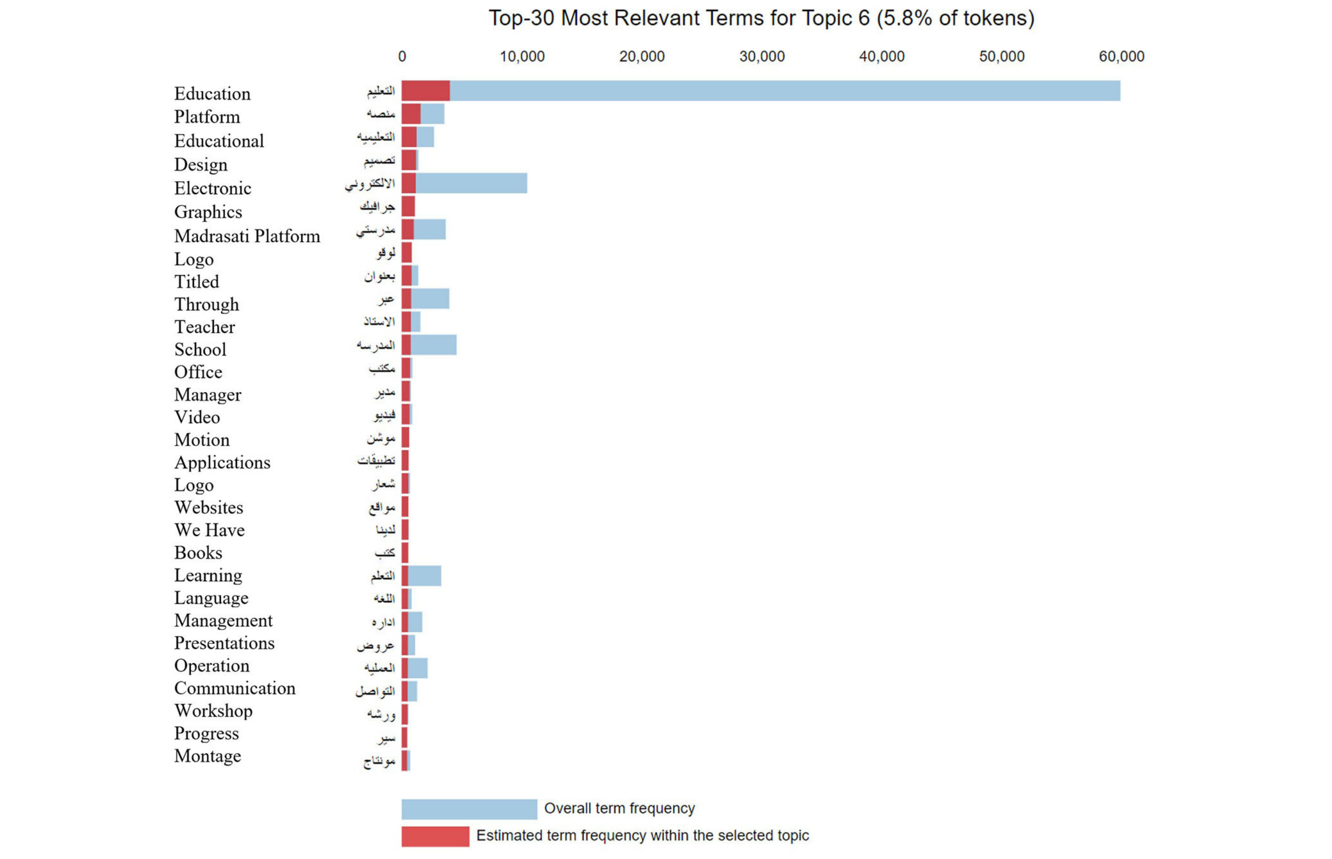

Figure 5 | The top 30 most relevant keywords/key terms by frequency (topic 6).

tweet related to this cluster found in our dataset is an example of many tweets that were posted on the 5th of October 2020 by students, families, and management to thank the teachers for their efforts.

"شكراً معلمي ٢٠٢٠ تجاوزتم الصعوبات وتغلبتم على التحديات وقدمتم بأجمل رسالة على وجه الأرض بكل أمانة وإتقان فكان التعليم عن بُعد ناجحاً بجهودكم فشكراً لكم"

"Thank you, teachers of 2020. You overcame the difficulties and the challenges and delivered the most beautiful message on the earth with honesty and excellence. Distance learning became successful with your efforts. So, thank you."

The sixth governance parameter is **New Economic Opportunities** (Rows 7–9, **Table 3**) that is included in the second macro-parameter **Economic Sustainability**. It is a merged parameter and includes Topics 6, 15, and 17. **Figure 5** plots the top 30 most relevant keywords for Topic 6 (we limit presenting one topic diagram rather than for all the three merged clusters to conform to the publisher's article guidelines). Topic 6 contains 5.8% of the total number of keywords. The Arabic keywords in the figure are translated into English in **Table 5**. Note that some of the keywords e.g., Graphics, Logo, and Motion, are only significant within Topic 6 since the overall term frequency is equal to the term frequency within Topic 6. The selected keywords from the three topics listed in Column 5 of Rows 7–9 (**Table 3**) characterize the governance parameter and include Design, Graphics, Video, Logo, Motion, Project, Income, Private, Photos, Discount, Solution, Presentations, Assignments, Research, and Exams. Many businesses were severely affected due to the COVID-19 related lockdowns causing many people to lose their jobs or their salaries to be reduced (Alomari et al., 2021a). This governance parameter relates to the new economic opportunities in online learning that people have developed as a result of these adverse effects of the pandemic. The economic opportunities include various educational services for students and instructors. These services are provided by individuals and small businesses including providing tuition and other services to help students with research papers, solving assignments and exams, designing logos and photos, and developing PowerPoint slides. Some services were also made available to the other stakeholders such as families, teachers, and other management staff to facilitate their migration to the online mode of learning. The following tweet posted on October 4, 2020, is an example of the many tweets related to this governance parameter.

Table 5 | The keywords and their English translation for **Figure 5**.

Keywords	التعليم، منصه، التعليميه ، تصميم، الالكتروني، جرافيك، مدرستي، لوقو، بعنوان، عبر، الاستاذ، المدرسه، مكتب، مدير، فيديو، موشن، تطبيقات، شعار، مواقع، لدينا، كتب، التعلم، اللغه، اداره، عروض، العمليه، التواصل، ورشه، سير، مونتاج
Translation	Learning, Platform, Educational, Design, Electronic, Graphics, Madrasati Platform, Logo, Titled, Through, Teacher, School, Office, Manager, Video, Motion, Applications, Logo, Websites, We Have, Books, Learning, Language, Management, Presentations, Operation, Communication, Workshop, Progress, Montage

"نقوم بعمل مجموعه من الخدمات للطلاب بحوث الجامعية حل الواجبات بشكل احترافي. عروض البوربوينت بروجكتات حل اسايمنتات"

"We provide a range of (tuition) services to help students with their undergraduate research, preparing PowerPoint presentations, projects, and assignments"

Some services were also made available to the other stakeholders such as families, teachers, and other management staff who lack technical and digital skills. These services aim to facilitate the migration to the online mode of learning. The following tweet highlights some of the services provided to teachers.

"كل مايخص خدمات (التعليم عن بعد) الإلكترونية نقدم لكم: -اختبارات إلكترونية -العاب تفاعلية -أوراق عمل -مونتاج فيديوهات وصور تعليمية. . هذا والكثير عبر حسابنا في سناب. . ."

"We offer everything related to (online learning) electronic services e.g., electronic tests, interactive games, worksheets, montage of educational videos and photos… a lot more through our account in Snap…"

Below are some tweets related to the private services provided. *"…student services: designing electronic questionnaires, statistical analysis SPSS, … research papers, translation, … writing articles, … convert the audio content to a Word file, formatting Word file …"*

The seventh governance parameter is **Evaluation** that is included in the third macro-parameter **Accountability** and is represented by the keywords from Topic 2 including Teacher, Student, Experience, Success, Thank, Process, Kingdom, Technology, Level, Skills, and Efforts. **Figure 6** plots the top 30 most relevant keywords for Topic 2. It shows that Topic 2 includes 8.9% of the total number of keywords. The English translation of the Arabic keywords is depicted in **Table 6**. The governance parameter relates to the evaluation of the online learning programs in Saudi Arabia that, according to the National eLearning Center (NELC) in Saudi Arabia, was carried out by six international organizations in two different studies (Saudi National eLearning Center, 2020). The studies reported on the experience of public and higher education in the Kingdom during the pandemic. The aim of these studies was to analyze the experiences of online learning during the pandemic and suggest initiatives for improvements. These studies benefitted from the participation of 342,000 students, parents, teachers, and other staff from schools and higher education institutions. The first study was conducted by the Organization of the E-Learning Consortium (OLC), along with the International Society for Educational Technologies (ISTE), Quality Matters (QM), UNESCO, the National Center for Research on Distance Learning and Advanced Technologies in the United States of America (DETA), and the Institute of Information Technology in Education (IITE). The second study was conducted by the Organization for Economic Co-operation and Development (OECD) together with Harvard University. OLC applauded NELC Saudi Arabia particularly for the diversity of options available to the students and stakeholders (free access to lectures through Satellite TV, Internet, exceptional support to equip teachers with the required skills and access to various digital platforms, etc.) and the speed of response in ensuring a successful transition to online learning. The tweets detected under this governance parameter included the tweets reporting the outcome of these two evaluation studies and people and various institutions responding to the topic. For example, King Abdulaziz University, Jeddah, posted the following tweet.

"تفخر جامعة_الملك_عبد العزيز بمشاركتها مع الجامعات السعودية في نجاح تجربة المملكة في التعليم عن بعد حيث أشادت الدراسات التي قامت بها منظمات وجهات عالمية بدور المملكة في التعليم الالكتروني من حيث سرعة الاستجابة، وتعدد الخيارات، والتحسين المستمر."

"King Abdulaziz University is proud of its contribution in the successful experience of Saudi Arabia in transitioning to electronic learning, assessed by two studies conducted by six international organizations, the studies demonstrated strong aspects of the Saudi experience including fast response, diversity of options, and continuous improvements."

We now discuss the governance parameters related to the fourth macro-parameter, **Challenges.** It includes three governance parameters, **Exam Procedures**, **School Timings**, and **Digital Services**. The eighth parameter, **Exam procedures,** is a merged governance parameter created from three topics, Topics 5, 10, and 14. **Figure 7** plots the top 30 most relevant keywords for Topic 5. The Arabic keywords in **Figure 7** are translated into English in **Table 7**. Note that the key word "الاختبارات" (Exams) is at the top of the list of the key terms which shows the importance of it in this parameter which is about Exam procedures. The selected keywords from the three topics listed in Column 5 of Rows 9–11 characterize the governance parameter. The keywords include Exams, Physical Attendance, COVID-19, Ministry, Universities, Schools, Infection, Health, Demand, Risk, and Social Distancing. Exam procedures during COVID-19, whether these should be online or in-class, were a major concern for people and were vehemently discussed on Twitter by students, parents, instructors, and others. Some

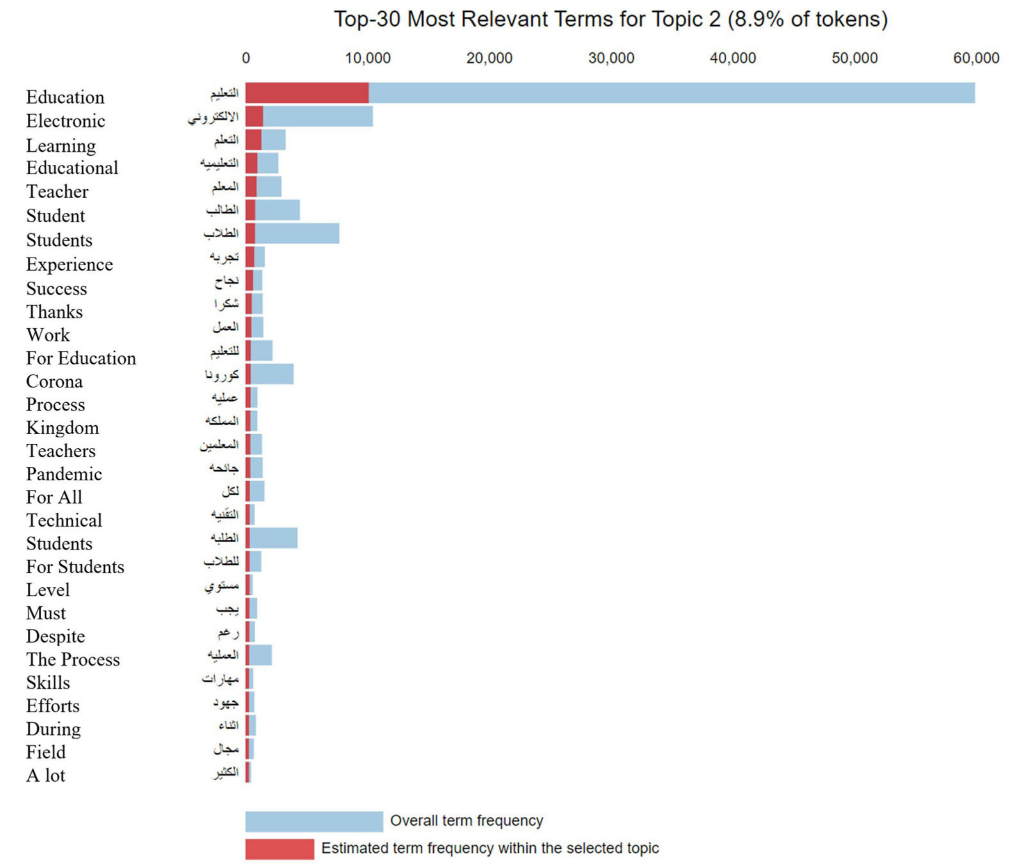

Figure 6 | The top 30 most relevant keywords/key terms by frequency (topic 2).

Table 6 | The keywords and their English translation for **Figure 6**.

Keywords	التعليم، الالكتروني، التعلم، التعليميه، المعلم، الطالب، الطلاب، تجربه، نجاح، شكرا، العمل، للتعليم، كورونا، عمليه، المملكه، المعلمين، جائحه، لكل، التقنيه، الطلبه، للطلاب، مستوي، يجب، رغم، العمليه، مهارات، جهود، اثناء، مجال، الكثير
Translation	Education, Electronic, Learning, Educational, Teacher, Student, Students, Experience, Success, Thanks, Work, For Education, Corona, Process, Kingdom, Teachers, Pandemic, For All, Technical, Students, For Students, Level, Must, Despite, The Process, Skills, Efforts, During, Field, A Lot

universities required students to physically attend the final exams so people were afraid that it created risks for higher infection rates during exams. While the public concern was valid, the universities view on physical attendance in final exams also seems to be valid because of the inability of the current eLearning systems to detect cheating during exams and enforce honesty on the students' part. This challenge creates opportunities for the development of digital systems that provide better online learning and assessment capabilities.

The ninth governance parameter is **School Timings** part of the fourth macro-parameter **Challenges** and is represented by the keywords from Topic 7 including Time, Platform, Studying, Teacher, Better, Excessive, Problem, Consider, Elementary, and Difficult. Online school timings in Saudi Arabia were scheduled based on the school levels. The intermediate and high school classes were scheduled in the mornings while the elementary school classes were scheduled in the afternoons. This became a problem for many families particularly mothers with children in multiple school levels who had to supervise their kids throughout the day. Tweets such as the following were found in our dataset.

"..... التعليم عن بعد جميل للأسف وقت المنصه للمرحلة الابتدائية جدا متعب خاصه اذا كنتي معلمه وام بضيع اليوم وحنا بالمنصة وبعده عندك مسؤوليات اخرى ارهاق"

> *"…. distance education is good. however, the school timings for the elementary stage are very exhausting, especially if you are a teacher and a mother, the entire day is wasted while we are on the platform, and after that, you have other responsibilities. That is exhausting."*

While the parents and mothers had valid reasons to be exhausted, we believe that school timings were decided considering a number of factors. Scheduling the senior school students in the mornings allowed working parents to carry

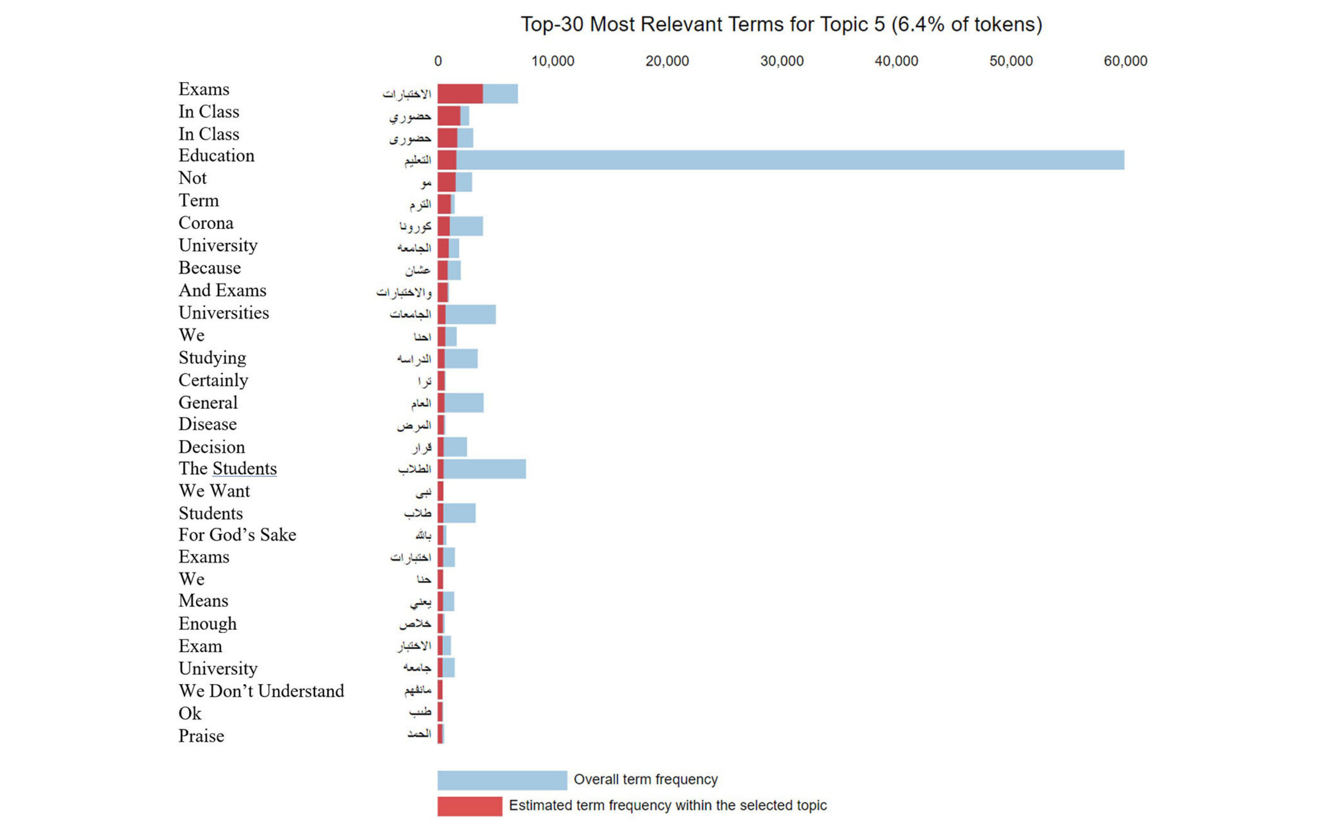

Figure 7 | The top 30 most relevant keywords/key terms by frequency (topic 5).

Table 7 | The keywords and their English translation for **Figure 7**.

Keywords	الاختبارات، حضوري، حضورى، التعليم، مو، الترم، كورونا، الجامعه، عشان، والاختبارات، الجامعات، احنا، الدراسه، ترا، العام، المرض، قرار، الطلاب، نبى، طلاب، بالله، اختبارات، حنا، يعني، خلاص، الاختبار، جامعه، مانفهم، طبب، الحمد
Translation	Exams, In Class, Education, Not, Term, Corona, University, Because, And Exams, Universities, We, Studying, Certainly, General, Disease, Decision, The Students, We Want, Students, For God's Sake, Exams, We, Means, Enough, The Exams, University, We Don't Understand, Understanding, Ok, Praise

out their jobs in the morning because older kids required less supervision. This enabled working parents, or older kids, to be able to supervise the younger kids during the afternoon schools. Dividing the school timings to mornings and afternoons also allowed the sharing of resources such as computers and tablets.

The tenth and the last governance parameter is **Digital Services** (see **Table 3**) that reflects the challenges associated with the digital services that people encountered during the online learning sessions. People reported a lack of response or delays in accessing the online platforms due to the poor internet services and the inability of the digital platforms to manage a large number of users (Alhebtali, 2020). These issues did exist, however, considering the emergent and rapidly evolving nature of the pandemic situation and rapid improvements in the internet services and digital platforms, we believe the Saudi government managed the situation very well. This was evident from the two studies carried out by six international organizations that we have mentioned earlier (Saudi National eLearning Center, 2020).

Finally, note that Topics 16, 20, 18, 11, and 13 were excluded from these discussions because these were related to Iraq, Jordan, and Kuwait, and these were not our focus in this study.

