Viewpoint

The Sustainability of Artificial Intelligence: An Urbanistic Viewpoint from the Lens of Smart and Sustainable Cities

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Abstract: The popularity and application of artificial intelligence (AI) are increasing rapidly all around the world—where, in simple terms, AI is a technology which mimics the behaviors commonly associated with human intelligence. Today, various AI applications are being used in areas ranging from marketing to banking and finance, from agriculture to healthcare and security, from space exploration to robotics and transport, and from chatbots to artificial creativity and manufacturing. More recently, AI applications have also started to become an integral part of many urban services. Urban artificial intelligences manage the transport systems of cities, run restaurants and shops where every day urbanity is expressed, repair urban infrastructure, and govern multiple urban domains such as traffic, air quality monitoring, garbage collection, and energy. In the age of uncertainty and complexity that is upon us, the increasing adoption of AI is expected to continue, and so its impact on the sustainability of our cities. This viewpoint explores and questions the sustainability of AI from the lens of smart and sustainable cities, and generates insights into emerging urban artificial intelligences and the potential symbiosis between AI and a smart and sustainable urbanism. In terms of methodology, this viewpoint deploys a thorough review of the current status of AI and smart and sustainable cities literature, research, developments, trends, and applications. In so doing, it contributes to existing academic debates in the fields of smart and sustainable cities and AI. In addition, by shedding light on the uptake of AI in cities, the viewpoint seeks to help urban policymakers, planners, and citizens make informed decisions about a sustainable adoption of AI.

Keywords: artificial intelligence (AI); artificially intelligent city; climate change; planetary challenges; smart and sustainable cities; smart city; technological disruption; urban policy; sustainable urbanism; urban artificial intelligences

1. Introduction

Artificial intelligence (AI) is one of the most disruptive technologies of our time [1]. In simple terms, AI can be defined as machines or computers that mimic cognitive functions that humans associate with the human mind, such as learning and problem solving [2]. The field of AI is vast and constantly expanding, and such characterization concerns AI beyond its current capabilities, namely artificial narrow intelligence, thereby comprehending two potential future types of AI: artificial general intelligence and artificial super intelligence [3–5].

AI is already here. AI applications are being used in areas ranging from marketing to banking and finance, from agriculture to healthcare and security, from space exploration to robotics and transport, and from chatbots to artificial creativity and manufacturing [6,7]. In recent years, AI applications

have been also started to become an integral part of the city. AIs manage the transport systems of cities in the shape of autonomous cars [8–10]. Robots run restaurants and shops where core aspects of urban life are everyday played out, and repair urban infrastructure [11,12]. Invisible intelligent platforms govern multiple urban domains ranging from traffic to safety, and from garbage collection to air quality monitoring [13,14]. We refer to this strand of AI as *urban artificial intelligences*—where AIs are embodied in urban spaces, urban infrastructures, and urban technologies, which together are turning cities into autonomous entities operating in an unsupervised manner [15].

Focusing mostly on artificial narrow intelligence and present AI technology, this viewpoint elaborates the rise of AI in cities and discusses the *sustainability of urban artificial intelligence* from the lens of *smart and sustainable cities* [16–19]—where such cities utilize digital technologies to make infrastructure services more efficient and reactive to reduce resource consumption, increase environmental quality, and cut down on carbon emissions [20]. In other words, this viewpoint investigates how AI is being utilized in urban domains, unpacking the sustainability potential and risks that AI technology poses for our cities and their citizens.

In terms of methodology, this viewpoint deploys a thorough review of the current status of AI and smart and sustainable cities literature, research, developments, trends, and applications. Following this introduction, Section 2 highlights the key challenges that humankind faces to achieve sustainability at a planetary scale. Next, Section 3 advocates smart and sustainable cities as a potential urban model to realize sustainable futures. Section 4 puts emphasis on the increasing role of AI as an emerging technology fitting the smart and sustainable city paradigm. Afterwards, Section 5 explores the idea of a possible symbiosis between AI and smart and sustainable cities, and its likely offspring—i.e., the artificially intelligent city. Section 6 discusses how urban AIs can be improved to reach more sustainable urban futures. Lastly, Section 7 concludes the viewpoint with a set of insights meant to orientate urban research, policy and development towards a sustainable adoption of AI in cities.