DISCUSSION

This paper investigates the use of AI in urban governance as to how AI could help governments learn about urban governance parameters on various subject matters in order for the governments to develop better governance. Saudi Arabia has demonstrated a fine example of good governance during the pandemic in terms of both managing the pandemic and managing education. In terms of managing the pandemic, the government had used good practices from around the world including quarantine, social distancing, closure of public and private facilities to contain the virus, curfew, cleaning services, financial incentives for the public and private sector to keep the economy afloat, and effective return to normal strategy once the infection rate reached a certain low (Alomari et al., 2021a).

We studied governments approach toward education governance during the pandemic by automatically detecting twenty topics related to urban governance of online learning using the LDA algorithm. We merged these topics into ten governance parameters and then structured these ten parameters into four governance macro-parameters, **Strategies and Success Factors**, **Economic Sustainability**, **Accountability**, and **Challenges**. We found that regarding online learning, the government's stance was similar to its approach in managing the pandemic. The government was cautious not to open public facilities that could lead to an increase in the infection rate and therefore schools and universities provided online learning services.

The first macro-parameter **Strategies and Success Factors** touches upon strategies and success factors including developing social sustainability and enhancing educational performance through supporting families, students, teachers, and other stakeholders. In August 2020, before the beginning of the academic year, the Ministry of Education announced that the schools and universities will be online for the first 7 weeks of the first semester and later on decided to continue online learning over the whole Fall Semester of 2020–2021. The Ministry of Education used various strategies for supporting the transition to online learning. It provided free access to lectures through Satellite TV, Internet, exceptional support to equip teachers with the required skills, and access to various digital platforms. The ministry strengthened the family involvement in supporting their children for online learning and arranged some online activities and involved the families in these activities using the online learning platform "Madrasati." The ministry also developed at the school and city levels certain competition exercises among the students to strengthen distance learning, aiming to encourage students, promote hard work, and reduce laziness among them. The government also launched the "Schools Promoting Positive Behavior" program that aimed to nurture positive behavior such as honesty among students, create an institutional environment that stimulates positive behavior to achieve psychological and social compatibility for the student, and emphasize the strengthening of the relationship between the students, schools, the families, and the local communities. The teachers and other stakeholders were commended for their hard work to show them appreciation, create a positive and motivating environment for all, and enhance the overall performance of online learning.

The financial crisis throughout the world due to the COVID-19 pandemic is well-known. For example, in our earlier work where we attempted to public concerns and government measures in Saudi Arabia during the COVID-19 pandemic, we found that many businesses were severely affected due to the COVID-19 related lockdowns causing many people to lose their jobs or their salaries to be reduced (Alomari et al., 2021a). The second macro-parameter reports on new economic opportunities enabled by individuals and SMEs in providing services to fill the service gaps created through the rapid transition of in-class learning to online learning. The economic opportunities include various educational services made available for students and other stakeholders such as teachers and families to facilitate their migration to the online mode of learning. These services are provided by individuals and small businesses including providing tuition and other services to help students with research papers, solving assignments and exams, and designing logos and photos.

The third macro-parameter touches on governance accountability and provides evidence through two studies for the government to have successfully managed the pandemic-induced emergency for transitioning the whole national education delivery system from in-class to online learning. The studies involved 342,000 students and other stakeholders in education and were carried out by international organizations including OLC, ISTE, QM, UNESCO, DETA, IITE, OECD, and Harvard University (Saudi National eLearning Center, 2020). The aim of these studies was to analyze the experiences of online learning during the pandemic and suggesting initiatives for improvements (see Section Results and Findings for details about this evaluation exercise). OLC applauded Saudi Arabia for the diversity of options available to the students and stakeholders including free access to lectures through Satellite TV, Internet, etc. and the speed of response in ensuring a successful transition to online learning.

The fourth macro-parameter touches upon the challenges that the people faced during the online learning period and the government's strategies to manage those challenges. The matter whether the school and university exams during the pandemic should be online or in-class was a major concern for people and was vehemently discussed on Twitter by students, parents, instructors, and others. While some citizens justifiably felt the exams should not be in-person due to health and safety, the universities' view on physical attendance in final exams, under strict physical distancing, also seems to be valid because of the inability of the current eLearning systems to detect cheating during exams and enforce honesty on the students' part. The school timings where classes were scheduled in the mornings and afternoons based on school grades was another issue for parents because it required parents to supervise their kids throughout the day. However, the school timings scheduled by the government had several advantages including sharing of computing and internet resources and allowing senior kids to attend classes in the mornings to allow working parents to carry out their jobs. People also encountered challenges associated with the quality of digital services during the online learning sessions including a lack of response or delays in accessing the online platforms. These issues did exist initially, however, were managed well by the government over some time into the semesters as became evident from the results of the two studies carried out by international organizations that we have mentioned earlier.

Comparing our work with other works in the literature, we are able to make significant contributions to the literature. The differences include in the context, focus, time period, geography, data, language, design, findings, and the particular perspective on the use of AI in urban governance presented in this study. The existing studies on modeling COVID-19 related issues using NLP methods have focused on detecting symptoms of stress due to COVID-19 in the US (Li et al., 2020), detecting government measures and public concerns in Saudi Arabia (Alomari et al., 2021a), investigating the differences in responses to the pandemic between university students and the general public in the US (Duong et al., 2020a), and sentiment analysis of closures of seven types of public and private facilities containing the pandemic in Saudi Arabia (Alhajji et al., 2020) (see Section Literature Review for a detailed literature review). Our work complements significantly to these works as it holistically studies a specific government function (online learning during COVID-19) in greater detail touching upon the success factors, accountability, challenges, social sustainability, and economic sustainability.

The data-driven approach proposed in this paper and the urban governance parameters for online learning during COVID-19 discovered in this work align with the smart cities and urban governance literature in multiple ways. The governance parameters and macro-parameters discovered for online learning in this work align with general urban governance policies, strategies, and methods. These include continuing education via support for online learning, supporting families to help them and their children to adapt to the changing (learning) environments, developing competitions and incentives to achieve (learning) objectives, nurturing positive behavior, commending stakeholders, government allowing or facilitating people to find new economic opportunities, evaluation of government policies, strategies and actions, developing new (exam) procedures to manage the changing environments, developing (school) timings and schedules that are convenient to the public, providing digital services to facilitate the public in performing the desired actions. It is clear that while these parameters are specific to online learning, these broadly fall into the general policies and methods used in urban governance. Secondly, it supports the premise that research and practice in smart cities and urban governance should be driven by data (Liu et al., 2017; Bibri, 2021; Yigitcanlar et al., 2021b) and confirms that digital media including social networks data are important sources of data that could be used for smart urban governance (Barns, 2020; Ahmad et al., 2022; Alahmari et al., 2022; Yigitcanlar et al., 2022).

Governance involves the processes of making and implementing decisions (ESCAP, 2009). The study in this paper and the analysis of the findings have provided vital information about the urban governance decision-making and implementation processes concerning online learning during COVID-19 in Saudi Arabia. Evaluating the urban governance parameters discovered from our case study against widely used characteristics of good governance (ESCAP, 2009), we make the following observations. The Saudi governments' response could be considered exceptional on several good governance metrics including participation, responsiveness, equity and inclusiveness, accountability, responsibility, transparency, and consensus-orientation. The government was efficient and effective in implementing measures that allowed a successful transition to online learning (Saudi National eLearning Center, 2020) without affecting the educational goals while keeping people safe through physical distancing and other pandemic measures (Alomari et al., 2021a) [for example, evidenced by the low number of infections and deaths in the country (Worldometer, 2022)]. The government provided all the citizens access to online learning through free TV lectures (Ministry of Education, 2022; Saudi Ministry of Education, 2022) and other financial incentives (Saudi Ministry of Education, 2020a) that support equity and social sustainability. Several initiatives and programs were devised by the government to nurture responsibility, honesty, and positive behavior among students (Madrastati, 2020; Saudi Ministry of Education, 2020e, Saudi Ministry of Education, 2021b). Noteworthy was also the government's efforts in creating appreciation and harmony among teachers, families, and other stakeholders (Saudi Ministry of Education, 2020b). We did not detect any issues raised by people related to the lack of equity of treatment by the government in providing access to online educational resources. No issues were detected related to lack of food, security, or other basic needs of people. Relatedly, the government provided free COVID-19 treatment and vaccination for all citizens facilitating people to focus on education without worrying about food, healthcare, and vaccinations (Unified National Platform GOV.SA., 2022).

Finally, the case study presented in this paper shows that the use of data-driven AI can help governments learn about public feedback and reactions on government matters, the effectiveness of government policies, strategies, programs, and procedures, the challenges people are facing in adapting to the government measures, new economic, social, or other opportunities arising out of the situation, and so on. These parameters could help the Saudi government to learn about the design and operations space of its various functions and state services and improve these through participatory governance incorporating public and other stakeholders' feedback and consultation. For example, some of the parameters that have touched upon economic sustainability can be used to improve sustainability of economy such as by learning about new economic opportunities from the natural responses and behaviors of people and supporting these opportunities to form into economic instruments, institutions, and outputs specific to pandemic responses or also for normal times. Similarly, governments can learn about better social sustainability instruments from the case study. The case studies can be focused on specific sustainability or other matters. The focused case studies can be enhanced through focused data collection and deeper analytics on the matter under study to develop effective instruments. We did not focus on environmental sustainability in this paper but this could be done by adding filters for data collection. The developed methods can be applied to learn from specific countries, or on a global scale, such as analyzing various governance parameters for countries that have shown success, failure, or poor performance in education, COVID-19, or other sectors to find the best practices and pitfalls. Good governance characteristics can be incorporated into the design of our proposed method, for example in the data collection process to investigate those specific governance characteristics for a specific government service under study. Good governance characteristics can also be included in the design of the proposed method, such that automated comparison and evaluation of a government's services are made against established standards of good governance. The government could use the knowledge gained through this data-driven AI process to develop better urban governance instruments and this whole process could be implemented as a perpetual loop for real-time urban governance with much finer levels of engagement with the public.

CONCLUSIONS AND FUTURE WORK

Data-driven artificial intelligence is becoming so fundamentally ingrained in smart city developments that cities have been called artificially intelligent cities and autonomous cities. AI is helping us increasingly in everything we do and making decisions for us in many spheres of our life. The study in this paper demonstrated that the use of data-driven AI can help governments learn about public feedback on government matters, the effectiveness of government instruments, and the challenges and opportunities arising out of a situation. The method can be applied to learn best practices and pitfalls of government instruments nationally and internationally on any governance matter, to develop new or better instruments (such as for new economic opportunities) and to evaluate governance against international standards.

Moreover, we argue through the case study that the use of AI does not have to necessarily replace humans in urban governance and other decision-making tasks, rather the use of AI, under human supervision, could allow governments to monitor and improve—in real-time and at a much finer level—the effectiveness of government policies, strategies, programs, and procedures in light of continuous feedback from the public and other stakeholders. Many of the functions in urban governance requiring human expertise could be automated using data-driven AI to a large extent and the whole process of urban governance can become more and more autonomous. This automation and autonomy will make humans contribute to higher cognitive levels in the urban governance life cycle using the information provided by AI. How much AI-driven autonomy urban governance would have, would ultimately be determined by us humans. Until humans continue to believe in the superiority of the designer—i.e., we humans—we will manage AI to act autonomously but within a certain bound defined by us. Certainly, it will also depend on political empowerment of masses as opposed to human masses being controlled by a few of them. And if this happens (AI becomes autonomous and controls humans), then it is the fault of humans whose majority feels no or little concern about themselves and they have left their fate to a few among them without any restraints.

Our earlier work on NLP-based social media big data analytics has developed a number of tools and focused on its methodological and computational aspects for various applications. We have looked at distributed machine learning to manage big data (Alomari et al., 2021a), automatic labeling (Alomari et al., 2021b), developing an improved stemmer for Arabic NLP (Alomari et al., 2020a), in application areas including healthcare (Alotaibi et al., 2020), logistics (Suma et al., 2017, 2020), detecting general public concerns during COVID-19 (Alomari et al., 2021a), and government services' analysis (Alsulami and Mehmood, 2018). We plan to extend the case study presented in this paper by improving its breadth and depth in terms of the machine learning methods to enhance its functionality and usability, data and computing scalability, real-time functionality, and the novelty and utilization of its findings in urban governance. The tool currently works for the Arabic language but the broader methods developed in this work are applicable to other languages.

The whole of humanity has faced great trials during this pandemic and this adversity is continuing. The people and governments have shown great resilience during the pandemic and we will come out of it stronger and united. Challenges are part of life and a cause for improvements and innovations. There is no life in this world without challenges and no one is perfect. We believe that these challenges (discovered and reported in this paper) will allow the development of new industries nationally and internationally, providing new opportunities for economic developments and reducing unemployment by creating new jobs. For example, the challenge of online learning and assessments detected in this study creates opportunities for the development of digital systems that provide better online learning and assessment capabilities. The shortcomings in the required quality of internet services and digital platforms in terms of dealing with the QoS (delay, bandwidth, response time, functionalities of the online learning platforms, etc.) also present technological and business development opportunities. Looking into challenges and finding opportunities to accelerate innovation will form another direction of our research.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because data was obtained from Twitter. Restrictions apply to the availability of these data. Requests to access the datasets should be directed to https://twitter.com/.

AUTHOR CONTRIBUTIONS

SA and RM conceived, developed, analyzed, and validated the study. SA developed the software and prepared the initial draft, reviewed, and edited by RM. RM, IK, and EA provided supervision, funds, resources, and contributed to the article editing. All authors contributed to the article and approved the submitted version.

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Urban AI in China: Social control or hyper-capitalist development in the post-smart city?

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Research and wider societal debates has explored the potentially transformative role of AI in extended social control and hyper-capitalist development in China. In this paper, we use those debates to reflect on experiments with Urban AI in China. The key issue is whether AI offers something distinctive or different compared with the logics and imaginaries of ideas of the smart city. Analysis of emblematic sites of urban AI management in the cities of Shanghai and Hangzhou demonstrates: the resonances and dissonances between urban AI and smart. But they also demonstrate distinctive and complex landscape of urban AI experiments that is not neatly captured in social control and free market applications perspectives on AI. Moreover, the urban experimental contexts in which AI is being rolled, reveal aspirations for creating new "digital empires," exploring new limits on data power and potential social resistance. The paper makes a distinctive contribution by providing a new framework for comparing logics of computational urban management in the context of emerging AI applications. As such the paper provides a distinctive framework for situating future applications of urban AI management in China and identifies the future urban research priorities.

KEYWORDS

artificial intelligence, cities, post-smart, social control, computational power

Introduction

Over the last decade, the urban has been a central focus for the application of computational systems most graphically captured in the growth of the smart cities discourse (Hollands, 2008; Vanolo, 2014; Luque-Ayalaand Marvin, 2015; Luque-Ayala and Marvin, 2020; Taylor Buck and While, 2017). A critical literature has traced the various ways in which robotic and computational technology is being used to extend surveillance and control in the city, through new technologies of surveillance, predictive policing and software sorting (Graham, 1998, 2005; Graham and Wood, 2003; Kitchin and Dodge, 2011; Eubanks, 2017). But automation is also being deployed to ease the stresses and strains of urban life, for example through weather forecasting, congestion management and automated environmental control (Luque-Ayala and Marvin, 2016).

Our interest in this paper is to take forward growing interest in the potential of Artificial Intelligence (AI) to vastly extend and perhaps transcend the existing landscapes and possibilities of computational urban management. AI can be defined as the extended capacity for replacing and supplementing human decision making with automated data processing and prediction (Cugurullo, 2020). The possibilities for AI are being extended significantly through advances in AI applications and technologies that rely on AI or generate data that can be used for extended AI applications - drones, facial recognition software, automated traffic management - in the urban context (see Macrorie et al., 2021).

Urban contexts are emerging as key sites for AI experimentation, demonstration and application related to automated management of people, energy and mobility and surveillance (Vander Ark, 2018; Tomer, 2019; Cugurullo, 2020, 2021). However, there has been little critical assessment of the socio-spatial geography of experimentation, the urban challenges being addressed, and the potential consequences for urban life and infrastructures. This paper therefore attempts to understand the emergence of the new urban technological imaginary of Urban AI. Located in a number of different national contexts multiple claims are being made about the potential of AI as a more desirable and effective form of urban decision making – most notably in China and US where national AI priorities are being compared to a new arms race for global economic dominance (Ding, 2018).

The aim of the paper is to examine whether, and if so how, AI represents a distinctive mode of automated urban decision-making. Is AI a distinct - post-smart city - socio-technical logic and is it characterized by an extension of social control or intense hyper-capitalist development? The paper has three objectives. First, to provide an overview of the wider landscape of urban AI experiments, seeking to understand their resonances and dissonances with smart cities discourse in order to better understand their specificity and potential distinctiveness as an urban socio-technical capacity. Second, to understand how AI is becoming urbanized through a case study of the spatial dimensions of China's national AI strategy focuses on two sites with different styles of urban AI development – a commercial logic in Hangzhou and a strategic state exemplar in Shanghai. Third, we compare the cases by highlighting the way in which the cases exemplify a diverse and highly experimental landscape that simultaneously extends social control through AI enabled surveillance and also develops new contexts for urban AI products and services.

The research design for the project was three-fold. First, the paper is informed by a systematic review of key social sciences and urban studies literature related to AI and cities on the internet and *via* Scopus. The review of urban AI was based on web searching key words and put into a database of urban AI initiatives to identify exemplary and emblematic contexts of which China emerged as a key national context for urban AI experimentation. Second, the paper draws on empirical research on the development of urban AI projects in Shanghai - the Shanghai AI urban development zone and Hangzhou - the Alibaba city Brain project through a study visit in 2019 and following up interviews and discussions. These case studies were researched through study visits in Shanghai and Hangzhou, five interviews and a review of primary policy documents. The empirical research also included discussion and dialogue with six experts on smart cities and AI in China, including academics, entrepreneurs and government officials in Chengdu, Nanjing and Beijing. Third, following the study visit interviews were transcribed, key documents translated and empirical material reviewed and analyzed.

The structure of the paper is as follows. Section "China: National AI leadership produces urban experiments" provides a conceptual framework for situating urban AI within the longer history of computational urban management. Section "Experimental urban spaces of AI application in China" interrogates national AI priorities in China and the way in which these are shaping urban AI responses orchestrated through strategic intermediaries. Section "Urban AI: Social control and hyper-capitalist development" compares the two emblematic cases studies of urban AI in Shanghai and Hangzhou assessing the extent to which these constitute a complex landscape of both intensified modes of social control and hyper capitalist development. Finally, section "Conclusions" concludes by summarizing the key findings and identifies the future research priorities for urban AI.

Urban AI: Post-smart city?

There is now a significant and growing literature on "Smart Cities," which explores various aspects of the theory, practice and claims about the potential for improved urban management through the application of digital and computational technologies (Hollands, 2008; Vanolo, 2014; Luque-Ayalaand Marvin, 2015; Taylor Buck and While, 2017; Barns, 2020). Although its lineage reflects a much longer history of computationally assisted urbanism and cybernetics, the smart city imaginary is grounded in advances in computational and digital power, including the increased automation of key aspects of urban management to transcend the limitations of human management. Much of the recent work on smart cities has been critical of the promissory claims for smart cities made by firms and governments. However, a wider body of work on the computational reworking of cities has raised concerns about issues of power and control *via* predictive techniques, "software sorting," the city as a site for mass surveillance and the selective enhancement of urban infrastructure (Graham, 1998, 2005; Graham and Wood, 2003; Kitchin and Dodge, 2011; Eubanks, 2017; Caprotti et al., 2017; Barns, 2021).

Research and policy interest in the computational restructuring of urban management has now also focused on the technological possibilities and potential of AI. While AI can be defined in many ways in our paper AI represents the increased potential for automated and robotic applications that can undertake functions and/or solve problems commonly associated with human intelligence, such as learning, problem solving and pattern recognition (Marr, 2018; Bratton, 2021). A distinction might be made between the application of AI in different contexts of application, for example, the AI that enables robotic autonomy is different from the application of AI to sift through different types of data, or AI that is used to monitor and highlight "unusual" human movement, or AI that is used to predict behavior. From an urban management perspective, what is important is the potential of AI (i) to sift and process a larger amount of data much faster and more efficiently than any human system; and/or (ii) for AI to make complex decisions autonomously or semi-autonomously of human control. In short, AI allows for a vastly extended reach of computational power and automated control in urban management that cuts across infrastructure management (energy grids, traffic and pedestrian management) and policing (surveillance and tracking, traffic and pedestrian control, monitoring of social media use) (Vander Ark, 2018).

Much of the popular preoccupation of AI is with the idea of totally automated decision-making and autonomous systems outside of human control. Yet the interesting political questions about the use of AI are instead focused on the appropriate boundaries between "blended" forms of AI and human decision-making. Rather than total autonomy or total human decision-making the questions are instead at what point and in what circumstances should humans be brought into the decision-making process. It becomes critical to understand the variables and priorities that are used to inform AI applications and decisions and those the aspects of human activity and decision making that are controlled, triggered, augmented or displaced by AI. As with all forms of technology, the enhanced computational power of AI can be mobilized for social benefit or to enhance power and control. There are certainly major concerns about the potential for vastly enhanced forms of social control and the development of more nuanced automated mechanisms for controlling access to infrastructure and services and rewarding and disciplining aspects of human behavior *via* AI enabled techniques.

Urban AI technologies make significant demands on data provision, monitoring technology and application contexts. In its initial phase, AI will largely make use of existing data sources and infrastructures of data collection provided by the smart city. But the extended computational potential of AI is capable of managing enhanced data collection and monitoring. This is likely to be facilitated by the development of data gathering, monitoring, tracking and policing technology that relies on AI for extended functionality - sensors, cameras, tracking *via* mobile phones and cashless payment systems, the use of drones. Yet the technology has to be tested and developed in real world contexts to understand its feasibilities, limits and opportunities. Effective AI applications will co-evolve with infrastructures of data collection, tracking and monitoring these are often expensive to implement and operate, relying for example on significant energy inputs. AI technologies also raise significant concerns about privacy and safety that will need to be negotiated in urban contexts and with national governments and regulators.

In summary, urban AI may offer a way of automating urban decision making either by displacing humans from routine monitoring tasks or more rapidly and accurately substituting for human decision making. The critical questions then are what is distinctive about the functionalities and capabilities of AI that separates it from the smart city, why might AI be applied in the urban domain, and what happens to AI as it becomes embedded in existing social and technological arrangements within the urban context.

China: National AI leadership produces urban experiments

AI extends the smart cities logic that computational applications can solve a range of urban problems through enhanced decision making and monitoring/control. However new urban AI applications are likely to require substantial upfront investment in data processing capacity and monitoring infrastructure and also significant investment of time and resource in the recalibration of urban services - policing, traffic management - around urban AI management. In China three factors are converging to generate a particular interest in the possibilities for investment in urban AI.

First, the development of AI is now major part of national state strategy in China reflecting the economic potential of AI and China's advantages in AI research and application.

> "By 2030, China seeks to become the world's ***primary*** AI innovation centre, with a core AI industry gross output exceeding RMB 1 trillion (USD 150.8 billion) and AI-related gross output exceeding RMB 10 trillion (USD 1.5 trillion)." (State Council of the People's Republic of China, 2017)

Governments and leading tech firms in China are developing and extending the country's role as a leader in AI (Fischer, 2018; Dempsey, 2019; Roberts et al., 2021). Chinese firms such as Alibaba, Tencent, Baidu and Alibaba's fintech affiliate Ant Financial are now well represented in lists of the world's leading internet firms (Ding, 2018). *Urban* AI is not necessarily a major element of national R&D in AI technology and applications, but cities (and the things that happen in cities) are important for AI application and the market for specific urban AI applications is significant in its own right.

Second, the speed, complexity and challenges of urban growth in China might be expected to generate considerable interest from governments and cities in urban AI applications. The story of China's fast urban expansion is well-known. Rapid urbanization has given way to an emphasis on growth management as cities seek to maintain economic competitiveness whilst addressing pressing problems of congestion and pollution (Mee Kam Ng, 2019). Simply moving large numbers of people around and supporting ways of living at high density are significant challenges in many Chinese cities. There is intense competition between Chinese cities for skilled workers and inward investment. For many of those cities, the second wave of growth is about reconciling high density living with quality of life, environmental quality and reduced journey times. Chinese governments have become increasingly interested in the potential of smart city technologies to address urban challenges (Caprotti et al., 2017).

Third, the extended monitoring and control functions of urban AI resonate with the broader and distinctive digitalization of Chinese society through the development of the platform economy (Chen, 2020). China is now one of the leading cashless countries through two main mobile and online payment platforms, Alibaba's Alipay and Tencent's WeChat Pay (Lee, 2018, pp. 57–61). Moreover, as part of wider strategies of social management there is widespread monitoring of population movement across China, which is being further extended through the ubiquitous use of the integrated WeChat and Alibaba platforms and extensive use of CCTV and facial recognition software in cities. As Ding (2018) suggests, the hardware and software for data harvesting gives China a potential 'data advantage' for AI, generating large volumes of data that can underpin AI applications (and can only be utilized fully through AI applications). In turn, AI technology opens up new possibilities for citizen monitoring and management, stimulating investment in technologies for generating new urban data (notably extended and higher resolution facial and movement recognition). China is recognized as the global leader in facial recognition algorithms (Liu, 2018) with a large pool of talent and expertise (Ding, 2018). However, as Ding (2018) points out, the potential data advantage is not necessarily reflected in reality because of organizational fragmentation within the large firms. Ding argues that 'economic benefits' are the primary driving force behind both the major public and private Chinese actors in AI, but social and political priorities are also significant in driving the application of AI in China.

Within that context, a key dimension of the Chinese urban AI nexus is the potential for different urban trajectories in urban AI application and development. Although there is strong central government management of urban development and R&D priorities, leading cities now have significant autonomy in urban management and development strategies. Indeed, there is growing inter-urban competition in China for higher value firms and workers and urban government officials have strong incentives to find innovative solutions. Moreover, as Ding (2018) points out, "China is not a monolithic actor" in high tech and that "matters when it comes to AI." National and municipal governments are important actors alongside private companies, state owner companies, mixed ownership companies and the People's Liberation Army. Leading high tech cities such as Shenzhen, Hangzhou, Shanghai, Guangzhou and Beijing have distinctive AI R&D milieus which could provide the basis for place-specific interests approaches in using cities as demonstrators and test beds for new technology - and also spatial variations in technology specialisms and expertise. Companies have particular attachments with their cities, with national AI aspirations underpinned by geographical variation and intense competition between cities to attract and retain high-tech firms and skilled graduates.

Experimental urban spaces of AI application in China

Research on the application of AI in urban contexts has been largely speculative because it has been difficult to find explicit "urban" AI projects. Variants of machine learning, automation and AI are increasingly used in computational work and data analysis that impact on cities, but experiments in the automation of urban infrastructure have been limited. In the following sections, we examine two notable urban AI experimental initiatives from China—the Hangzhou City Brain project and the AI development zone initiative in Shanghai—through which government and/or private interests are scoping out the potential for urban AI. Each case is structured through: a review of the specific origins of urban experimentation; an assessment of the role of urban authorities and the use of the context as an experimental site; and, the wider consequences and implications of the experiment both within and outside the urban context.

Shanghai – The infrastructure for an urban AI test bed

Shanghai is positioned as one of China's most emblematic urban test-beds for the development, production and utilization of AI technologies. In May 2019, Shanghai was approved by China's Ministry of Science and Technology (MST) as a National Pilot Zone for Innovative Development of New-generation AI - Shanghai AI Development Zone - the second of its kind in the country after Beijing (Wang, 2019; Xinhua, 2019). The Shanghai AI (SAI) initiative has a distinctive urban dimension designed to transform the city's economy, public services and develop new modes of management (Municipal Commission of Economy Informatization, Shanghai, 2019). Shanghai's status as national urban AI test bed was a result of interplay between multiple socio-political and spatial priorities.

First, as a national priority, the formation of the AI pilot zones needs to be placed within China's all-of-nation strategy of being the global leader in AI fundamental theories, technologies and applications by 2030. State Council of the People's Republic of China (2017) suggested that selected pilot zones should be set up as models for others to follow. MST stated:

> Shanghai AI Development Pilot Zone will focus on in-depth integration of AI technology and socioeconomic development, exploring new mechanism and approaches to development of new-generation AI. Shanghai should gain experience from AI experimentation, shaping an AI growth model that can be spread and replicated nationwide. Shanghai's AI initiative will play a significant role in shaping a global influential sci-tech innovation hub, and advancing the integrated development of Yangtze River Delta (MST, 2019).

The Shanghai AI Development Zone also had a strong urban dimension in compliance with China's "new-type urbanization plan" (State Council of the People's Republic of China, 2014), which placed a high priority on technologically upgrading the economies of three mega-city clusters, namely, Yangtze River Delta (YRD), Pearl River Delta, and Beijing-Tianjin-Hebei region. Located geographically at the heart of the Yangtze River, Shanghai was widely viewed as a strong economic engine of growth in the YRD urban agglomeration (China Development Research Foundation, 2019). In this sense, the Shanghai AI initiative was becoming strategically significant as part of China's new urbanization strategy. Shanghai was becoming a national global center for AI entrepreneurs, skilled workers and venture capital investment. By the end of 2018, the city hosted more than one third of China's AI scientists and engineers, and thousands of tech companies specializing in, or partially engaging with, AI hardware and software service, ranging from chip makers to computer vision technology and venture capital firms actively involved in deals related to financing AI industries (AI Era, 2019; International Talent, 2019). Shanghai demonstrated its potential by attracting new AI labs affiliated to Baidu, Microsoft, IBM, Alibaba and other major IT tech companies, and further turning AI innovations into commercial products for wide use in domains such as autonomous vehicles, facial recognition cameras, and smart speakers.

Second, the municipal government was one of the early adopters of AI for its internal operations, which was arguably a key factor driving urban AI development. In its *Shanghai Master Plan (2017–2035)*, the Shanghai city government set out the vision of transforming Shanghai into a sci-tech innovation hub (Urban Planning Land Resource Administration Bureau, Shanghai, 2018). In 2017, Shanghai issued an *Opinion on Facilitating Implementation of New-generation AI Development*, the city's first AI policy document, that marked the municipality's effort to launch large scale urban AI experimentation. The *Opinion* set out the 2020 targets of 'forming 60 real-life contexts with AI applications, building five leading AI industrial clusters, and expanding the city's scale of AI industry to more than 100 billion yuan (Shanghai City Government, 2017). The *Opinion* prioritized the adoption of AI in the "optimization of the urban operating system," in order:

> "to improve intelligent sensing and data collection mechanisms, thus upgrading the urban management capabilities in security, environment, and infrastructure; to enhance the application of image and biometric recognition technology to society management and the mass surveillance system, thus boosting the city's intelligent capabilities in security control". (2017 no page)

In 2018, in a more detailed delivery document *Implementation Measures for Accelerating High-Quality Development of AI* (Municipal Commission of Economy Informatization, Shanghai, 2018), the municipality put forward 22 specific policies designed to import high-end international AI talent, set up the Shanghai Municipal Big Data Center to integrate data across the city's different government departments for utilization by AI companies, and provide financial support for core AI technologies and AI companies (Municipal Commission of Economy Informatization, Shanghai, 2018). Additionally, in 2019, the municipal authorities set up an AI development fund worth 100 billion yuan ($14.78 billion).

Finally, the city's recent initiative has focused on providing both the funding and 'real-world' contexts for AI companies in China and from abroad to live-test their technologies and products in the urban context. A total of 40 social and business settings – involving schools, hospitals, government services, living communities, foreign exchange centers, parking lots, metros, trash sorting, farming – were made available for AI applications (Sun, 2019). The city government would fund and provide access to the context for firms to develop and demonstrate live applications. There is a notable absence of key governmental priorities in this strategy in relation to the purpose of AI applications. Instead the logic is simply to experiment – and presumably to learn about the potential of these systems to automate services and substitute AI for human decision making of both routine and specialist functions.

A notable example of this will to experiment with AI applications is in the waste sector. Increasing solid waste flows and an increasing emphasis on resource recovery have stimulated AI applications to develop more sustainable forms of waste management (Abdallah et al., 2020). A new mandatory trash-sorting rule was introduced in Shanghai with the aim of increasing levels of recycling to 35%. The challenge of sorting waste into 4 categories initially prompted multiple complaints from citizens about the challenges involved in complying. In response dozens of AI bins capable of automatically distinguishing 95% of waste items from "recyclable" to "compostable" were put to the test on AIsland of the Pudong AI Application Zone (Lin, 2019). Waste bins automatically classified deposited trash into four categories and then collection

FIGURE 1
A real-time image captured by AI chip-embedded surveillance cameras.

vehicles automatically identified the appropriate bins and processed them accordingly. The waste was then transported to temporary transfer stations by driverless vehicles, and robots then sorted out recycled or hazardous items before sending them to different end points for processing. The experiment, jointly enabled by national and city government and AI companies, explored a possible trajectory for an AI-enabled operating waste system. This produced an experimental mode of automated waste management used driverless vehicles, image recognition cameras and robotics to autonomously monitor, collect, transport, recycle, dispose of waste without – apparently - the intervention of humans. However, this pilot system needs to be viewed as part of a much wider experimental landscape of technical and social measures designed to promote waste sorting (see Li and Wang, 2021). Yet the urban AI can also be used to control humans (see Figure 1). Shanghai uses AI to autonomously identify lawbreakers, jaywalkers, and other criminal suspects. This is reflected in trial installments of facial recognition cameras in the Shanghai Bund and some of the city's metro stations for the aim of ensuring urban security.

Hangzhou City Brain: A commercial urban AI operating system

Hangzhou is headquarters to Alibaba, China's most valuable technology company and a leading provider of cloud computing power (Brandz, 2019), and three of China's largest providers of AI enabled video surveillance equipment (Hikvision, Dahua and Uniview) (Dai, 2019). The city is ranked along with Beijing, Shenzhen, and Shanghai in 'the top tier with the combination of AI and urban development' (Deloitte China, 2019, p. 15), but has had far less state support than other leading Chinese cities. Hangzhou's configuration as an urban test bed for AI applications, notably in its urban traffic management and public security, hinges largely on the technological affordances of Alibaba Cloud's ET (meaning "extreme technology") City Brain and the city's booming surveillance technology market (Curran and Smart, 2021; Caprotti and Liu, 2022).

First, initially applied to Hangzhou's Xiaoshan district in 2016, the ET City Brain project was carried out by Alibaba Cloud (AliCloud) – a subsidiary of Alibaba Group – in collaboration with the Hangzhou government with the initial the aim of easing road congestion. City Brain aggregated data from multiple sources, such as video cameras installed at road intersections, real-time GPS locations of cars sent from mobile mapping apps, and traffic police's social media feeds (Alibaba Cloud, 2018a). Powered by AI technologies and its large-scale cloud platform Apsara, City Brain is said to have the capacity for analyzing a huge amount of heterogeneous data and come up with real-time solutions for road transportation, like automatically adjusting traffic signals to allow emergency vehicles to travel through the city without interruption, or identifying vehicle breakdowns through image recognition technologies.

The critical factor contributing to Hangzhou's urban AI trials was the ready availability of sufficient AI-powered surveillance equipment, driven by the overlapped interests of local companies and the central government's priority in managing public security. Hangzhou is also known as a center for surveillance technology firms for instance the Binjiang district in Hangzhou is famed for its AI-assisted surveillance camera industry, as it is home to Hikvision, Dahua and Uniview. The three companies' combined revenues accounted for 30% of the global video surveillance sales, while more than half of China's video camera market shares is supplied by Hikvision and Dahua (IHS Markit, 2017). These local companies laid a technological foundation for Hangzhou to be extensively equipped with AI cameras, which can automatically track a vehicle, recognize a person or spot a criminal suspect through gait or face recognition techniques (see Figure 2). After a two-year pilot run Hangzhou saw its ranking on the list of China's most congested cities drop from 5th place in 2016 to 57th in 2018 according to data provided by Alibaba-owned digital map AutoNavi (Hsu, 2018, n.p.). Alibaba Cloud said its ET City Brain has increased people's traveling speed by 15% in Xiaoshan district, and halved the amount of time it took ambulances and fire trucks to get to the scene of emergencies [Alibaba Cloud, (n.d.)].

Second, in 2018, an updated version of "ET City Brain 2.0" was jointly launched by AliCloud and the Hangzhou government, demonstrating the effort of multiple-party interests to create a new metropolitan wide control infrastructure for the city. The new version was designed to monitor and control the city's traffic at a larger scale (see Figure 3). In addition, the cloud platform extended its actionable data insights beyond the traffic management to the city's fire rescue system, by identifying fire emergencies, flashing green lights for fire trucks, and providing

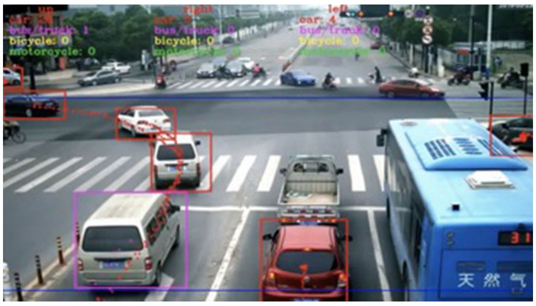

FIGURE 2
Screen shot of AI enabled CCTV camera screen.

FIGURE 3
City Brain control room Hangzhou.

real-time information for fire fighters through IoT sensors, trans-department data integration, and video footage (Alibaba Cloud, 2018b). In Hangzhou, the City Brain has extended its intervention from the initial scope of transportation to city management and government service areas, such as public security, fire control, health care, and tourism, as evidenced by its continuously updated versions (Xu, 2018). Hangzhou's City Brain pilot project has supported AliCloud's position in rolling out AI-embedded smart cities in other contexts.

Finally, in 2017, Alibaba was named alongside Baidu, Tencent – collectively known as BAT – and voice recognition specialist iFlytek as the first tranche of China's national technological leaders in boosting AI development (Meng and Dai, 2017). In the case of Alibaba, the Chinese government suggested its AliCloud subsidiary leverage its "City Brain" cloud computing capabilities to build an open innovation platform, thereby providing AI solutions for urban development. ET City Brain then became a core part of its ambition to create an all-encompassing "ultra-intelligent" agent for the city, because in addition the company also started working on Medical Brain, Environmental Brain, Industrial Brain, Aviation Brain, Sport Brain, and Financial Brain (Alibaba Cloud, 2018c). According to Min Wanli, then Chief Scientist of Machine Intelligence at Alibaba Cloud, the ET brain is "an ultra-intelligent platform capable of multi-dimensional perception, real-time analytic insights, optimization of overall performance, and continuous evolution" (Min, 2018). The premise of Min's argument was Alibaba Cloud's ultra-strong machine-learning and real-time visual computing capabilities, which can help connect, extract meaningful values from a huge amount of heterogeneous data (Zhang et al., 2019) could be applied in other domains.

Subsequently, the City Brain project was soon introduced to more than 10 other cities in a company-government collaborative model, including Xiongan – a brand new city of national significance for performing Beijing's non-capital functions, Macau – Alibaba's first smart city market outside mainland China, and Kuala Lumpur – the capital of Malaysia. The City Brain had wider resonance with the Chinese market for surveillance equipment – in particular, the deep learning-enabled video surveillance while "city surveillance is the largest end-user industry" in China (IHS Markit, 2018, p. 9). This huge investment in video-controlled cities needs to be understood from a broader socio-political context, wherein the government's Xueliang Project became a booster. With its name deriving from a Mao-era idiom that "the masses have sharp eyes," the Xueliang Project was launched in 2016 as part of the country's Skynet national security network. By installing surveillance cameras in cities, towns and villages, the project was designed to establish a comprehensive video data-sharing network to guard against potential terrorists and criminals. Given the rise in China's AI innovations and cloud computing, the public surveillance cameras enabled with AI were in widespread use.

Urban AI: Social control and hyper-capitalist development

Chinese aspirations for global leadership in AI provide an active context for urban responses. State and private sector prioritization in AI technologies has created a context in which significant resources and capacity can be mobilized at the urban level to undertake AI experimentation. There are, however, important differences in the urban landscape of experimentation within China and potentially different trajectories for the AI in the future focused on combinations of social control and market competition. This evidenced through three areas of tension:

First, there are tensions in Chinese urban AI policy between state security and corporate priorities. While historically Chinese state sponsored digital megaprojects have been primarily focused on ensuring internal control and external military security this is not solely the case with the AI programme (Ho, 2018; Horowitz et al., 2018; Keane and Hu, 2019). Chinese state owned and private corporate interests are strongly represented in initiatives that target the development of building internal leadership in key AI technologies. Research needs to recognize that urban AI is likely to represent both these agendas with the cases illustrating logics of social control through security, surveillance and AI enabled facial recognition which co-exist with strategies designed to develop new products and services and establish these as internationally competitive platforms to complete with US dominance in urban platform technologies. These dual priorities are closely reflected in the case studies we have considered above where find logics of enhanced social control and market development. Shanghai provides evidence of a state sponsored test-bed that involves the development of AI initiatives designed to enhanced social control and develop new commercial priorities. Recognizing the significant business opportunity for AI control systems, Alibaba has since sought to market City Brain as platform for its wider urban functionality in different contexts with cities able to pick and mix from different functions depending on their priorities and budget. Further iterations of the system have been developed and more than 10 urban municipalities have purchased the programme in China. These products also contain the potential for intensified commercial control. Consequently, there is a need to recognize the dual processes involved in urban AI development and its inherent overlaps and tensions between commercial and military domains. The movement across these domains and their translation into urban applications has been central to the development of smart cities in the West (Marvin and Luque-Ayala, 2017). Further work needs to be undertaken on the dynamics of these processes of transmutation in the Chinese context (see Luque-Ayala and Marvin, 2020).

Second, there are tensions between central direction and fragmented implementation. There is a tendency to overstate the degree of state direction and control in the social organization of Chinese megaprojects (Ding, 2018). While the national priorities and funding are set centrally our cases demonstrate that there is considerable diversity in how urban municipalities and their wider city-regions respond to these opportunities (Horowitz et al., 2018). National AI priorities are reworked through particular forms of place based partnership and through contextual urban priorities to produce specific experimental configurations and applications. In the case of Hangzhou, a coalition was developed between local government and the locally embedded digital corporate Alibaba *via* an application created to address issues with heavily congested highway networks. In contrast Shanghai was positioned as a national exemplar, alongside Beijing, and with its much more significantly well-resourced programme was able to use the programme to position the city-region as national test-bed for Chinese companies, attract local talent and also incentivise west tech companies to established AI research centers in Shanghai. This is designed to be part of a wider strategy to diverse the Greater Shanghai area economic structure. In both contexts, there is a much more varied and diverse programme of AI experimentation in which urban authorities have differing degrees of autonomy to set priorities and form partnerships.