2. Living in Interesting Times: Planetary Sustainability Challenges

We live in "interesting times", where such period refers to—as in the legendary Chinese curse—a time of danger, uncertainty, and complexity [21]. Unless the underlining drivers behind such dangers, uncertainties, and complexities are not eliminated or brought to a manageable level, these interesting times might coincide with the end of human civilization [22]. The primary underlining reasons—which are the key challenges of humanity today—include: (a) rapidly increasing global population; (b) rapidly depleting natural resources and climate change; (c) technological inequality and disruption; (d) misuse of data and information; (d) ruthless neoliberal economies; (e) global, regional, local conflicts; (f) corrupt or ineffective governance. These challenges are illustrated in Figure 1, and further elaborated below.

Rapidly increasing global population: With the appearance of *Homo sapiens*, the origin of humankind goes back to about 300,000 years ago. However, it is only during the last 10,000 years that we have managed to establish safer living conditions thanks to progress in the spheres of technology, knowledge, and wisdom. Subsequently, in the year 1800, the world's population reached the one billion mark. During the same year, London was the only city in the world hosting a million people. Today over 220 years later, our population is over 7.8 billion, and London is home to 9.3 million people. But, London is no longer the largest city in the world. The metropolitan region of Tokyo is approaching 40 million people, and there are over 30 other megacities around the world with over 10 million people. Population projections suggest that by the end of the century the global population will range between 9 and 12 billion. Along with megacity developments, all major metropolitan regions are also experiencing rapid peri-urban expansion [23]. This dual human–urban growth is causing alarming water, food, and energy insecurity [24–26].

Rapidly depleting natural resources and climate change: Ever increasing populations, coupled with unsustainable development practices, are pushing the limits of the world's carrying capacity [27–30]. Heavy fossil fuel dependency and limited clean-energy options—only about 25% of all the world's energy comes from renewable resources—together with various other contributing factors, are triggering

biodiversity loss and anthropogenic climate change, and increasing the frequency and severity of natural disasters dramatically [31–33].
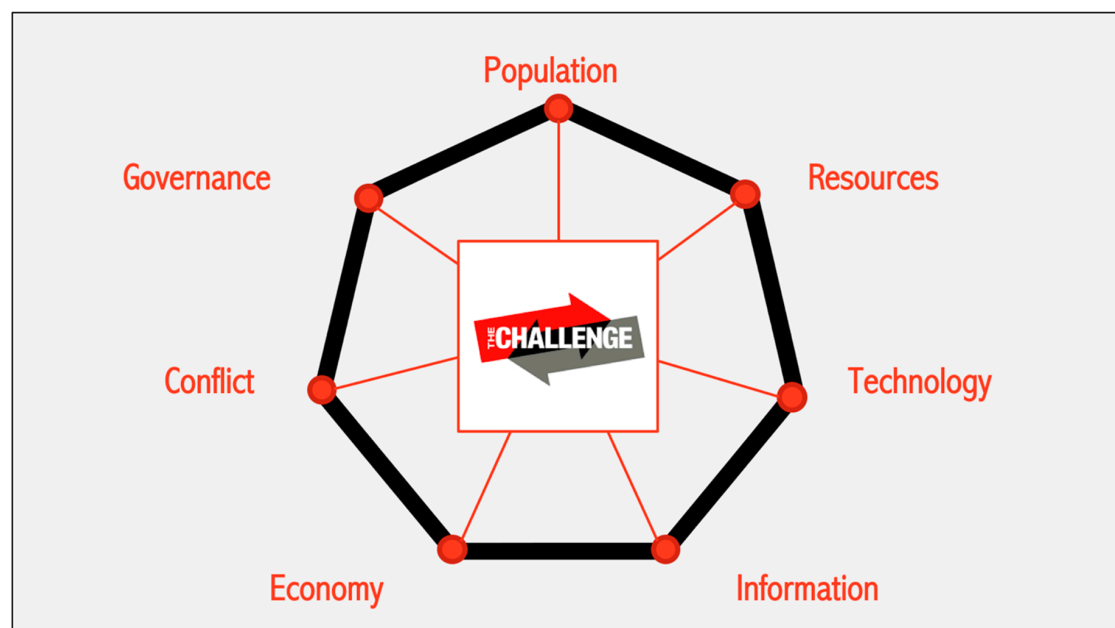

Figure 1. Key global sustainability challenges (Source: Authors).

Technological (or digital) inequality and disruption: Whilst there have been many positive technological inventions and developments, technology also creates disruption in our societies—particularly for those who cannot afford, access or adopt new technologies [34,35]. For instance, despite the fact that there are four billion smartphone users in the world, not everyone has access to the internet and mobile services at the same speed and bandwidth [36]. Particularly from an urban perspective, expensive urban technologies are often unevenly distributed across cities, thus contributing to the fracturing of urban societies and to the formation of high-tech *premium ecological enclaves* where only rich minorities can shield themselves from the burdens of climate change and environmental degradation [37–39].