Finally, it is therefore by no means inevitable that the national strategies priorities will be realized in practice. The aspirations to build a "digital empire" utilizing Chinese AI platforms outside China (Keane and Hu, 2019) that can compete with incumbent platforms is challenging. To date only the City Brain product has only found one other context for application outside China in Kuala Lumpa the capital of Malaysia. Within China the 996 movement has campaigned against long hours and exploitative working conditions in the technology sector. Online digital resistance to the priorities and activities of urban and regional government – but rarely the central party – is used to gauge levels of dissent and used by the state to modify central messaging. In the Chinese context extended AI applications are so far justified that they are needed to help manage the difficulties created by the movement of large numbers of people in dense urban contexts, but the national embracing of AI may raise unintended consequences and contradictions that are difficult to anticipate and control. AI roll out is subject to multiple contingencies that go beyond the potential for citizen resistance, including: the energy costs and capacity needed to process data, the staff costs required to act on information provided, and the on-going task of defining what sorts of data and AI might be useful and for what purposes.

Conclusions

The paper highlights considerable political and financial investment in the hardware and software of urban AI in China. There are a range of interests and priorities in the 'national' AI initiative, including the potential to use AI for internal social control, the potential for external military and political control, the search for profit by firms and entrepreneurs, and intense competition to establish the technology for future tech platforms that can be applied outside China. While commentators and critics have the rise of AI as part of an authoritarian state project (Feldstein, 2019) others have linked it to a distinctive logic of hyper-capitalist development in China (Keane and Hu, 2019). Both perspectives have perhaps overstated the coherence of the national AI project in China. There is not necessarily any singular logic to the "national" AI development push, and that becomes particularly the case for AI applications in urban contexts (see Horowitz et al., 2018). In effect, AI is being taken forward through a trial and error process of experimentation around particular sites of intervention – which involves the urban context – to address both security and economic priorities. The national innovation system for AI in China is multiple, dispersed and fragmented, consisting of a large number of actors and stakeholders whose interests might conflict, coincide and coalesce. The key dimension of that complexity is the relationship between different central agencies (the Army, government) and cities as sites of distinctive clusters of semi-autonomous AI technology and also as sites of application and experimentation.

Further research needs to unpack the dynamics of this landscape of urban AI experimentation. We suggest three research priorities that are of critical importance in understanding the distinctiveness of urban AI as a mode of urban governance. The first is the need to understand the ***specific genealogies of AI*** before they are transmuted into urban context. AI has more diverse origins beyond the computational sector, including in advanced manufacturing, automated logistics, automation of aviation, military and defense robotics. It is necessary for urbanists to unpack the ways in which operational logics, rationalities and modes of organization from existing contexts where AI and robotics are already applied might shape their transmutation into urban contexts (Luque-Ayala and Marvin, 2020). These histories are critically important for revealing the controversies, glitches and tensions associated with the prior use of AI systems. Fundamentally this raises wider questions about who owns AI technologies, whether this then creates new opportunities for private involvement in urban development and crucially how can urban authorities govern the roll pout of AI systems. The second research priority is to focus on teasing out the techno-spatial ***distinctiveness of urban AI systems*** and the ways in which they are inserted into an already highly technicised urban context (Macrorie et al., 2021). While urban AI applications build on the data structures, computational and digital systems they also seek to extend these in novel ways through new enhanced functional capacities. Key to this is the ability not solely to generate new ways of knowing the urban but also to provide the capacity for enabling novel forms of machine-mediated action in urban life. This requires engagement with the ways in which AI enables modes of automated decision-making that exceed the cognitive capacity of humans and how AI enables material and physical action(s), whether this is in the form of AVs, drones, delivery robots, the repair of infrastructure, or other actions. Research will need to focus on the different spaces AI occupy whether constituted as metropolitan wide platforms or selectively incorporated into highly specific products or services in a highly distributed manner. The third research priority is to interrogate the ***ambivalent logic*** of urban AI. On the one hand the promise of AI is that it provides more accurate, efficient, error free and rapid decision making but on the other there are clearly risks of social control and deepening inequalities. While at their inception new technologies are often associated with utopian imaginaries these progressive social and environmental potential are often marginalized when constituted as private liberalized services. The question then is whether and how urban authorities can develop the knowledge and capacity to shape the trajectory of urban AI application in order to capture and promote wider social and environmental benefits that support strategic urban priorities. National state sponsored programmes of urban AI experimentation provide an important context in which learning about the potential and limits of AI can take place. Critically it is important that urban research capacity is developed and deployed comparatively to understand the ways in which urban life is being reshaped.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Author contributions

SM and AW applied for funding, structured the paper and led writing of conceptual, analytical sections, and conclusion. BC and MK led writing of the case studies. BC led in setting up of site visits. All authors undertook relevant see visits and agree to be accountable for the content of the work.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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No city on the horizon: Autonomous cars, artificial intelligence, and the absence of urbanism

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In this perspective piece we use a case study of Phoenix (Arizona) to explore the ways in which the implementation of autonomous vehicle technology is tied to the political economy of the city. We highlight the potential urban benefits that can stem from the use of autonomous vehicles, while also bringing to the fore the necessity of governance in realizing these same benefits. By using Phoenix as a case study, we illustrate the dissonance that exists between policymakers within government and the future urban imaginaries that are used as reasons to justify Phoenix as a test ground. By viewing the position of stakeholders within industry and within government we address the individual and political gains that adoption of such technology can bring on an inter-state competitive level. These dynamics of market competition, combined with a lack of proactive engagement in urban planning show that the potential urban benefits that can be brought on by the autonomous vehicle are left solely to the imagination.

KEYWORDS

artificial intelligence, autonomous vehicle, urban governance, Phoenix (Arizona), Waymo, cities, urbanism

Introduction: Autonomous cars inside/outside the city

This paper seeks to put forward a narrative to provide insight to both academics and policymakers regarding the wider forces that are at play in the autonomous vehicle (AV) implementation taking place in Phoenix (Arizona). The city of Phoenix has been chosen as AVs are currently a fully operational service available to the public within areas of the city. The goal of this paper is to contribute to a dialogue regarding the importance of proactive cooperation between drivers of technology and urban policymakers. AVs driven by artificial intelligence (AI) keep gaining traction. Their growing popularity can be observed through three key dimensions. First, in existing urban spaces where AVs are being tested in real-life environments, thereby becoming part of the transport portfolio of cities and their road infrastructure (Dowling and McGuirk, 2020; Acheampong et al., 2021). Second, in the scientific literature where, particularly in the fields of computer science and engineering, the AV is being hailed as a revolutionary urban technology capable of significantly improving the efficiency and sustainability of cities' transport system (Guériau et al., 2020; Deveci et al., 2021). Third, in the realm of policy where we see many countries, such as the Netherlands, US, UK, China and Singapore, implementing agendas to accelerate the diffusion of AVs (see, for instance, Government of the Netherlands, 2021).

Underpinning these three dimensions, there is one common narrative: AVs are good for cities. While this is a disputed topic, it remains the predominant narrative that is seen in relation to the implementation of AV technology. Many computer scientists, engineers, urbanists and planners argue that the city can benefit from the AV in several ways. In terms of traffic flows, for example, it has been estimated that a single shared AV can replace up to 11 conventional cars and four taxis, thus reducing the total amount of vehicles in transit (Fagnant and Kockelman, 2018; Guériau et al., 2020). From a planning perspective, urban scholars point out that such reduction offers a unique chance to redesign cities in a less car-centric way, decreasing the space currently reserved for vehicles lanes, junctions and parking spaces, in favor of public spaces, urban gardens and cycling infrastructure (Duarte and Ratti, 2018; Cugurullo et al., 2021). Similar optimistic perspectives echo in policy. The transfer of driving functions from humans to AI is often depicted by policymakers as an unparalleled opportunity to liberate cities from traffic jams. As the Government of the United Kingdom (2020, p. 2) succinctly puts it, one of the AVs potential benefits is "to call an end to urban congestion." Moreover, AVs are portrayed by policymakers as lifesavers that, by removing human error from the driving equation, can save thousands of lives and improve urban mobility. Emblematic is the position of the United States Department of Transportation (2022, p. 2) which claims that "by eliminating poor human choices while driving, AV technology has enormous potential to save lives."

What these urban visions and related discourses suggest is that the AV is *inside* the city. Not simply in material terms as a physical object traversing urban spaces, but also as a technology that is being consciously integrated by policymakers and planners into the built environment, in order to benefit cities. In this perspective article we seek to counter this narrative, by showing that in reality, AVs are often outside urban agendas (McCarroll and Cugurullo, 2022). We discuss the case of Phoenix (Arizona), a prominent testbed for autonomous urban transport experimentation, to demonstrate that, despite the substantial presence of AVs in the city, their diffusion is not connected to urbanistic initiatives related to urban transport systems, road infrastructure, land-use and road safety, but rather to national and international political economies that are largely disconnected from the metabolism of individual cities. As such, highlighting that without the proactive engagement of urban governance the above-mentioned potential benefits of AVs will remain potential and not manifest themselves into the tangible reality of the urban environment. We use the concept of a lack of urbanism to highlight this disengagement between technology and urban governance in the case of the AV. Leading to a state of inertia within the urban environment where AVs are shown as a solution to urban problems, yet without the governance needed to facilitate these solutions their benefits remain unattainable.

Inside Phoenix

The city of Phoenix has emerged as a key location in the training and early stage implementation of AVs. With Waymo now offering the Waymo One ride-hailing service to the public. The Waymo One service is an on demand ride hail where the customer uses their smartphone to call a vehicle to their current location. The vehicle will bring them to their chosen destination. The service itself is fully autonomous, meaning that there is no safety driver present. The service is currently available within the subregions of Tempe, Mesa, and Chandler. While this service is currently operational in Phoenix, Waymo is already beginning the scaling process into other US cities such as San Francisco and Los Angeles (Singh and Saini, 2021). When first exploring reasons as to why an AV company may choose a city, Phoenix seems to be a logical choice. The topography of the area is flat, allowing for a rigid grid system of roads to have been put in place. The climate of the region is also very dry, having on average 300 days of sunshine per year. Such dry conditions are beneficial for early stage AV training, as rain can often create difficulties for the sensor suites used to perceive the road and surrounding environment (Zang et al., 2019). These factors combine to make Phoenix suitable for early stage AV use as there are fewer obstacles in the form of adverse weather conditions, difficult road patterns and edge case scenarios such as cyclists. Upon initial inspection this would seem an appropriate place for AV testing. However, the choice to use Phoenix as a test ground did not develop so clearly.

Former governor of Arizona Doug Ducey signed an executive order in 2015 which vastly decreased regulation on the testing and implementation of AV pilot programs in the state of Arizona. The primary goal of the executive order was to "undertake any necessary steps to support the testing and operation of self-driving vehicles on public roads within Arizona" (State of Arizona, 2015). Accompanying this executive order was the formation of a committee within the Arizona Department of Transportation whose goal was to advise how best to advance the testing and operation of AVs on public roads. This step solidified Arizona as the US state with the most favorable conditions, both physical environment wise and policy wise for the testing and introduction of AVs. With such steps taken to facilitate Waymo, Arizona is creating a welcoming regulatory environment for global multinational technology corporations to actively engage in reshaping urban space. As stated in the 2015 executive order by former Governor Ducey (cited in Dandazzo, 2017), "the state believes that the development of self-driving vehicle technology will promote economic growth, bring new jobs, provide research opportunities for the state's academic institutions and their students and faculty, and allow the state to host the emergence of new technologies."

Phoenix is an example of a city that thrived in the post war period. As Shermer (2015, p. 59) notes, "by the mid-1940s, they had already tentatively moved past voluntarism to take advantage of but also stymie the liberal regulatory state. In the process, they had completed much of the ideological groundwork for a homegrown neo-liberalism that embraced government power to free industrialists from regulation and taxation." A practice that is still visible in former governor Ducey's decision making. Due to increased internal migration, the population of Phoenix has been steadily expanding since the 1990s. Combined with cheap cost of land compared to neighboring states, Phoenix has grown as a rapid urban sprawl (Heim, 2001; Torrens, 2006; Guhathakurta and Stimson, 2007). With these urban issues clearly identifiable in the academic literature, it is easy to assume that committees formed to aid in the dissemination of AVs would indeed be linked to urban design and planning bodies. Such links would aid in realizing the potential benefits of mobility technology in the urban environment, in a way akin to what the scientific literature discussed in the previous section suggests: reducing traffic congestion, preventing car accidents, decreasing car ownership and redesigning urban spaces in a less car-centric manner. While such initiatives may seem like an obvious step for policymakers, the role of the committee is clear and narrow in its focus which is not urbanistic in nature. It seeks to eliminate all potential barriers in the way of this emerging technology. In contrast with neighboring states there are no legal requirements on AV companies to report their findings such as disconnection data. There are also no legal requirements on AV companies to have their vehicles registered in the state of Arizona (MacDonald-Evoy, 2017). The lack of rigid legal framework is at odds with other states in the US that are allowing AVs to operate.

In the revised executive order signed by former Governor Ducey in 2018, the reasons for facilitating AV implementation become more clear. Within the text of the executive order it is stated that Arizona's soft regulatory approach has led to increased investment and economic development throughout the state. The document also references that this economic growth has been identified by national publications and has categorized Arizona's growth as a *tech-boom*: "The business friendly and low regulatory environment has led to increased investment and economic development throughout the state, the economic growth has been recognized by numerous national publications, including the New York Times that identified Arizona's growth as a tech-boom" (State of Arizona, 2018, p. 1).

The rationale provided in this executive order combined with some of former Governor Ducey's statements highlight that the presence of Waymo as well as other tech corporations is an economic goal designed to boost Arizona's competitiveness with other US states in drawing the investment of multinational technology corporations. In 2016, Ducey is quoted in saying: "This is about economic development, but it's also about changing the way we live and work. . . . California may not want you, but we do" (Office of the Governor – Doug Ducey, 2016).

In 2017, a year after Waymo had set its roots in Arizona, former Governor Ducey awarded a no-bid contract worth in excess of $24 million to Waymo's parent company Google to provide the Arizona state governing department with new email and communication accounts. This symbiotic relationship between Waymo and Doug Ducey has been beneficial on both sides. The significance of the connection between an incumbent disruptive technology such as AVs and platformization is highlighted by Alvarez León and Aoyama (2022) as key in increasing a company's market capture. With Google successfully gaining control over the communication platforms used by the governing body of the state of Arizona, such a coupling between platform, contemporary technology and stakeholders can be seen. Waymo has been provided with lax legal regulations to allow for easier operation in the area. In response to this Waymo has contributed $100,000 to Ducey's recent COVID-19 relief fund as well as providing opportunities for positive publicity (Harris, 2020). When seen in conjunction with the narrative put forward in AV publicity as well as government statements, a sense of the mutual gain comes to the fore.

What is happening on the ground right now in Phoenix is indeed proactive in the sense that AVs are being given free reign to test and operate as they please. This is beneficial for their long term deployment on larger scales. However, the visible regulatory and policy work is clearly focused on the short term. The committees formed by former Governor Ducey exist solely as tools to dismantle barriers in the way of economic progress. Cities need to be conceptualized in all their complexity and diversity, rather than reduced to a form of strategic essentialism (Aoyama and Alvarez León, 2021). A short term approach to the governance of contemporary technology fails to engage with the potential urban and social implications of AVs. Without insight into the way in which urban space shifts and evolves there can be no engagement with deciding the direction of the city. Such short-term approaches are not aligned with the realization of wider urban and societal benefits (greater road safety, reduced traffic congestion and a less car-centric urban design, for instance) that can come with the use of AVs. In using these potential benefits as justification for allowing AVs to operate but failing to proactively engage with urban change, the non-economic benefits of the AV may be left solely as future urban imaginaries.

Conclusion: Urban AI in the absence of urbanism

There is an evident dissonance between the advertised urban benefits of AVs and the lack of action being taken by governance to aid in achieving these goals in cities. The case of Phoenix shows that while AVs may be operational, without proactive governance there will be little positive change to the urban environment. This shift will require engaging researchers and policymakers to address political, social, and infrastructure design realms to create a more efficient, equitable, sustainable, and healthy transportation system for the next era of transport innovation (Gaio and Cugurullo, 2022). On the one hand, the scientific literature portrays the AV as a potent driver of urban change which has the potential to reshape both mobility and the built environment, thereby favoring the production of public spaces and the reduction of traffic congestion levels and road collisions. On the other hand, however, despite the fact that similar benefits often feature in public policy discourses, our critical perspective on the case of Phoenix shows that AV technology is being employed as a medium to boost the economy of the state and fulfill the political interests of single politicians. When we look at the trajectory that the development and deployment of AVs is following, we see no city on the horizon.

In Phoenix, the AV-related initiatives led by the governor and his committees are grounded in the intention to diversify and grow the economy of Arizona and make the state more competitive, so to be economically successful particularly against other states such as California. This rationale mirrors the broader political economy of the US. The United States Department of Transportation (2022, p. 1) maintains that the AV 'holds tremendous promise to strengthen the U.S. economy' and it is committed 'to ensure the United States leads the world in AV technology', especially in light of the growing international competition against China in the field of AI (Lee, 2018). But where is the city in all of this? Where is *urbanism*?

The AV is an urban artificial intelligence. It is a type of AI that operates primarily in cities, thus influencing key urban services and spaces (Cugurullo, 2020). Yet, urban AIs, such as AVs, are often being implemented and integrated into the city without an urbanistic sensitivity. In other words, we have urban AIs that are entering our cities and changing them, but such urban transformations triggered by AI are not being addressed by policymakers by means of the science and philosophy of urbanism. We argue that this lacuna is very problematic. Unless policymakers employ the practical and conceptual tools of urban planning, urban design and urban governance to inform and discipline the diffusion of AI in cities, then the urban benefits of AI will exist solely as imaginaries. The current trend whereby AI serves the goals of national and international political economies as an apolitical instrument of economic progress, has to stop (Rodríguez-Alcázar et al., 2020; Cugurullo, 2021). AI, in the shape of autonomous cars and other urban artificial intelligences ranging from service robots to city brains, is a place-based technology firmly located in the city, and it is through the study and understanding of cities that the deployment of AI should take place.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

CM authored the draft of the manuscript. FC supervised the publication process, edited the paper, and contributed elements to the final manuscript. All authors contributed to the article and approved the submitted version.

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Humans, robots and artificial intelligences reconfiguring urban life in a crisis

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Autonomous urban robots were introduced in Milton Keynes (MK), UK, in 2018 to automate on-demand grocery delivery. Two years later the COVID-19 pandemic rendered routine activities such as delivering groceries or visiting the supermarket unexpectedly unsafe for humans. The ensuing disruption provided opportunities to investigate the potentialities of robotic and autonomous systems to provide cities with resources for coping with unexpected situations such as pandemics, heatwaves and blizzards and ultimately to transform and reinforce urban flows, leading to new ways of living in the city that arise as a result of emerging human-robot constellations. The crisis accelerated the ongoing transformation in human-robot relationships and made its tensions and potentials visible. The case of MK suggests that the cognitive capabilities of urban AIs are not to be found exclusively in computer bits and human neurons but arise from encounters and contexts, with institutions, policies, practices and even the materiality of the city itself being crucial to the emergence of urban AI.

KEYWORDS

urban robots, urban AI, artificial intelligence, robotic and automated systems, AI-human interaction, collective intelligence, delivery robots

1. Introduction

In 2018 artificial intelligence (AI) enabled robots were introduced in Milton Keynes (MK), UK, to automate on-demand grocery delivery. The demonstrator was the first of its kind in the UK, introducing unsupervised robots in public spaces and complex urban environments. Starship Technologies, the company that designed and operated the robots, was one of several commercial organizations investigating the technological, legal and logistic challenges of last-mile delivery robots, with similar technologies being developed and tested inter alia by Nuro and Kiwibot in the US and White Rhino in China (Hoffmann and Prause, 2018; Figliozzi and Jennings, 2020; Zhao et al., 2022). By using AI to perform a task that would otherwise be performed by humans, robots were expected to reduce carbon emissions associated with urban logistics while also changing the cost structure of on-demand deliveries by substituting labor costs with a one-off capital expense (Ackerman, 2015; London Assembly, 2017).

In 2020, 2 years after the introduction of urban robots in MK, the COVID-19 pandemic rendered routine activities such as delivering groceries or visiting the supermarket unexpectedly unsafe. Delivery robots were reframed as a safer contact-free alternative to in-person deliveries and the autonomous fleet in MK was rapidly expanded. Robots, by virtue of not being susceptible to viral infection, were able to undertake a task potentially too dangerous for humans to perform. As demand for contactless deliveries arose and the use of robots in MK intensified, their role went beyond that of convenience or novelty (Hern, 2020). Robots became part of a multi-layered response to a crisis and after the pandemic they remained as a widespread and even mundane infrastructure (Dempsey, 2022).

The case of MK is emblematic of the ongoing introduction of AIs in urban settings, which remains largely experimental even as such intelligences are applied to automate and optimize critical urban functions such as transport, policing and security, the delivery of goods and food, healthcare, maintenance and repair (While et al., 2021). The introduction of robots in MK was explicitly intended to facilitate learning in advance of deployment in other locations (Pinsent Masons, 2021), with the pandemic subsequently accelerating such processes of learning and diffusion (Starship, 2022). The robotic presence in MK may thus be seen as a prefiguration of robotically augmented futures elsewhere. A quote famously attributed to science fiction author William Gibson states that "the future is already here- it is just not evenly distributed". The quote alludes to the fact that technologies that will be mundane to those living in the future already exist for some today (Chatterton and Newmarch, 2017). The quote also draws attention to inequality—specifically to the risk that the future will be defined by inequalities deliberately or inadvertently reproducing those of the present (Chatterton and Newmarch, 2017). Thus, critical attention to the tensions and potentials prefigured by such early trials of urban robots is required as they reconfigure urban flows, reshape the city and are reshaped by them and potentially introduce new forms of non-human intelligences and agencies into heterogeneous urban constellations.