Misuse of data and information: During the last two decades, with the raise of the second digital revolution and mass digitization, data and information have become more widely and easily accessible. Especially social media platforms and shared user-generated contents have provided large volumes of data. Nonetheless, this has also led to fake news and data integrity issues [40]. Furthermore, targeted Facebook and WhatsApp campaigns changed the results of the 2016 USA and 2018 Brazil presidential elections, and the 2016 Brexit referendum [41–43], thereby showing how data is being used not to inform, but rather to misinform and to protect the interests of certain political elites/groups.

Ruthless neoliberal economies: Today, the world is facing harsh economic challenges. Globally, we are moving towards another recession, if not already in. While some might blame the recent COVID-19 pandemic, the origin of the issue is neo-liberal capitalism and the consumeristic and materialistic practices that it reproduces [44,45] Only eight people, the richest in the world, have a net worth equivalent to that of the lower half of the world's population (about 3.8 billion people); this is the product of ruthless neoliberal economies [46]. Socioeconomic inequality is rapidly widening, and poverty and recession are making life harder for most people across the globe. Particularly with the existing COVID-19 pandemic, the situation is much more dramatic and unsustainable in developing countries, and for disadvantaged communities and individuals [47].

Global, regional and local conflicts: Human civilization has always experienced conflicts and wars over resources, land, or power. However, contemporary wars are not only taking place as trade, diplomatic and armed conflicts, but also as cyber warfare [48]. These multiple conflicts, together with

climate change, are displacing many people, thus substantially increasing the number of refugees in the world [49,50].

Corrupt or ineffective governance: Governments should have supposedly addressed the aforementioned challenges. Instead, short termism in political circles, corporate influence, and various degrees of corruption make governments unable to be part of the solution [51]. An example is the Paris Agreement on climate change, which, although signed by 197 countries (and ratified by 189), has led to little or no tangible outcome due to government inaction [52].

3. Smart and Sustainable Cities: An Urban Focus to Achieve Sustainability

The aforementioned issues are extremely challenging to tackle, but they are not discouraging many scholars and thinkers from searching for solutions to realize more sustainable futures [53–55]. Today, approximately 55% of the global population lives in cities whose fabric is rapidly expanding across the planet [56]. The figure is over 85% in many countries—such as Australia, the UK, and the Netherlands [57]. This makes urban areas the prime focus of sustainability policy, not only because they house the majority of the world's population, but also because they contain the core of global socioeconomic activities [58,59]. The changing focus from *nation* to *city* has created new and alternative ideas for building sustainable futures by placing cities at the center of policy actions [60].

In recent years, one of the most prominent ideas in urban policy circles has been the imperative to employ information and communication technology (ICT), in order to address major urban and societal challenges [61]. This trend gave birth to the notion of 'smart city'. While the origin of the concept of smart city dates back to centuries ago, the practice of smart urbanism has been made popular only in the 2000s with urban projects led by private companies like IBM and Cisco [62–64]. Since then, many major technology, construction, and consultancy companies, together with policymakers and city planners, have jumped onto the smart city bandwagon [65,66]. This has resulted in a myriad of smart-city initiatives that are reshaping existing cities and building new ones all over the world [67,68]. In a nutshell, a smart city is, in theory, a locality that uses digital data and technology to improve efficiency in different interconnected urban domains (such as energy, transport and safety), eventually resulting in economic development, better quality of life and sustainability [69].

Nevertheless, in practice, this is not always the case. Numerous studies have shown that, actually, existing smart cities are often disproportionately driven by economic objectives and incapable of addressing social and environmental concerns [70–75]. This is why, in recent years, the focus of smart-city research has shifted towards the 'smart and sustainable city', in the attempt to rebalance the economic, social, and environmental dimensions of smart urbanism [76–78]. A conceptual framework is provided in Figure 2. A smart and sustainable city is defined as an urban locality functioning as a robust system of systems with sustainable practices, supported by community, technology, and policy, to generate desired outcomes and futures for all humans and non-humans [79].

This conceptualization utilizes the Input-Process-Output-Impact approach [80]. As the key 'input', we have the city and its indigenous assets. By using this asset base, three 'processes'—i.e., technology, policy, and community—generate strategies, actions, and initiatives. These result in 'outputs' in the economy, society, environment, and governance domains. When these outputs are aligned with knowledge-based and sustainable urban development goals, principles, and practices, they produce the desired 'impact' for a smart and sustainable city [79].