This article presents a case study tracing the introduction of artificially intelligent delivery robots in an urban context, their role in response to a crisis and the subsequent stabilization and diffusion of the robotic delivery service here conceptualized as a Robotic and Automated System (RAS). The research presented in this article, focusing on the tensions, potentialities and new ways of living in the city that arise as humans and artificially intelligent robots encounter each other and jointly respond to shared contexts and contingencies, is thus driven by three questions to support a broad, open-ended exploratory enquiry:

1) What new forms of intelligence, if any, emerged in the city following the introduction of the RAS?
2) How did the RAS interact with the urban constellation?
3) What difference did the RAS make to humans in the city (during the crisis and beyond it) and how were the benefits and externalities of the RAS (if any) distributed?

2. Analytical framework and method

Robots of various forms (e.g., delivery robots, drones, driverless cars) make it possible for artificial intelligences (AIs) to be physically present in the city and interact with it. The tensions, potentials and implications of the introduction of artificially intelligent robots in urban settings is a matter of concern and subject of ongoing debates in urban studies (e.g., Cugurullo, 2019; Macrorie et al., 2020; Sumartojo et al., 2021; While et al., 2021; Del Casino Jr et al., 2022). Robots have the potential to augment human capabilities and to automate jobs that humans find repetitive, tedious or even dangerous but there is also a risk that they will reinforce or automate inequalities (for example, due to unequal access to robotic services, or due to displacement of labor). Robots in cities can provide measures to address pressing global risks (for example, as discussed in the case study, by supporting the response to a pandemic) but they can also give rise to new risks as cities becomes subject to code errors or cyber-security attacks by malicious actors (Kitchin and Dodge, 2019; Guenat et al., 2022).

The presence of robots in cities is a recent phenomenon. Robots have been predominantly deployed in controlled or semi-controlled environments with controls to protect human safety and limited human interaction (While et al., 2021). Consequently, research about urban robotics has often relied on proxy approaches including modeling (Figliozzi and Jennings, 2020), scenarios (Pani et al., 2020), and deployments in semi-controlled setting such as hospitals, airports and schools (Sumartojo et al., 2022). Recent advances in AI make it feasible to deploy autonomous robots in complex and unpredictable contexts including urban environments, with this article contributing to a small but expanding body of case studies grounded on such deployments (e.g., Chen et al., 2020; While et al., 2021).

In this article, a case study is used to trace and narrate the processes through which humans and robots learned to live with each other in a complex urban context subject to change and contingency. The COVID-19 pandemic was one of such contingencies encountered during research. The disruption caused by the pandemic inspired a twofold exploration. One strand of research acknowledges the pandemic as an unprecedented crisis and an opportunity to investigate how robots may make cities better able to cope with disasters. A parallel strand frames the pandemic as a revelatory but by no means unique example of how human and artificial intelligences coexist and adapt to each other in cities that are inherently complex and unpredictable. Analysis therefore draws on two somewhat overlapping lenses.

First, we apply a lens informed by literature on urban resilience and the governance of crisis. Although this article does not aspire to make a contribution to the field, the use of such a lens in needed because the role of robots in response to disaster has become a matter of concern as a result of the global COVID-19 pandemic (Chen et al., 2020; Wang et al., 2021; Lin, 2022). Other urban crises may be expected and robots can be expected to play ever-increasing roles in crisis responses (Yigitcanlar et al., 2021). For instance, global climate change is causing increasingly unpredictable extreme weather events including for example floods, blizzards, storms and heat waves. In consequence, cities need a large array of options for coping with the unexpected (Roe, 2020).

The case of MK contributes to a growing body of evidence on how artificial intelligences may have a role to play in the governance of urban crisis, here studied in terms of formal and informal institutions undertaking coordinated action when unknown and unknowable shocks push the operations of urban systems into unstudied conditions. Contemporary governance arrangements increasingly shift away from traditional state-centric approaches to multi-level governance systems and multi-actor alliances (Renn et al., 2011; McGuirk et al., 2021). We investigate how the addition of artificial intelligences to urban constellations in MK might have inflected such multi-institutional and experimental arrangements.

Following MacKinnon and Derickson (2013) and Roe (2020) we adopt a language of coping rather than one of resilience to analyse the role of robots in times of crisis. Resilience, referring to the stability of a system against interference, is a notion derived from ecology and systems theory but conservative when applied to the social sphere (MacKinnon and Derickson, 2013). A conservative rather than transformative response to a shock brings with it a return to the same position of risk that made the system vulnerable in the first place (Roe, 2020). With the reservations above, we borrow a conceptual toolkit associated with resilience for analytical purposes and thus study how AI may have improved urban ability to cope in terms of the "4 Rs of resilience": redundancy, robustness, rapidity and resourcefulness (Bruneau et al., 2003; Zona et al., 2020). Here redundancy refers to the ability of a system to provide alternative options for effective and efficient management; robustness, to the ability to withstand a certain level of stress while preserving functionality; rapidity, to the rate at which pre-event functionality can be attained and resourcefulness to the community's capacity to identify problems, establish priorities and mobilize resources.

A second analytical lens informing this research draws on recent debates in the field of urban studies to investigate the tensions and potentials that arise when robotic and automated systems (RAS) are deployed in cities to automate, manage, sustain and augment urban functions ranging from surveillance to healthcare to logistics and transport (Cugurullo, 2019; Macrorie et al., 2020; While et al., 2021) and is also inflected by research on cyborg urbanisms (Gandy, 2005; Swyngedouw, 2006) which foresaw the need for a framework for studying the interaction of human and non-human intelligences in cities long before technology developments made empirical study of the issue possible. We therefore investigate the robots in their context- first, robots are studied in the context of a robotic and automated system, a distributed configuration of sensors, processors and actuators spread across a physical environment and possessing the ability to purposefully and autonomously sense it and manipulate it (Marvin et al., 2018). Robots are thus seen as mechatronic actuators of non-human intelligences that may be embedded in the robot, remotely present in a control center or distributed across the system. The RAS, in turn, is investigated in an urban context where human and non-human intelligences participate in contingent unscripted encounters, interacting with and learning from each other.

As AI and robots are introduced to cities there is growing interest in investigating the extent to which RAS might generate new and unanticipated forms of urban life and social organizations, thus (re)configuring the contextual, contingent constellations of places, institutions, infrastructures and the myriad of entities and encounters that constitute the urban (Macrorie et al., 2020; While et al., 2021; Yigitcanlar et al., 2021; Mintrom et al., 2022). We therefore investigate the tensions and potentialities of the RAS and discuss how its deployment in MK may prefigure similar deployments elsewhere. Here, disruption reconfigures the city (McGuirk et al., 2021) and reveals aspects of urban life that would otherwise remain invisible, with breakdowns bringing fleeting visibility to the complex practices and technologies that continuously bring urban life into being (Graham, 2010). Following the geographical sensitivity of this body of research, the following themes directed our analysis: Encounters and interfaces, distributed learning and cognition, (re)configuration, and splintering.

Initial data collection focused on six expert interviews of volunteers and representatives of community organizations supporting vulnerable populations during the crisis, as well as representatives from vulnerable and at-risk groups. This selection of interviewees responded to the original scope of the research, which sought to investigate the role of robots in supporting vulnerable populations (Valdez et al., 2021). As the scope expanded to include broader tensions and potentials of urban AI, data collection and analysis moved predominantly toward non-intrusive observational and documentary approaches. Owing to COVID-19 regulations on research by the Open University, researchers engaged in socially distanced observation (∼30 h) through various stages of the pandemic, attending to the interactions of robots, pedestrians, vehicles, pets and other heterogeneous elements that constitute the urban. Desk research included news items, with 50 articles selected for analysis drawing from national publications (The Guardian, BBC News) as well as local MK publications (MK Citizen, MKFM 106.3). Ten technical briefs and press releases published by Starship Technologies were also selected for analysis as well as 20 policy documents including minutes and agendas published by the UK Parliament, the London Assembly and Milton Keynes Council.

When relevant, documents identified through desk research were incorporated into the corpus for thematic analysis, with the critical skepticism required for study of what are often promotional materials. Documents also provided quantitative data used through the case study—e.g., regarding the number of robots in the fleet and deliveries completed at various points in time. Representatives of Starship Technologies were contacted by the authors but interviews could not be secured. Such difficulties in gaining access to data are often associated to research of the urban-digital interface on account of the proprietary nature of algorithms, the value of secrecy and commercial sensitivity in highly competitive fields, and the emphasis on confidentiality and privacy in the venture capital industry (Fields et al., 2020). The study of AIs introduces an additional layer of black-boxing or opacity as machine learning processes do not naturally accord with human logics or explanations, so that machines make meaningful decisions that cannot be fully assessed or explained (Burrell, 2016). Fields et al. (2020) suggest that, rather than "lifting the black box" researchers can usefully look for the meaning achieved through the relations of networked humans and non-humans. Tracing and narratives approaches providing a sense of the sites of transformation, for instance, can be usefully applied to attend to the messiness that the notion of the black box helps to hide (Fields et al., 2020).

The case study was produced to narrate results of a thematic analysis (Braun and Clarke, 2012) pursued through an iterative engagement between data and matters of concern identified in the developing agenda for research on urban AI and robotics (Macrorie et al., 2020; Yigitcanlar and Cugurullo, 2020; While et al., 2021), with a focus on themes across two strands as discussed above—the RAS contribution to the city's ability to cope was studied in terms of Redundancy, Robustness, Rapidity and Resourcefulness, while the urban geography of the RAS was studied in terms of encounters and interfaces, distributed learning and cognition, (re)configuration, and splintering.

3. Case study

The case study will be organized in four sections corresponding to distinct phases of the deployment in MK. First, we will discuss the background to demonstrator including the characteristics of the robots, the AI driving them and the RAS in which they were deployed. Secondly, we will discuss the introduction of robots on a commercial basis to MK, covering the period between the launch of the autonomous delivery service in 2018 and an announcement of how the 30-robot fleet completed its 100,000th delivery in MK, issued in March 2020. The third section of the case study begins with the announcement of the first COVID-19 lockdown in the UK, which coincidentally took place days after the RAS in MK met the 100,000-delivery milestone. This period was characterized by a rapid growth in demand for contactless deliveries, matched by a corresponding increase in the size of the robotic fleet. The size of the fleet in MK went from 30 to ∼120 robots during the period covered in this phase, which concludes in August 2020, when most restrictions arising from the first lock-down came to an end. The fourth section of the case study will cover the period of stabilization that followed, when the demand for robotic deliveries and the size of the fleet in MK remained stable despite the end of the crisis, as well as the dissemination that followed when the RAS was introduced to five new urban locations with 500 robots operating across the UK.

3.1. Background—The robots and their RAS

Starship Technologies was founded in 2014 and produced its first prototype robot the same year. The current iteration of the 6-wheeled robot (Figure 1) measures ∼56 × 68 × 56 cm (or 125 cm on account of the bright antenna added for visibility), weights ∼27 kg and can transport up to 10 kg in its lockable cargo compartment. With its speed of 6 km/h it is suitable for on-demand last-mile deliveries.

Autonomous operation of the robots is made possible by machine learning through neural networks (Pärnamaa, 2018) which allow them to navigate their surroundings, detect real-time changes (including the change of traffic lights as well as the movement of pedestrians and cars) and adapt to major changes in their environment (for example, road closures or new constructions). Ten cameras and radars provide inputs to the trainable neural network, which over time becomes better able to create an internal representation of the locations in space of entities such as pedestrians, cars, cyclists, dogs on leashes and navigational landmarks. Individual robots thus sense their environment and then use neural networks to structure low level data into high-level information (Pärnamaa, 2018). Urgent information (e.g., about cars and pedestrians) is processed by the robot while less time-sensitive information related to navigation and operations is transferred to remote servers and aggregated, with robots collectively creating a picture of the city and its flows (Kosonen, 2020; Lääne, 2020). Robots therefore learn collectively and pool their collective knowledge to create a unified three-dimensional map of a given area, which they use to identify and navigate the shortest and the safest path between their hub and their destinations. Collective artificial intelligence is also used to orchestrate fleet operations—deciding which robot should do which delivery based on predictions about the expected demand, the availability of robots and the expected battery state after each journey (Kosonen, 2020).

FIGURE 1
Starship robot in MK, traveling along a segregated path for pedestrians and cyclists colloquially known as a "Redway".

Customers order groceries through a mobile phone application. The robots are loaded at the local hub and then navigate autonomously to the destination indicated by the user. Once the robot arrives, users receive an alert through the mobile application so they can meet the robot and unlock its cargo compartment. Delivery robots therefore perform a similar function to that of a bicycle courier but they are expected to operate at a fraction of the cost of other last-mile delivery alternatives when deployed at scale (Ackerman, 2015; London Assembly, 2017). Consequently, there is a risk that robots will displace human workers- with some predictions warning that ultimately 50% of the jobs that currently exist may be replaced by robots AIs (Bissell and Del Casino, 2017). Such automated labor futures are full of complexities and ambivalences as artificial intelligences still requires the (frequently backgrounded) support of human intelligence and labor (Sadowski, 2022). Initially, human support for the RAS was intensive as well as overt—two or even three people were needed to remotely monitor every single robot, including a human minder walking with it. As time progressed human support was backgrounded and the RAS moved asymptotically toward full autonomy- according to the company, robots can operate autonomously 99% of the time and one human can now oversee the operations of ten robots remotely, confirming the decision of the AI or taking control if needed. Robots can send a request for human control if their path is blocked, if a wheelchair is identified or if the robot is unable to move. In some cases, if the operator cannot solve the problem remotely, a field assistant is dispatched from an operation center in the area. On occasion, robots also receive unscripted assistance—e.g., when passers-by encounter a robot that has fallen off the pavement, is stuck in a tight space or is struggling to climb an icy incline (Dempsey, 2022; Dobrosovestnova et al., 2022).

3.2. MK—Early demonstrator

When a RAS for grocery deliveries was first envisioned, the legal status of unaccompanied autonomous robots in urban environments was unclear owing to a lack of regulations and legal precedent (Ackerman, 2015). Early demonstrators preceding that of MK took place in corporate and academic campuses in the United States (Jennings and Figliozzi, 2019). Benefits of campus deployments included the ease of navigating orderly, pedestrianized spaces and a high concentration of generally affluent and time-poor consumers. Importantly, campuses are not subject to regulations (or lack thereof) regarding the use of autonomous robots in public space. In order to set precedent and capture knowledge regarding the operation of robots in public spaces, Starship representatives cultivated connections with industry bodies, becoming embedded within the autonomous and connected vehicle community in the UK, as well as with innovation-friendly local authorities (Pinsent Masons, 2021). Milton Keynes, a city in the southeast of England with a population of ∼250,000 residents and located some 100 km North of London was selected for the first commercial deployment of delivery robots operating autonomously in an urban setting. Operations started in April 2018.

MK council was willing to work with a technology which they acknowledged was not yet fully proven because of their potential to support their agenda for the economy (by stimulating innovation and job creation), environment (by replacing car trips or van deliveries) and inclusion, as they anticipated that the robots would be useful for providing deliveries to households that suffered from reduced personal mobility (Milton Keynes Council, 2018). MK was also a suitable location for the pioneering deployment of autonomous robots in an urban environment on account of its low density and its extensive network of segregated roads for pedestrians and cyclists (see Figure 1) which were relatively safe and easy for AIs to navigate (CMK Town Council, 2018).

MK was founded in 1967 as part of the "new towns" movement that followed the second world war. As the intellectual successor of the "garden cities" movement of the late 19th and early 20th century, the new town movement was characterized by a modernist, rationalist approach to planning, and incorporated garden city principles such as enforcing a separation between pedestrians and road traffic (Clapson, 2017). Consequently, the development of MK followed a masterplan that was meant to result in a pedestrian-friendly city and incidentally made streets easier to transverse for robots as well. The masterplan also advised that every house in MK should be within 500 meters of a "local center" where amenities such as shops, pubs, and schools would be concentrated. Such local centers work well with the logistics of short-distance on-demand robotic deliveries, as robots can reach households within walking distance of such local centers in a reasonable time. The autonomous delivery service in MK was thus organized around local hubs where the robots were loaded, recharged, and cleaned between deliveries.

The RAS initially delivered groceries on behalf of partner supermarkets which would not have provided on-demand deliveries otherwise, and consequently there was not an obvious displacement of workers. The partner organizations had human-operated vans suitable for making next-day deliveries of a week's worth of groceries and robots complemented their capabilities by making it possible to arrange, for example, the cost-effective delivery of a pint of milk within 30 min. While one of the supermarkets supported by the RAS also offered 1-h delivery without robots by relying on human motorcyclists, this service was only available in London, where the high density and the affluent customer base made human deliveries feasible. In effect, human deliveries made sense for areas with high density and complexity while robot deliveries thrived in the opposite.

In principle, the use of delivery robots in dense urban centers would also benefit from high customer density, with more potential customers living within the area served by a delivery hub (Figliozzi and Jennings, 2020). However, further developments in AI are needed before the deployment of robots in high-density urban centers can be realistically considered (Loke and Rakotonirainy, 2021; Mavrogiannis et al., 2022). Low-density footpaths such as those available in MK make it possible for people to make their way around robots when they stop, as they often do when faced with an uncertain or unexpected situation. However, if a robot were to stop in a crowded footpath in London or a sidewalk in New York it would cause considerable aggravation and risk for pedestrians (Salvini et al., 2021). Classical mapping and navigation algorithms are considered insufficient for safe operation of robots in high-density urban settings which are likely to require consideration of the sometimes random and sometimes linear flows of pedestrians (Du et al., 2019). Narrow AI driven by neural networks may achieve the sophistication needed to monitor and identify pedestrian trajectories (Nasr Esfahani et al., 2022) so that robots can learn to either "go with the flow" or "get out of the way". However, the ability to navigate crowded urban settings such as those that might be found in London or New York requires capacities approaching those of general AI, such as the ability to understand the social and psychological constraints on pedestrian behavior and cultural conventions of behavior in public space (Bera et al., 2017; Woo et al., 2020; Gao and Huang, 2021). In contrast, the low density of MK, which is comparable to that of suburban areas of larger cities, made it possible for pedestrians to accept the limited social intelligence of the robots and adapt to their behavior, which is seen as non-threatening, helpful and endearing even as they occasionally struggle to complete their assigned task (Sumartojo et al., 2021). As the wide footpaths of MK make it easy for robots and pedestrians to coexist, 70% of pedestrians do not pay any attention to the robots, with most of the rest of street-goers reacting positively to them (Jennings and Figliozzi, 2019). Consequently, the robots were rapidly accepted by users in MK and they were considered part of its everyday life, as even non-users would encounter them as they made their way along pavements or footpaths and kids would try to pet them or feed them (Hamilton, 2021). This is consistent with recent research emphasizing the power of affect in robot-human interaction, as well as role that anthropomorphism plays in the production of such affective responses (Chuah and Yu, 2021; Spatola and Wudarczyk, 2021; Sumartojo et al., 2021).

Initially, the RAS was only available in a relatively affluent neighborhood of MK. As its operations expanded its geography became more socially inclusive. Particularly, expansion of the RAS to the city center made autonomous deliveries available to several offices including corporate headquarters, but also to some of the most deprived areas of MK. A barrier to access remained in the form of the delivery fee of £1. Although the company acknowledged that some early users were attracted by the novelty of the service, they also identified regular users who appreciated the convenience and were willing to pay a premium for it. By April 2019 50,000 deliveries had been completed and the company was aware of users who had placed more than 100 orders through the year (Starship, 2019). 11 months later, on March 13th, 2020, the company met its next milestone, with a 30-robot fleet having completed 100,000 deliveries across MK, leading to a major expansion in the service area which would include the city center. Three days later the United Kingdom unexpectedly entered its first COVID-19 lockdown, with the UK Health Secretary announcing that all unnecessary social contact should cease. The British population was instructed to stay home, all non-essential shops and services were ordered to close and those at the highest risk of severe complications from COVID-19 were advised to follow special shielding measures. MK, like so many other cities across the world, was faced with a major disruption of key aspects of urban life including transport and food provision (Boons et al., 2021).

3.3. MK crisis—The role of robots during the pandemic

Uncertainty about the duration of the stay-at-home orders and the capacity of supply chains to overcome the disruptions caused by COVID-19 provided a rationale for consumers to build up their stocks of groceries and basic household supplies, engaging in what can be described as hoarding and panic buying (O'Connell et al., 2021). Traditional online grocery delivery services were affected by the disruption. Delivery drivers worked extended ours while supermarkets implemented restricted queueing systems and released additional delivery slots but struggled to cope with the sudden growth in demand (UK Department for Environment, Food and Rural Affairs, 2020; BBC News, 2021). Customers faced waiting times of several weeks for scheduled deliveries (Hobbs, 2020). The disruption to online grocery deliveries was problematic for vulnerable individuals including older adults, people with underlying health conditions or those less able to move (Hobbs, 2020), who often rely on home deliveries to remain independent (Jesus et al., 2021). Despite attempts by supermarkets to allocate additional slots, some vulnerable or at-risk individuals were unable to secure deliveries when services were inundated by requests (Gleason et al., 2020). Consequently, 55% of disabled adults surveyed by the Office for National Statistics reported difficulties accessing groceries, medication and essentials (Office for National Statistics, 2020)—this included those who were not considered vulnerable enough to receive government or community support, as well as people who qualified for assistance but struggled to secure support (Eskyte et al., 2020). Over three million people reported going hungry in the first three weeks of the UK's COVID-19 lockdown (YouGov, 2020) and ~8% of the adults in the UK advised to self-isolate experienced food insecurity because they were unable to go out and did not have any other way to get the food they needed (Loopstra, 2020).