The framework underlines that, despite the prevalent technocentric perspective in the making of smart cities, in order to create cities that are smart *and* sustainable, we actually need a balanced view on the community, technology, and policy trio as the driver of transformation. It also highlights that cities should not be understood and treated as mere technological artefacts, but rather as social processes, and that sustainability should not be approached in a one-dimensional way, but rather holistically as the equilibrium among diverse social, environmental, and economic spheres [81–83]. In other words, technology will only lead to sustainability if its adequateness is thoroughly scrutinized via community engagement, and its implementation is carried out via a sound policy and government monitoring [79].
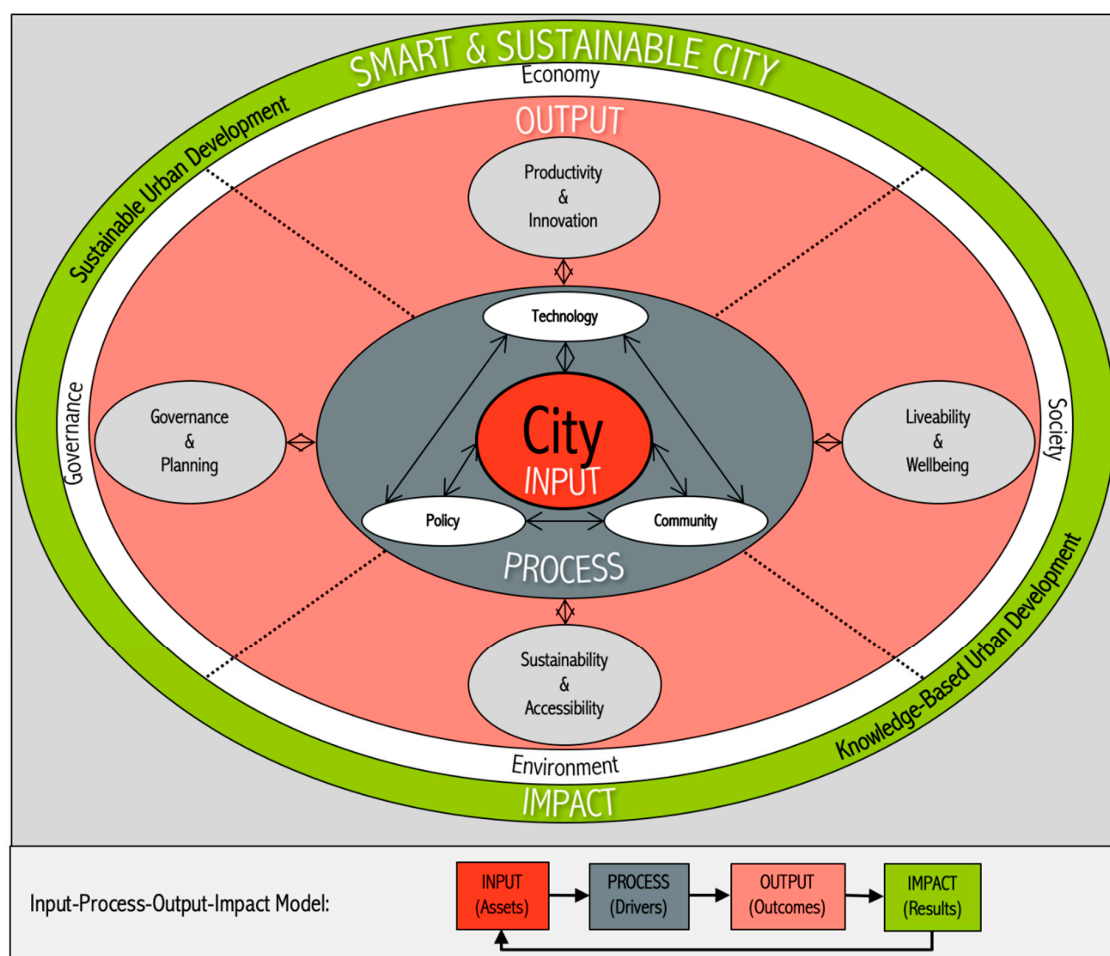
Figure 2. A conceptual framework of smart and sustainable cities, derived from [79].