In contrast to conventional online-delivery services, the RAS proved to be sufficiently robust as to meet the sudden spike in demand and continued operations in MK during the pandemic with very little disruption. Company executives state that the number of orders doubled virtually overnight. The fleet of autonomous robots was working non-stop 14 h a day (Shirbon, 2020) but the RAS remained able to support same-day deliveries. Although the delivery service had not been specifically designed for that purpose, robots which replaced humans and thus prevented face-to-face interactions proved to be well suited for delivering groceries to those housebound, shielding or self-isolating on account of the pandemic. Disability advocacy groups included deliveries by Starship robots, where available, in guidance for clinically vulnerable and extremely vulnerable groups (Disability Horizons, 2020). A decision was made to expand the coverage and capacity of the fleet as quickly as possible, so that the number of robots available for deliveries in Milton Keynes doubled from 30 at the beginning of the pandemic in March 2020 to 70 by April and 100 by July of the same year.

Achieving a 300% increase in capacity in a matter of weeks would have been difficult for car-based and human-based services on account of the cost and challenge of acquiring new vehicles in the middle of a pandemic which severely affected supply chains in addition to the difficulties of recruiting and training staff on a short notice. The case of MK suggests that AI-driven robotic systems can be reconfigured and can rapidly adapt and respond to crisis situations. The RAS in MK benefited from a fortuitous contingency—delivery robots in other locations were predominantly deployed in university campuses which were closed due to the pandemic, leaving them available for redeployment to MK. Such a rapid redeployment still required considerable human effort [for example, for the staff loading the robots at the delivery hub (Bird, 2021)] but was facilitated by the AI powering the robots: new additions to the fleet could be readily connected to the servers storing the aggregated navigational knowledge of the collective intelligence and could be readily handled by the AI system orchestrating fleet operations.

Company executives framed contactless delivery as one of the most reliable ways to protect vulnerable populations, preventing face-to-face contact and reducing the risk of contagion (Starship, 2021c). The robots completed over 1.5 million deliveries through the duration of the pandemic (Starship, 2021c). The rapid growth in demand suggests that the robots performed a useful role during the crisis although, like so many other urban technologies, robots also demonstrated potential to reinforce social and spatial inequalities (Macrorie et al., 2020). According to interviews with local community organizations and support groups, such inequalities were present to some degree in MK. Spatial inequalities were present because the robots were only available in selected areas of MK, with a tendency to cover more affluent areas and neglect poorer ones and those that were somewhat marginalized. The ability to cope depended on managing scarce resources and therefore entailed some degree of exclusion. Before the pandemic, the delivery service operated under a flat fee of £0.99. The pricing scheme was temporarily changed at the height of the pandemic to prevent demand from exceeding the capabilities of the robotic fleet, with the service operating under a variable pricing scheme. The company lowered service fees when fewer people requested deliveries and increased it during periods of high demand (Starship, 2021b). The variable pricing scheme, which was by design a barrier to use intended to manage an excess of demand, had the disadvantage of privileging those better able to pay the additional fee while marginalizing the economically disadvantaged. Members of vulnerable or marginalized groups such as those subsisting on a disability allowance would not be able to pay the variable delivery fee on a regular basis. Other vulnerable individuals who would have liked to rely on the robots during the pandemic were unable to use them because they were not able to use the mobile phone application. Vulnerable populations are often less connected to the internet and less able to use online resources, particularly if they are older, have lower incomes, or live alone (Eskyte et al., 2020; Gleason et al., 2020). The robots are also unsuitable for some users with physical and mobility impairments. For instance, wheelchair users may find it difficult to reach and unload the robot while those with visual impairments may be unable to use the mobile phone application.

Nonetheless, even if a RAS was not a suitable replacement for voluntary organizations, community groups and other components of the social safety net, they usefully complemented it—the availability of robots and human volunteers increased the redundancy and resourcefulness of the support network, and therefore made the city better able to cope with an unexpected crisis. Various initiatives and responses by governmental, commercial and community organizations demonstrated distinct capabilities, strengths and weaknesses and served (or failed to serve) distinct groups at various points through the crisis. Although the safety network provided by robots was not equally available to everyone in need of grocery deliveries, it had the distinct advantage of being robust and rapidly able to adapt and respond to an unexpected situation in real time, thus providing a crucial safety net during the early weeks of the pandemic when many vulnerable individuals experienced food insecurity (Loopstra, 2020; YouGov, 2020).

In contrast, national and local authorities were not well suited to take rapid action when faced with an unprecedented situation. Weeks after the beginning of the lockdown, local authorities were still waiting for guidance from national government and did not have access to the full lists of people identified as extremely vulnerable in their area (Local.gov.uk, 2020). Community and volunteer organizations were also largely caught by surprise by the rapidly changing situation, with a study conducted by the Research Institute for Disabled Consumers (2020) finding that 50% of the respondents were unable to receive support previously available to them during the early weeks of the pandemic (Eskyte et al., 2020). Interviews of MK-based volunteers confirms that some organizations were able to respond in a matter of days but for others it was a matter of weeks before they could adapt to the new situation and provide safe and effective support to those who needed it. Volunteer and community organizations benefited from their pre-existing knowledge of vulnerable individuals (Chevée, 2021) and were able to reach and support people that robots could not reach, but they could not easily identify and reach people who had not considered themselves vulnerable before the pandemic. Those same individuals were potentially excluded from government initiatives intended to ensure that vulnerable people could get food (UK Parliament, 2020), which were subject to triage (Department for Environment and Rural Affairs, 2020) and consequently excluded some individuals who considered themselves vulnerable but were not considered a priority. People with manageable health conditions (e.g., immune deficiencies, asthma) who were able to live independently under ordinary circumstances unexpectedly found themselves vulnerable, housebound and unfamiliar with the support networks that could have helped them, but many of them were able to rely on the autonomous robot delivery system. Urban responses to the developing crisis can therefore be conceptualized as a multi-layered safety net, with each layer having different gaps or potential points of failure. For some vulnerable households, access to autonomously delivered groceries provided a first safety net before the other layers could be set in place. In other cases, the robots provided one last extra layer for vulnerable individuals who had slipped through the cracks in all the others, for example because they were not eligible for government support and were not aware of community organizations.

3.4. Stabilization and diffusion

The first lock down was eased in August 2020. The size of the RAS in MK had largely stabilized by then with a fleet of ∼120 robots. Public acceptance and demand for autonomous deliveries continued well beyond the end of the lock-down. The robotic delivery service, initially positioned as purely commercial, benefited from its framing as part of a pandemic response. This is reflected in PR materials made available by Starship (2021b), in announcements by adopting local authorities and commercial partners (Milton Keynes Council, 2018; Hutton, 2022), investors (Lienert and Lee, 2020) and commercial partners (Co-op, 2020).

In November 2020, the RAS was introduced in a second location in the UK, with the service becoming available to 5,000 households in a suburban area of Northampton. A second lock-down was announced by UK government shortly afterwards and the Northampton RAS was once again framed as a safer option in a time of crisis (Northamptonshire Council, 2021). No new locations were announced in the UK for the duration of the restrictions (although the robots gradually returned to university campuses in the US). Following the easing of restrictions in the UK in September 2021 Starship announced a plan to bring the RAS to 5 new urban areas across and increase the size of the fleet to 500 robots across the UK (Starship, 2022). By the end of 2022, following the expansion of the RAS and its post-pandemic return to university campuses, 4 million autonomous deliveries had been completed globally.

The urban layout of successive locations, initially similar to MK but gradually departing from its suburban qualities, suggests that the reach of robots was inflected by learning processes pertaining to the navigation spaces of increasing complexity. Deployments in Cambourne (May 2022), Bedford and Northamptonshire (July 2022), Cambridge and Leeds (November 2022) suggest that navigation of university campuses was a steppingstone toward navigation of the segregated pedestrian footpaths of a suburban setting, which in turn lead to crossing urban roads and navigating the pavements of historic market towns.

Despite the diffusion of the robots to other urban settings (or, perhaps, on account of it) the robots have remained closely associated with MK, to the point that one of them was tasked with delivering a bid for MK to be granted formal city status by Queen Elizabeth on occasion of her platinum jubilee. At the same time, familiarity made the robots appear mundane- a resident reported that his younger child, too young to remember life without robots, considered them to be somewhat less interesting than buses.

4. Discussion and conclusions

As stated in the introduction, the case study above supported parallel explorations of a revelatory episode in the introduction of urban robots to MK with potential to prefigure similar deployments elsewhere. We acknowledge the pandemic as an unprecedented crisis and an opportunity to investigate how robots and cities respond together to disruption. At the same time, we consider disruption, contingency and unpredictability as defining characteristics of urban life. The case can thus be considered as a revelatory but by no means unique example of how human and artificial intelligences coexist and adapt to each other in cities. We now return to the three questions driving this open-ended exploratory enquiry of artificial intelligences, of how they may reconfigure urban constellations and of what the impact of such reconfigurations may be.

First, what new forms of intelligence, if any, emerged in the city following the introduction of the RAS? The intelligence demonstrated by individual robots was limited and based on repetition, a consequence of the nature of machine learning (Sumartojo et al., 2022). Repeated journeys along the footpaths and pavements of MK trained them to navigate more efficiently, identifying and avoiding obstacles and choosing more reliable routes. However, such repetitions could not lead to new behaviors by the robots. Consequently, the intelligence demonstrated by them was limited to navigation and to the optimisation of urban flows. Qualitatively, the intelligent behaviors demonstrated by robots were not significantly different before, during or after the pandemic.

Nonetheless, the RAS demonstrated rapid, intelligent adaptation. Where services that predominantly relied on human labor and human intelligence were overwhelmed by a sudden increase in demand, the RAS proved to be robust and adaptable, continuing operations without disruption. In a sense, however, the RAS did not adapt, but was adapted—human intelligence was behind the decision to expand the fleet by 300% and human operators had to institute new practices such as regular disinfection of the robots. However, such an adoption would not have been possible without the AI, as the intelligence of the robots, limited as it may have been, was built on a logic of connection (Sumartojo et al., 2021) and therefore made it possible for 90 new robots to join the fleet and immediately have the knowledge to intelligently navigate the city and maintain its flows.

Through the case study, the effective operation of the robots before, during and after the crisis was revealed as a result of hybrid intelligences—with the narrow intelligence of the robots acting as a multiplier, enhancing and opening new possibilities of action to human intelligences. Thus, the robotically enhanced response to the pandemic could not be attributed decisively to human or non-human intelligences but (following McGuirk et al., 2021) was revealed to be a form of hybrid cognition and governance by experiment collectively produced by actors in the private sector, civic groups, philanthropies, users and even passers-by.

Here, the intelligence of urban AI is seen again as emerging not from the machine alone but from its use in context. Sumartojo and Lugli (2022) see the robots not as purely mechanical but as lively and unfinished—active, but never quite completed as their potentialities exceed those of their design process. The case illustrated how robots, or rather, the RAS in which they are embedded, can be quickly hacked or redesigned in response to unprecedented demands, and such hacks are not necessarily implemented as changes to the hardware or software. Adaptive capacity and intelligence exceeding that actually present in the RAS emerged from reconfigurations of the ongoing robotic relationalities with people, environments and other technologies.

Second, how did the RAS interact with the urban constellation? Cities are heterogeneous, and the urban response to the crisis in the case study was similarly heterogeneous and multi-layered. Robots could be readily incorporated into the shifting and heterogeneous constellations coalescing around the distribution of groceries to households before, during and after the pandemic. Their narrow intelligence and the capabilities of their physical bodies did not exceed those of a human in any way, but nevertheless they opened up new potentialities. The case of MK suggests that the RAS became one more actor readily integrated to already present de-centralized and multi-layered networks for crisis governance and management (Renn et al., 2011). When a critical societal function (e.g., ensuring that groceries can reach households) is structured by a small number of practices, capabilities and technologies (e.g., buyers driving to stores or by couriers from the stores driving to households) there is a risk that when faced with a shock in their environment they will all experience highly correlated and destabilizing failures (Bronk and Jacoby, 2016; Beckert and Bronk, 2018). The case thus suggests that urban robots can make cities better able to cope with the unexpected when they initiate a shift away from technical and institutional monocultures. To achieve that end, it is important that they are not framed as the sole solution to a given urban challenge (potentially becoming a monoculture of their own) but they can usefully become part of a network of complementary commercial, governmental and volunteer-led approaches for supporting key urban functions such as that of getting groceries to households.

The RAS was intended to facilitate urban flows by inexpensively transporting groceries from hubs to households, and the case suggests that it did so effectively. However, the case also suggests that affects and effects were not independent, so that affective factors inflected the (re)configuration of the RAS. In terms of operation and institutional logic, the case of MK would seem to be similar to that of San Francisco (While et al., 2021), comprising a small-scale commercial initiative providing a robotic platform for grocery deliveries within an experimental space made available by a local authority. However, the affective response to robots in MK appears to be entirely different to the one in San Francisco, where opposition resulted in a temporary ban. Potential reasons behind the different affective responses are multiple and attributable, for instance, to culture, to place or to contingency. For an example regarding place, the case suggests that the layout of MK allows humans and robots to share public spaces without getting in each other's way and may even allow room for encounters where humans antropomorphise robots and have generally positive affective responses toward them (Dempsey, 2022). Regarding contingency, the case of MK is consistent with the observation by Yigitcanlar et al. (2020, 2022) suggesting that the use of AI for "greater good" areas such as disaster management is perceived uncritically in comparison to for-profit applications. Although further research would be needed to identify factors inflecting the differences in affective responses in MK and SF, the case strongly suggests that such responses are impactful.

Observation of the interactions between robots and urban constellations also draws attention to their mutually constitutive nature. RAS and related technologies such as driverless cars are expected to become more prevalent in the future, raising the possibility that urban forms may be altered and simplified to make it easier for robots to operate effectively in them (Sumartojo et al., 2022). The case suggests that such alterations to the urban fabric were not needed in MK because the city, designed according to a rational masterplan, was already repetitive, compartimentalised and generally amenable to robotic ways of seeing and acting. Later, as the RAS was deployed in other locations across the UK, the case may appear to suggest that robots, through a process of training and repetition, gradually learned to navigate urban forms that were somewhat different to those of MK and considerably more challenging than those of academic and corporate campuses. Therefore, it may appear that robots changed but cities remained obdurate and static, as no new roads were built for the robots and the operations of the RAS were run from already existing distribution centers. Nevertheless, the case suggests that although robots did not alter urban forms, they altered urban flows in ways that were not entirely determined by the materiality of the city but were rather constrained by the physical and computational possibilities of the RAS. The RAS acted as infrastructure for handling the flow of groceries with such flows determined by the location of distribution hubs and the reach of robots with a speed of 6 km/h. Consequently, although the city appeared to remain the same, some of its flows and institutions were altered to fit robotic logics of repetition and compartmentalization.

Third, what difference did the RAS make for humans in the city (during the crisis and beyond it) and how were the benefits and externalities distributed? Urban robots are expected to have complex beneficial and detrimental impacts on society, with potential to support and augment human capabilities but also to replace them altogether. Likewise, robots have potential to foster innovation, enhance access and provide data for improved decision-making but there is also a risk that they will reproduce and automate inequality or result in more fragmented and opaque urban governance (Guenat et al., 2022). Further research is needed to critically assess the long-term impacts of the RAS in MK. Ultimately, robots have become a mundane infrastructure and a normal part of the streetscape, but the scale of their deployment has not had a transformational impact. Data suggests that there are environmental benefits arising from the substitution of car journeys by electrically powered robot deliveries. A study commissioned by MKC suggests that 70% of the journeys undertaken by robots would otherwise have been undertaken by a car (Starship, 2021a). However, even with a 500-hundred robot fleet the reductions (estimated to be equivalent to 137 tons of CO_2 across the UK as of 2021) remain limited, if welcome. Meanwhile, further research is needed to assess the impact and distribution of externalities such as the displacement of human workers. Urban scholars have emphasized the need to shed light on the new socio-spatial relations of production and consumption enabled by AI, and on the emerging human-machine relations that the presence of urban AI is fostering in the city (Bissell and Del Casino, 2017). However, by accident or by design, robots in MK were deployed in niches where they did not overtly displace or compete with human workers. Consequently, the case did not provide conclusive data regarding the impact of robots on employment.

The difference made by the RAS is clearer when focusing on the response to the crisis. The case of MK suggests that autonomous robot systems can effectively provide cities with resources to better cope with future pandemics. The RAS made groceries available to some vulnerable or at-risk persons who would not have been able to get them otherwise and allowed many others to avoid exposure and potential contagion.

However, the case strongly suggests that the RAS would have failed if it had been expected single-handedly support the relevant urban function of delivering groceries in times of crisis, and indeed it was not intended to do so. The impact of robots has often been limited in scope and reliability when they have been pushed to their limits in crisis scenarios (Wang et al., 2021). The case study does not suggest otherwise but reveals that robots provide cities with more options, if deployed as part of a heterogeneous and multi-layered constellation. Robots made the city better able to cope with the unexpected not because they were inherently more effective or less prone to failure than other systems, but because they acted as a redundant system with different points of failure. A city that relied exclusively on robots for all its logistics would not necessarily be more robust nor better able to rapidly adapt than one relying exclusively on humans and automobiles. Urban robots, like other urban systems that rely on networked computation, are subject to malfunction as well as to forms of vandalism, disruption and criminal exploitation that risk making city infrastructures insecure and brittle (Kitchin and Dodge, 2019). However, even if the robots could not single-handedly address the crisis, they usefully complemented MK's response to it as the increased resources and options available increased its ability to cope.

Importantly, the ability of the RAS to rapidly adapt was not planned. The case suggests that it emerged as a result of the open-ended nature of urban RAS as lively technologies (Sumartojo et al., 2021). This matters because the potential of RAS to be hacked or

FIGURE 2
Starship robots have proven able to operate under a variety of conditions including heatwaves, storms and blizzards.

adapted may allow them to support key urban functions when faced with unknown and unknowable crisis scenarios (Figure 2). Global climate change is causing increasingly unpredictable extreme weather events including for example floods, blizzards, storms and heat waves. Hence cities need a large array of options for coping with the unexpected (Roe, 2020) as resourceful communities can better respond to disaster events as they have more options available to come with solutions (MacKinnon and Derickson, 2013; Zona et al., 2020). For instance, the RAS operated without interruption during the major weather disruption caused by Storm Emma in 2018 (Morris et al., 2018; Pärnamaa, 2018). However, it must be noted that the RAS was not specifically designed for adverse conditions- robots are currently unable to transverse flooded areas (MKFM, 2020) and they sometimes required human assistance to complete their task in icy weather (Dempsey, 2022; Dobrosovestnova et al., 2022).

The case of MK also suggests that the RAS was useful to support some vulnerable sectors of the population but not others—in this case, housebound or at risk-individuals without access to a human support network benefited from the robots, but such support depended on users living in areas covered by the RAS, being able to pay the delivery fee, and being physically able to interact with the robots. The case thus confirms that the introduction of robots in urban environments risks reproducing or reinforcing various forms of inequality, fragmentation, splintering and injustice, as has also been the case for digitally augmented smart and cybernetic cities (Martin et al., 2018; Clark, 2020; Macrorie et al., 2020; Odendaal, 2021).

Ultimately, the case study provided an opportunity to critically investigate the role of disaster as a productive catalyst for the accelerated development of urban AI. As Lin (2022) observed, COVID-19 accelerated research into new form of advanced automation with potential to achieve more resilient but also less inclusive urban flows. The resulting urban (re)configuration can be seen as confirmation of a familiar pattern, as the relationship between disruption, shock and innovation is well known in the literature (e.g., Schroeder et al., 2000; Bessant et al., 2015). However, what is unexpected is the speed of the response—Robots adapted (or were adapted) to the crisis in a matter of days or even hours, with the sudden rupture opening up potentials and creating an opening for AI-driven reconfigurations (Lin, 2022). Although robots possessed only a narrow intelligence based on repetition and compartmentalisation, they benefited from their ability to connect data and coordinate action, as well as from a logic based on real-time adaption to changes in urban flows which can be usefully described as smart (Kitchin, 2018) or cybernetic (Gandy, 2005; Swyngedouw, 2006). In the case of MK the outcome of such reconfiguration was simultaneously transformative and reinforcive. It was transformative because it made human-robot interactions appear mundane and because those robotic infrastructures, mundane in MK but largely unseen elsewhere, are now inflecting multiple urban sites (where they may then become mundane). Nevertheless, the reconfiguration was also reinforcive as it provided the city (or rather, commercial organizations in the city) with means to maintain pre-existing urban flows in the face of disruption.

Current debates about the impact of AI and their relationship with humans have generally coalesced around three broad perspectives (Peeters et al., 2021)—a technology-centric perspective claiming that AI will outperform and potentially displace humans, a human-centric perspective claiming that humans will always remain superior to AI and lastly a perspective centered on collective intelligence- ultimately, the case of MK suggests that assemblages of human and non-human intelligences have potential to lead to the emergence of cognitive capabilities greater than the sum of its parts (Ha and Tang, 2022). Crucially, the resulting forms of collective intelligence cannot be reduced to some combination of bits in a computer and synapses in human brains. Instead, urban intelligence is expanded ecology of intelligence that includes bits and brains but also institutions, cultural memories, communities, bits of paperwork and protocol, and even the materialities of the city itself (Mattern, 2020). The resulting constellation unexpectedly and almost incidentally, provided a city with more options to cope with an uncertain, unpredictable future, with robots simultaneously reconfiguring and sustaining urban logistics. A RAS faced with the unexpected was able to support some members of vulnerable populations but also replicated some pre-existing socio-spatial inequalities and exclusions. Ultimately, the case suggests that AI in cities unlocks potentials for more inclusive, socially just and sustainable cities, but such potentials cannot be taken for granted as they depend on a constant and open-ended interplay of human and non-human intelligences.

Data availability statement

The datasets presented in this article are not readily available because they contain information that could compromise the privacy of study participants. Participants of this study did not agree for their data to be accessed publicly. Requests to access the datasets should be directed to miguel.valdez@open.ac.uk.

Ethics statement

The studies involving human participants were reviewed and approved by Human Research Ethics Committee at The Open University—reference number 3756/Valdez. The patients/participants provided their written informed consent to participate in this study.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Frontiers of policy and governance research in a smart city and artificial intelligence: an advanced review based on natural language processing

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This study presents an advanced review of policy and governance research in the context of smart cities and artificial intelligence (AI). With cities playing a crucial role in achieving the United Nations Sustainable Development Goals, it is vital to understand the opportunities and challenges that arise from the applications of smart technologies and AI in promoting urban sustainability. Using the Latent Dirichlet Allocation (LDA) method based on a three-layer Bayesian algorithm model, we conducted a systematic review of approximately 3700 papers from Scopus. Our analysis revealed prominent topics such as "service transformation," "community participation," and "sustainable development goals." We also identified emerging concerns, including "open user data," "ethics and risk management," and "data privacy management." These findings provide valuable insights into the current progress and frontiers of policy and governance research in the field, informing future research directions and decision-making processes.

KEYWORDS

smart city, AI, governance, policy studies, natural language processing

1. Introduction

Urbanization is one of the most significant trends of the modern era, with more than half of the global population currently living in cities (Dong et al., 2013; Dong and Fujita, 2015; Chen et al., 2023). Cities face numerous challenges related to management, including traffic congestion, environmental pollution, public safety, and social inequality (Asogwa et al., 2022). In recent years, the rising concerns about sustainability have emphasized multiple issues on the urban scale, such as resource consumption, social equity, social inclusion, and climate risk. It calls for innovative policy and governance to address these interdisciplinary challenges (Gutberlet, 2015; Alessandria, 2016; Castor et al., 2020; Shah et al., 2020). and has also built a new research arena for urban policy and governance research focused on urban sustainability (Dong et al., 2018; Boossabong, 2019; Velenturf and Purnell, 2021; Chen et al., 2023).

Emerging technologies—particularly, smart and AI technologies—have emerged as promising solutions to address these challenges to urban sustainability (Allam and Jones, 2021; Modgil et al., 2021). Smart city governance refers to the use of cutting-edge technologies such as Big Data and AI to promote the innovation of urban management methods, management models, and management concepts (Angelidou, 2015; Allam and Dhunny, 2019). However, the implementation of smart city governance is not without challenges (Han et al., 2018; Wang et al., 2019; Kørnøv et al., 2020). The interaction between AI and urban planning presents numerous ethical and practical challenges, including the transparency, fairness, and accuracy of algorithms (Liu et al., 2020b; Allam and Jones, 2021; Malhotra et al., 2021; Pizzi et al., 2021). As people explore the boundaries of smart cities, more specific risks faced by smart cities may also emerge.

In this context, reviewing the current research arena on smart city governance is valuable to identify the aspects that have been extensively studied and those requiring further exploration. To achieve this goal, this study proposes a bibliometric research approach combined with natural language processing (NLP) to analyze the relevant literature and identify the trends in smart city governance and AI. This approach will provide a data-driven method to gain insights into the field and understand emerging issues and challenges.

The remainder of this article is organized as follows: after this Introduction section, Section 2 describes the research method for literature screening, reviewing, and data processing; Section 3 presents the main findings; and finally, Section 4 draws the conclusions and policy recommendations.

2. Related works

Smart cities employ information and communication technologies (ICT) and AI to augment the quality and efficacy of their urban services, diminish resource utilization, and elevate the overall quality of life for residents (Gams et al., 2019; Ullah et al., 2020; Kaginalkar et al., 2021). Multimodal AI—which integrates diverse data sources, such as text, images, videos, and sensor data—bolsters the understanding of urban environments and enhances applications in areas, such as traffic management, public safety, and infrastructure maintenance (Zadeh et al., 2018; Santosh, 2020). NLP plays an indispensable role in smart city governance by facilitating efficient communication between humans and machines, as well as by analyzing unstructured textual data (Nicolas et al., 2021; Alswedani et al., 2022).

With the progression of sentiment analysis techniques, NLP-based research has been employed to comprehend public sentiment more effectively, a crucial aspect of smart city management (Guo et al., 2016; Serna et al., 2017; Wang and Taylor, 2019). This research area has primarily concentrated on enhancing the accuracy and scalability of sentiment analysis techniques, including developing deep learning-based models for more precise classification of the sentiment (Ghahramani et al., 2021; Song et al., 2021; Dutt et al., 2023). Some scholars have also employed NLP to devise algorithms for real-time event detection, such as accidents, natural disasters, and public gatherings (Yang et al., 2020; Zhang et al., 2021a,b), with a focus on refining the integration of event detection systems with other city services for more effective governance.

These advancements, in conjunction with ongoing research on NLP and AI, hold the potential to substantially improve efficiency, sustainability, and overall quality of life in smart cities worldwide. Consequently, conducting systematic research on this rapidly evolving study area is imperative, particularly in terms of shifting themes to discern patterns in research focus points. Topic modeling employs unsupervised machine-learning techniques to automatically uncover themes within a corpus of unstructured text. In this study, the most extensively investigated topic, modeling algorithm, Latent Dirichlet Allocation (LDA), has been utilized to categorize topics on the governance of smart cities and AI, as well as to identify major trends based on the available literature.

3. Methodology

This study employs the LDA method based on a three-layer Bayesian algorithm model for research topic clustering and evolution analysis. The aim was to conduct an advanced review of the current progress and frontiers of policy and governance research in smart cities and AI and shed light on the future research arena in this theme. Figure 1 presents the workflow for literature processing, text and data mining, and topic clustering.

3.1. Step 1: literature mining

The first part was literature searching and processing. A keyword search on Scopus was performed. In terms of governance of a smart city and AI, the searching string adopted was TITLE-ABS-KEY (governance AND ["smart city" OR "artificial intelligence" OR "urban artificial intelligence" OR "autonomous city"]). This means that articles including the words "governance" and either "smart city" or "artificial intelligence" in their titles, abstracts, or keywords were sought for the study. The search retrieved articles related to the topics of governance and either smart city or AI or both. Scopus shows that between 2000 and 2022, a total of 4,021 documents specific to the governance of smart cities or AI were published. The exclusion criteria included the following literature types: editorials (27), notes (22), conference reviews (125), errata (2), retracted articles (7), short surveys (3), and letters (1). It is important to note that the quality of the results obtained using the LDA model partly depends on the language(s) used in the corpus. If the corpus contains documents in multiple languages, the model will struggle to identify coherent topics relevant to the research question. In such cases, preprocessing the data to separate the documents by language before applying the LDA model is more appropriate. However, the sample size of the non-English literature in the current study was too small (121 documents) to be sufficient for running the LDA model. Based on this consideration, the limitation was extended to "Publication in English" only, and then, 3,713 papers were left. The collected literature was further screened to exclude data with incomplete information, such as those showing no abstract available. The remaining 3,689 papers underwent further analysis in step 2.

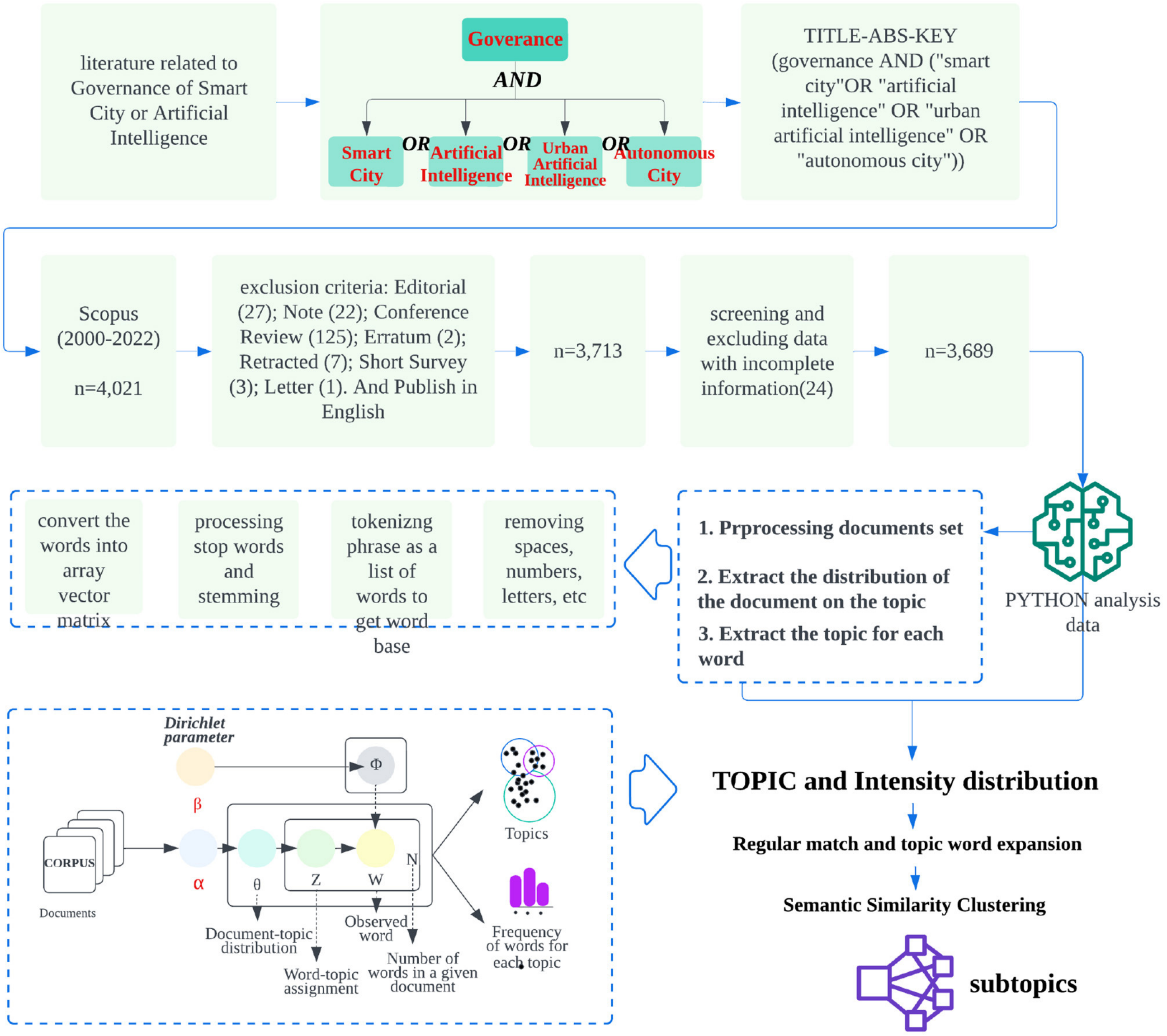

FIGURE 1
Literature processing, text and data mining, and topics clustering.

3.2. Step 2: data cleaning and keywords segmentation

The second part was data cleaning and word segmentation. To make the analysis and outcomes more trustworthy, basic preparation of the text material was performed. All punctuation was removed using a regular expression, and the text was converted to lowercase. After that, punctuation and extraneous letters were removed, and each phrase was tokenized as a list of words. In the third step, spaCy, a word segmentation tool, was used for segmentation processing on the text. It is also currently the fastest and best method for deep learning from text and can be written in the programming language Python (Honnibal and Johnson, 2015; Hu et al., 2022). The executed commands included removing stop words and stemming to reduce the total number of unique words in the dictionary. In NLP, vectors can represent text documents, which is a very effective way to find similarities between different pieces of text (Alvi and Talukder, 2021; Goyal, 2021). Finally, the words in the document were converted into a word frequency matrix by creating a unique id and calculating the number of occurrences for each word so that the keyword set was stored in the form of an array vector, presented as word-id/word-frequency.

3.3. Step 3: topic clustering

The third part was topic clustering or modeling. Topic modeling is one of the most powerful techniques in text mining, used for latent data discovery and finding relationships between data and text documents. A frequently utilized NLP technique in the field of topic modeling is LDA. This generative probabilistic model is designed to identify the underlying topics within extensive collections of text. It has gained widespread popularity due to its ability to uncover latent patterns in large corpora (Shatte et al., 2019; Liu et al., 2020a; Xue et al., 2020). According to the search results of Scopus, the research interest in this method has steadily increased since it was proposed in 2004. It has been widely used in computer science, social science, business, management and accounting, and environmental science.

LDA is a three-layer Bayesian algorithm model based on words, topics, and documents. The LDA model assumes that each document is a mixture of topics, and each topic is a probability distribution of words. The goal of the LDA model is to infer the topic and word distributions for a set of documents. The basic idea of LDA is that documents are generated in the following way: 1. A topic is randomly selected from a prior distribution of topics; 2. For each word in the document, a word is randomly selected from the word distribution of the topic. This process is repeated for each word in the document, resulting in a mixture of topics for each document. Based on the frequency counts of topics and words in the document set, the subject of each document in the set is presented in the form of a probability distribution, and finally, the group distribution of the clustered items is obtained (Blei et al., 2003). The resulting clusters can be used to better understand the content of a large document set and perform tasks, such as document classification and text summarization. Different from the conventional vector space model, the parameters in the LDA model do not grow exponentially with the size of the text set (D'Amato et al., 2017; Jelodar et al., 2019; Dieng et al., 2020; Han et al., 2020). Additionally, it makes up for the deficiency of other probability generation models that assume a text involves only one topic and can effectively model an actual situation based on this assumption, as texts typically have multiple topics (Snoek et al., 2012; Guo et al., 2017; Shatte et al., 2019; Abd-Alrazaq et al., 2020; Boon-Itt and Skunkan, 2020). As a result of these benefits, the LDA model was employed in this research. Python was used to treat the code and is provided in "Supplementary material".

In the LDA model, each document d is represented as a bag of words, which means that the order of the words in a document is ignored, and only their frequencies are considered. Let x be a word in the vocabulary, and let $n(x,d)$ be the number of times x appears in document d. The LDA model assumes that the probability of observing a word x in document d can be calculated as follows (Blei et al., 2003):

$$p\left(x|d\right) = \sum p\left(x|z\right)^{*} p\left(z|d\right) \tag{1}$$

where z is a latent variable representing the topic assignment for the word x in document d, $p(x|z)$ is the probability of observing the word x given the topic z, and $p(z|d)$ is the probability of the topic z given the document d. To compute $p(x|d)$, all possible topic assignments z need to be summed over. In other words, all possible topics that could have generated word x in document d must be considered.

The LDA model generates a document in the following way: sampling from the Dirichlet distribution to generate topic distribution θ_i of document i; sampling from the multinomial distribution of topic θ_i to generate topic $z_{i,j}$ of the jth word of document i; sampling from the Dirichlet distribution to generate word distribution $\varphi_{z_{i,j}}$ for topic $z_{i,j}$; sampling from the multinomial distribution of word $\varphi_{z_{i,j}}$ to finally generate word $w_{i,j}$. Thus, the joint distribution of all visible as well as hidden variables in the whole model is as follows (Jelodar et al., 2019):

$$P\left(w_i, z_i, \theta_i, \Phi|\alpha, \beta\right) = \prod_{j=1}^{K} P\left(\theta_i|\alpha\right) P\left(z_{i,j}|\theta_i\right) P\left(\Phi|\beta\right) P\left(w_{i,j}\middle|\varphi_{z_{i,j}}\right) \tag{2}$$

where N is the number of topics and α and β are the hyperparameters of the Dirichlet before the per-document topic distributions on the per-topic word distribution.

The maximum-likelihood estimation (Jelodar et al., 2019) of the word distribution of the final document can be obtained by integrating θ_i and φ of the above formula and summing $z_{i,j}$:

$$P\left(w_i|\alpha, \beta\right) = \int \theta_i \int \Phi \sum_{z_i} P\left(w_i, z_i, \theta_i, \Phi\ |\alpha, \beta\right). \tag{3}$$

Finally, Gibbs sampling can estimate the parameters in the model (Blei and Jordan, 2006; Wei and Croft, 2006; Jelodar et al., 2019) according to the maximum-likelihood estimation. Employing all these formulas in this study resulted in the determination of $\alpha = 0.3$ *and* $\beta = 0.9$.

The best topic number can be checked by calculating the value of the model "perplexity." Perplexity is calculated as the exponential of the cross-entropy between the model and the data. In the case of LDA, the predicted distributions are compared to the actual distributions in the data to calculate the perplexity score. The lower the score, the better the model fits the data, meaning that the model can predict the topics and words in the documents more accurately. In this research, the perplexity was calculated as follows:

$$per\left(D_{test}\right) = \exp\left\{-\frac{\sum_{d=1}^{M} \log p(w_d)}{\sum_{d=1}^{M} N_d}\right\}. \tag{4}$$

The perplexity index is calculated through the following parameters: the number of topics was [5, 25], the number of iterations was 1,000 (Wang et al., 2022), and the step size was 1.

In the LDA model, the topic intensity distribution provides insights into the relative weight of each topic within the corpus. The calculation formula for determining the relative weight is as follows (Wang and Taylor, 2018):

$$Pk = \frac{\sum_{i}^{n} \theta_{ki}}{n}. \tag{5}$$

Among them, Pk represents the topic intensity of the k-th word, θ_{ki} represents the probability of the k-th word in the i-th text, and n represents the number of literary texts. By considering factors such as the frequency of the keywords of the topic in the documents and the probability distribution of the topic, topic intensity can reflect how prominent or influential a topic is compared to the others in the dataset. Therefore, topic intensity can be used as an indicator of the prevalence of the topic within the corpus.

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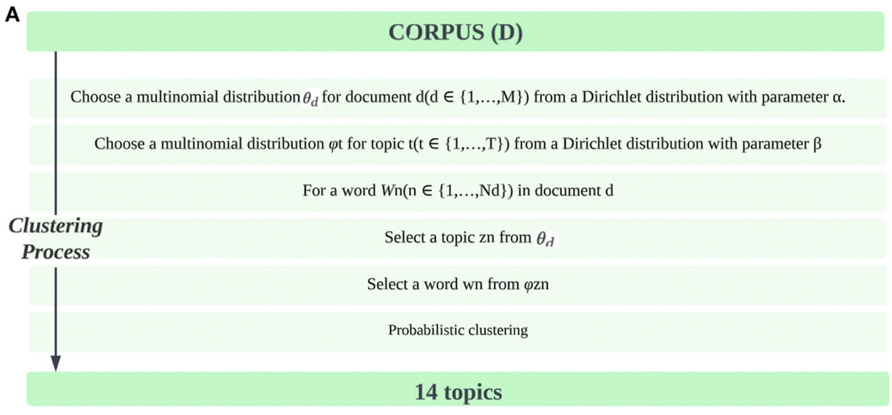

Topic 1	Service Delivery Transformation through Modernizing City Operations	0.136
Topic 2	Community Participation in Local Projects	0.113
Topic 3	Sustainable Development Strategies in Global Urbanism	0.095
Topic 4	Open User Data Platforms Governance	0.078
Topic 5	Ethics and Risk Management in Emerging Technologies	0.077
Topic 6	Impact of Digital Innovation on Business Transformation	0.072
Topic 7	Integration of GIS in Business Education	0.07
Topic 8	Integrated Governance of "Smart", "Green", and "Resilience"	0.066
Topic 9	Internet of Things (IoT) Security Management	0.063
Topic 10	Data Privacy Regulations in Healthcare	0.059
Topic 11	Performance Evaluation and Measurement	0.053
Topic 12	Machine Learning in Data Analytics	0.041
Topic 13	Cultural Heritage Preservation and Management	0.04
Topic 14	Human Resource Management and Organizational Behavior	0.037

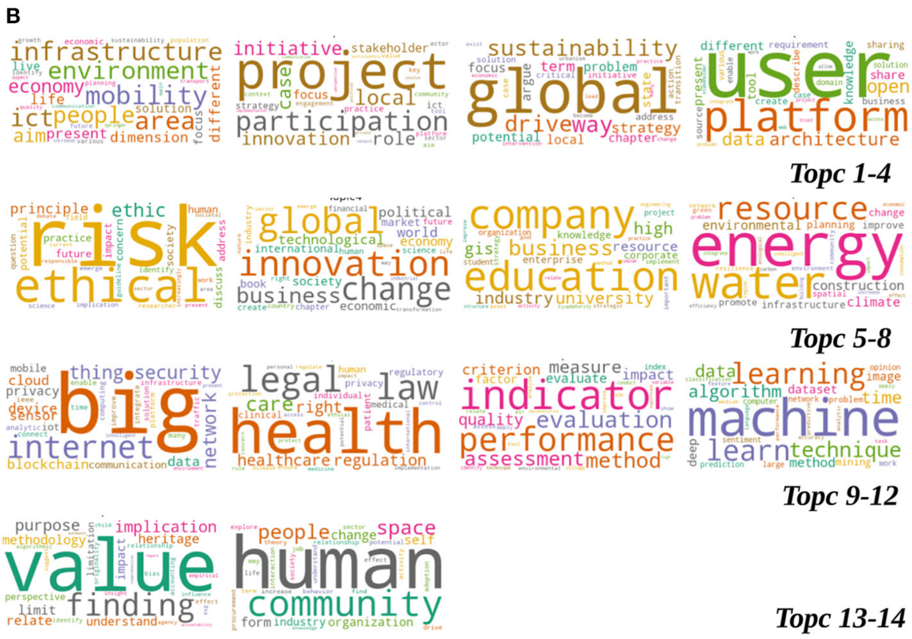

FIGURE 2
The 14 topics and their intensity for governance and policy of sustainability and cloud picture. **(A)** Topics and intensity. **(B)** Cloud picture for topics.

4. Results

4.1. Overview of topics for policy and governance research of a smart city and artificial intelligence

According to the findings regarding the optimization of the number of topics, the total number of text topics in the reviewed literature was 14. The 14 topics and their intensity are shown in Figure 2.

To display the focus of each topic and the interrelation between them more intuitively, the "Word cloud" visualization technique was utilized for the 14 topics extracted from the literature data spanning from 2000 to 2022 (refer to Figure 2B). The font size of the words positively correlated with their frequency of occurrence under the respective topic. The word cloud technique allows readers to conveniently and directly grasp the key information associated with each topic; additionally, the LDAvis visualization, arranged as a two-dimensional scatter plot (Figure 3), provides further insights. In Figure 3, the x-axis represents the measure of the distinctiveness of a topic, while the y-axis represents its coherence. The number of bubbles in the plot represents the number of topics, each bubble representing a different topic. The bubble size indicates the prevalence of the topic in the corpus, with larger bubbles representing more prevalent topics. By examining the position and size of the bubbles, insights can be gained into the relative strengths and weaknesses of the topics the model generates. For example, a large bubble positioned higher on the y-axis and further to the right on the x-axis suggests that the topic is both prevalent and coherent in the corpus. Additionally, the distance and overlap between the bubbles provide a sense of how the topics are related to one another.

The result shows that the literature related to the governance of smart cities and AI is broad and covers a wide range of topics, reflecting the diverse challenges and opportunities associated with the intersection of technology, governance, and societal issues in the context of smart cities and AI.

The relationships between these topics suggest that the governance of smart cities and AI is a complex and multifaceted issue requiring a comprehensive and integrated approach. For example, the high overlap between bubbles 4 and 7 in Figure 3 shows that the integration of geographic information systems (GIS) in business education can support employee skill development and organizational knowledge management, which can, in turn, improve the implementation of smart city technologies, such as intelligent mobility solutions and ICT-enabled citizen participation. Additionally, the ethical and risk management considerations related to emerging technologies, such as AI, are critical for ensuring the responsible implementation of these technologies in smart cities without negative implications for society.

The relationship between topics, such as sustainable urbanism (bubble 3) and local sustainability initiatives (bubble 2), indicates the importance of integrating sustainability considerations into the policy and governance frameworks of smart cities and the need for holistic approaches addressing the environmental, social, and economic aspects of urban development. While the overlap between healthcare data privacy (bubble 10) and bubble 2 suggests that privacy issues are a significant concern in the context of smart cities and AI, particularly in healthcare-related applications, indicating the need for robust privacy policies and governance mechanisms to protect sensitive healthcare data while leveraging the potential benefits of AI in healthcare services. Similarly, the relationship between topics, such as performance evaluation and measurement, environmental impact assessment, and air quality measurement, highlights the need for monitoring and assessing the impact of smart city technologies on the environment and public health.

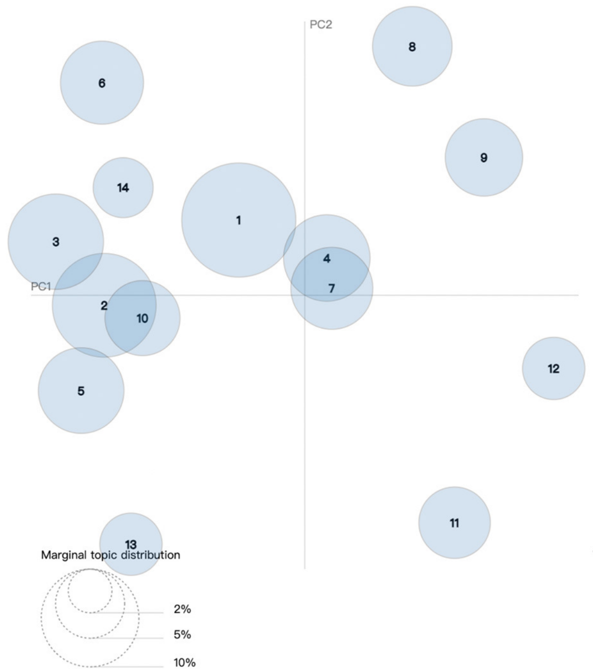

FIGURE 3
Intertopic relevance distance map.

Overall, these topics collectively indicate that the effective governance of smart cities and AI necessitates a comprehensive approach encompassing various factors. This approach should encompass considerations, such as technology implementation, ethical and risk management practices, environmental impact assessment, and active community engagement. It emphasizes that policy frameworks must carefully balance sustainability, privacy, and other pertinent factors to ensure responsible and efficient governance of smart cities and AI.

4.2. Subtopics for policy and governance research of a smart city and artificial intelligence and topic evolution trend

4.2.1. Subtopics under the 14 topics

According to the steps in the methodology, words similar to the subject words under the 14 topics were further searched for through regular matching. This exercise intended to extract the linguistic principles governing semantics and syntax from the literature corpus. Words sharing a similar context are represented by vectors in proximity to each other. The word sample size under each topic can be thus expanded to generate subtopics. The subtopics, research hotspots, and SDGs dimensions of each topic are shown in Figure 4. These sub-topics are expected to enlighten the future research arena of the policy and governance studies on smart cities and AI.

Topic 1 (Topic intensity: 0.136): the highest intensity reflects the central focus on improving the delivery of smart city services by leveraging modern technologies. The subtopics highlight various aspects, such as smart infrastructure management, intelligent mobility solutions, AI-based environmental monitoring, and ICT-enabled citizen participation and show that research of Topic 1 aims to enhance urban governance by promoting efficiency, sustainability, and inclusivity in city operations; Topic 2 (Topic intensity: 0.113): the second-highest intensity emphasizes the importance of engaging citizens in decision-making and fostering collaboration between stakeholders. The subtopics cover methods such as participatory budgeting, stakeholder engagement, ICT tools for participation, and innovative practices. The focus is on fostering collaboration between citizens, local authorities, and other stakeholders to address urban challenges, which is closely related to topic 1 (Service Delivery Transformation), as improved governance is often a prerequisite for effective citizen engagement (Neshkova and Guo, 2012; Sandoval-Almazan and Gil-Garcia, 2012; Granier and Kudo, 2016); Topic 3 (Topic intensity: 0.095): the third-highest intensity highlights the need for sustainable and environmentally responsible urban development. Subtopics, such as sustainable urbanism, local sustainability initiatives, urban economic transition, and sustainable urban planning practices, suggest a holistic perspective on addressing the environmental, social, and economic challenges in smart cities. This area intersects with both Topics 1 (Service Delivery Transformation) and 2 (Community Participation), as it seeks to address the environmental, social, and economic challenges in smart cities using technology-based governance and collaborative approaches; Topic 4 (Topic intensity: 0.078): this research area focuses on creating a robust data ecosystem for smart cities, fostering transparency and collaboration among various stakeholders and emphasizing aspects such as data architecture, knowledge sharing, business requirements, and trust and access. It is also related to both topics 1 (Service Delivery Transformation) and 2 (Community Participation), as data-driven decision-making and stakeholder engagement are essential for effective governance; Topic 5 (Topic intensity: 0.077): with an intensity similar to that of Open User Data Platforms Governance, this topic investigates the ethical considerations and risk management strategies associated with AI. The subtopics discuss ethical principles in AI, risk management strategies, societal implications, and responsible research practices, highlighting the need to ensure that technological advancements align with ethical norms and societal values.

The remaining topics, with relatively lower intensities, contribute to the overall research landscape by exploring specific aspects of smart city governance, such as Internet of Things (IoT) security management, data privacy regulations in healthcare, performance evaluation and measurement, machine learning in data analytics, cultural heritage preservation, and human resource management. Topic 6 examines the effects of digital innovation on businesses in the context of smart cities. The subtopics include digital transformation, economic impacts, social and cultural implications, and political and regulatory frameworks, demonstrating how businesses are influenced by and contribute to the broader digital ecosystem. Topic 7 investigates the role of GIS in business education, with a focus on learning strategies, training implementation, knowledge management, and employee skill development. The integration of GIS into business education aims to enhance data-driven decision-making, spatial analysis capabilities, and overall business performance in the context of smart cities. Topic 8 examines the interplay between smart, green, and resilient urban planning and management, emphasizing energy-efficient buildings, water resource management, climate resilience planning, and green infrastructure. The objective is to promote sustainable, adaptive, and technologically advanced cities. Topic 9 discusses IoT security in smart cities, addressing aspects such as privacy, sensor networks, cloud computing, and analytics. Responsible implementation and management of IoT systems are emphasized to safeguard privacy, prevent data breaches, and ensure system integrity. Topic 10 explores data privacy in healthcare, encompassing patient rights, privacy and confidentiality, clinical and medical ethics, and disease control and access to care. This topic highlights the need for robust regulations and ethical practices in handling sensitive health data within urban management. Topic 11 delves into methodologies and tools for evaluating smart city performance, covering performance evaluation, environmental impact assessment, air quality measurement, and evaluation tool application. These aspects aim to quantify the effectiveness of smart city initiatives, driving evidence-based decision-making and efficient resource use. Topic 12 investigates machine-learning applications in data analytics, focusing on algorithm selection, deep learning, predictive analytics, and sentiment analysis. Effective machine-learning applications enable improved decision-making, accurate predictions, and support for a wide range of smart city applications. Topic 13 studies the preservation and management of cultural heritage in smart cities, emphasizing sustainable tourism and social cohesion. These aspects contribute to the overall quality of life within urban environments. Topic 14 analyzes human resource management and organizational behavior in smart city development, encompassing social change, organizational behavior, human interaction, and job performance. Effective management and attention to organizational behavior can foster adaptability, a positive work environment, and improved productivity and performance in smart cities.

When a more comprehensive perspective is taken, these research topics also interact with each other in various ways, forming a complex network of interdependencies and synergies. The interactions among these topics can be characterized as follows:

4.2.1.1. Service delivery transformation and community participation

The modernization of a city's operations and the engagement of the city's residents in decision-making are closely related. AI and digital technologies can facilitate more inclusive, efficient, and sustainable urban governance, which, in turn, supports effective community participation and collaboration.

FIGURE 4
Subtopics and research hotspots for topics 1–14.

4.2.1.2. Service delivery transformation and sustainable development strategies

The push for sustainable urban development is directly linked to the transformation of city services. As cities leverage technology to improve their operations, they also need to focus on addressing environmental, social, and economic challenges. The convergence of these topics highlights the need for holistic and integrated approaches to smart city governance.

4.2.1.3. Open user data platforms for governance, ethics and risk management, and IoT security management

The increasing reliance on data and interconnected systems in smart cities necessitate robust governance mechanisms, ethical considerations, and risk management strategies. These topics are interrelated in their focus on ensuring the responsible and secure deployment of AI and IoT technologies in the urban environment.

4.2.1.4. Performance evaluation and measurement, machine learning in data analytics, and integration of GIS in business education

The use of advanced analytics and performance evaluation methodologies is critical for data-driven decision-making in smart cities. These topics are interconnected in their emphasis on leveraging advanced algorithms, models, and tools to extract insights and evaluate the effectiveness of smart city initiatives and policies.

4.2.1.5. Cultural heritage preservation and management, human resource management and organizational behavior, and data privacy regulations in healthcare

These topics explore specific aspects of urban management, emphasizing the need for specialized approaches in various sectors. Although they may not interact directly, they significantly contribute to the overall research landscape in smart city governance.

As mentioned above, the interactions between various research topics in the governance of smart cities and AI are complex. The intricate web of relationships among these topics highlights the need for a multidisciplinary and collaborative approach to address the challenges and opportunities in this field. Understanding these interactions can help identify potential synergies and areas for collaboration, ultimately contributing to the development of more efficient, sustainable, and inclusive smart cities.

4.2.2. Topics evolution from 2000 to 2022

The evolution of the topics is critical retreat the trend and future of the studies. This study separates the literature data into four periods to examine how themes have changed over time, as shown in Table 1. The first phase is from 2000 to 2008, with 40 articles overall; the second from 2009 to 2015, with 325 articles; and the third from 2016 to 2022, with 3,319 articles.

The LDA model determines the subject of the literature data in each period, and the number of iterations and the test for the optimal number of topics are compatible with the methodology section. According to the calculation findings, the best number of themes in the first period is 4, the best number of topics in the second period is 8, and that in the third period is 12.

TABLE 1 Literature amount in three periods, from 2000 to 2008.

Period	Time	Number
T1	2000–2008	40
T2	2009–2015	325
T3	2016–2022	3,319

To better display topics and research objects in each period, based on the trained LDA model, the top 30 core words for each topic are output, regular expressions are used to extract target information containing keywords, and topics are refined by classification. The result is shown in Figure 5.

The concentration of literature on the governance of smart cities and AI from T1 to T3 has evolved, indicating a shift from a narrow focus on the management of AI applications toward a broader range of multidisciplinary topics.

To look in general, from T1 to T3, the concentration of the literature has expanded, covering a wider range of topics that reflect the growing complexity of smart city initiatives. In T1, the concentration was focused on four topics, with the highest intensity being on the management of AI and its applications in business and health. In T2, the concentration shifted toward broader topics that reflected the need for a more comprehensive and people-centered approach to smart city governance. The topics with the highest intensity in T2 were innovations in infrastructure development, cloud-based architecture design, and environmental monitoring with IoT devices. Finally, in T3, the concentration of literature expanded even further, covering topics such as regulatory frameworks for AI, technological advancements in financial performance, and blockchain technology for enhancing cybersecurity.

When looking at the information in more detail, the shift in T2 toward topics, such as infrastructure development, sustainability, stakeholder engagement, and cultural heritage preservation, highlights the importance of smart city initiatives being people-centered, environmentally sustainable, and responsive to citizen needs. These topics underscore the need for a more comprehensive and collaborative approach to smart city governance, which considers a broad range of factors and stakeholder interests. In T3, the concentration of the literature further expanded, covering topics, such as regulatory frameworks for AI, technological advancements in financial performance, and blockchain technology for enhancing cybersecurity. The shift toward sustainability, citizen participation, and the governance of emerging technologies underscores the need for smart city governance to be responsive, inclusive, and ethical.

Overall, the shift in topic concentration over time reflects a growing recognition of the complexity and multidisciplinary nature of smart city initiatives. The trend toward broader topics that incorporate sustainability, stakeholder engagement, and responsible innovation underscores the importance of smart city governance being people-centered, environmentally sustainable, and aligned with societal values and priorities.

Based on these trends, smart city governance requires a multidisciplinary and collaborative approach that considers a broad range of factors and stakeholder interests. The expansion of topics in T2 and T3 reflects a growing recognition of the need for

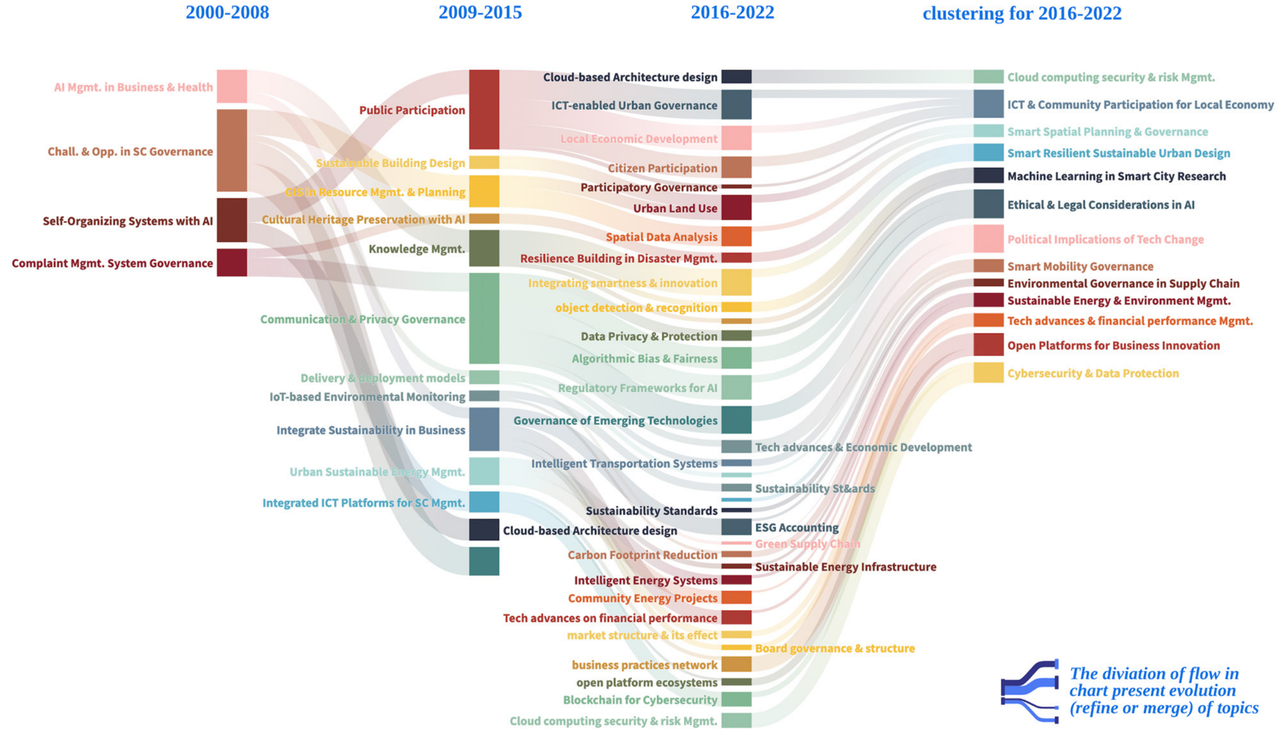

FIGURE 5
Topic evolution from T1 to T4.

smart city initiatives to be inclusive, ethical, and responsive to citizen needs. To achieve these goals, smart city governance should prioritize sustainability, stakeholder engagement, and responsible innovation to ensure that smart city initiatives are effective, efficient, and aligned with societal values and priorities.

5. Conclusion and discussion

New smart technologies and AI technologies have emerged as promising solution to address various challenges in the transition toward urban sustainability. They are also widely identified as a double-edged sword. Therefore, investigating the general trend and status of the literature would be valuable to enlighten future research with a focus on the innovation of urban management methods, management models, and management concepts. Particularly, emerging technological change and forecasting require more attention from academia to address the challenges of social change.

This study conducted a data-driven analysis based on the NLP method to systematically review the status and evolution of the policy and governance research in the scope of smart cities and AI. The results highlighted several emerging fields, such as "Service transformation", "Community participation", and "Sustainable development goals", "Open user data", "Ethics and risk manages", and "Data privacy management".

Concerns have been soaring on privacy management, ethics and risk management issues related to technological advancement, and political implications of smart technologies, which have reflected the rising concerns on the "opposite" edge of the double-edged sword. However, there has also been fast-growing literature on how smart technologies and AI could play a vital role to address urban sustainability challenges, such as "smart spatial planning and governance", "smart and resilience to address the sustainable urban issue", "smart mobility governance", and "environmental impact governance for smart logistics in cities", covering the interdisciplinary fields that could provide solutions to the economic, social, and environmental aspects of urban sustainability.

The clustering and evolution of the analyzed topics call for future efforts to address the frontiers of the research field. This review is expected to enlighten the future research arena of the field and offers critical policy and governance solutions to urban sustainability under the smart city and AI era.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

LD: conceived the research idea, made the structure, supervised the study, and wrote the manuscript. YL: collected the data, performed the analysis, and wrote the manuscript. All authors significantly contributed to this study through reading and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frsc.2023.1199041/full#supplementary-material

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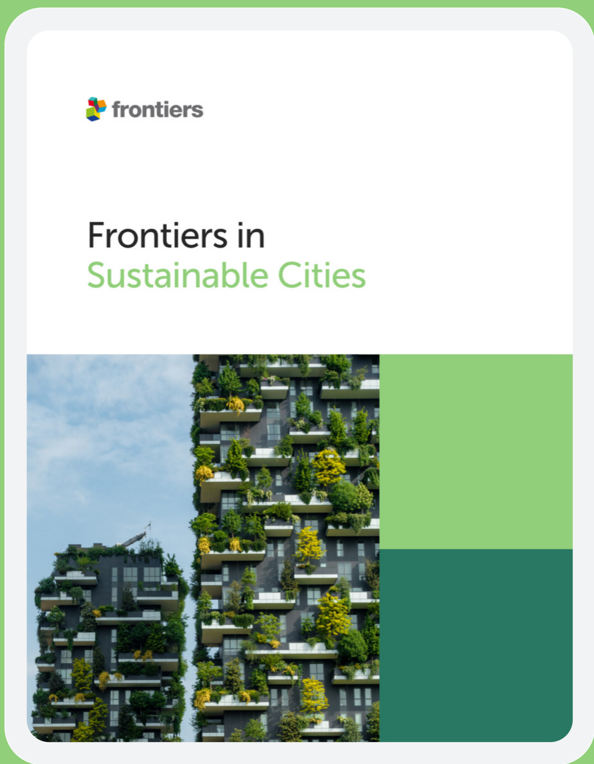

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