4. Smart and Sustainable City Technologies: The Increasing Role of Artificial Intelligence

Digital technologies are increasingly offering new opportunities for cities in their journey to become smart and sustainable—especially in relation to issues of community engagement and participatory governance [84]. There is a large variety of smart and sustainable city technologies available today and their list is exhaustingly long [85,86]. For instance, in a recent study, Yigitcanlar et al. [87] have identified the most popular smart and sustainable city technologies in Australia by means of social media analytics. The study concentrated on determining what the key smart city concepts and technologies are, and how they are perceived and utilized in Australia. The results have shown that the concepts of innovation and sustainability, and Internet-of-things (IoT) and artificial intelligence (AI) technologies, are the dominant ones. Unsurprisingly, these top technologies are merging today to form artificial-intelligence-of-things (AIoT) [88] to achieve more efficient IoT operations, improve decision-making and human-machine interactions, and enhance data management and analytics [89].

There is neither a universal definition of AI, nor an established blueprint to build one [4,90]. In simple terms, an AI is a nonbiological intelligence that mimics the cognitive functions of the human mind, such as learning and problem solving [91,92]. More specifically, an artificially intelligent entity is supposed to possess the following capabilities: the ability to learn by acquiring information on the surrounding environment, the capacity to make sense of the data and extract concepts from it, the skill of handling uncertainty, and the power to make decisions and act without being supervised [15]. There are several types of machines and algorithms, which possess the above capabilities at different levels of development, meaning that there are various levels of AI [93]. These levels are illustrated in Figure 3 and described below.
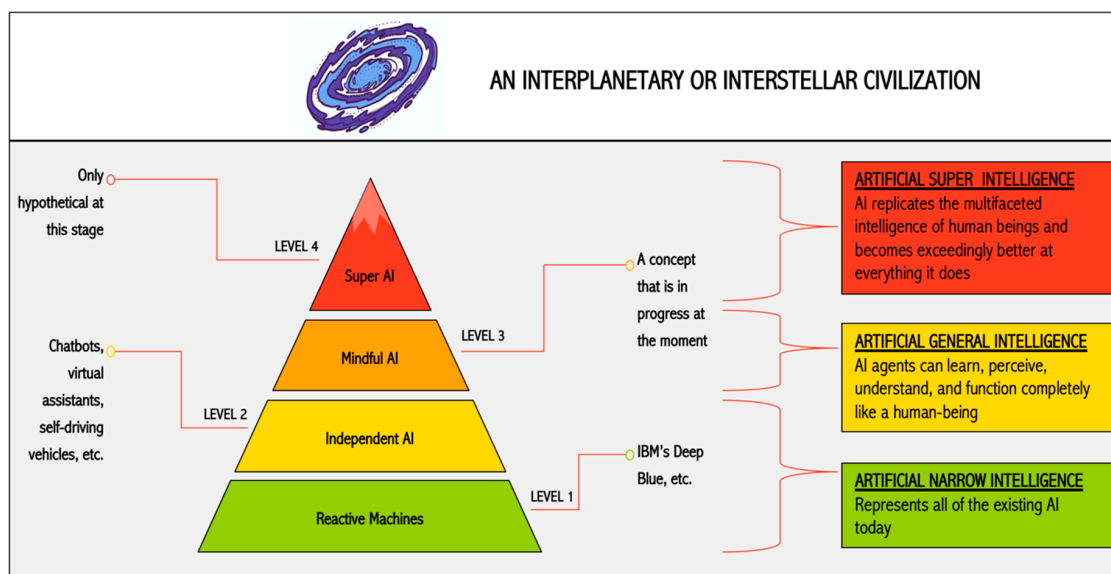
Figure 3. Levels of artificial intelligence (Source: Authors).

In 1997, IBM's Deep Blue defeated the then World Chess Champion Garry Kasparov—that was a remarkable twist in the story of AI and intelligent machines. However, it is more appropriate to classify Deep Blue as a 'reactive machine' (Level 1), since this AI is programmed to undertake one single task, and it does not have the capacity to learn and improve itself [94]. Above all, this type of AI does not take the initiative. It mostly *reacts* to human inputs, rather than planning and pursuing its own original agenda. Its actions and ideas are derivative and are triggered in response to external stimuli.

The next level (Level 2) is the 'Independent AI'. In 2016, Google's AlphaGo beat the international Go champion Lee Sedol. Go is arguably the most complex board game ever invented by mankind, and AlphaGo won thanks to its learning ability and capacity to take original actions that its human opponent could not foresee. This victory was an extraordinary outcome and boosted AI research world-wide. A similar, although less spectacular example, are now common AI chatbots which today many companies are using to interact with their customers on their websites. Other examples range from apps that regulate our phones and homes, to autonomous vehicles that are capable of determining and executing complex routes in chaotic urban environments [95–97]. What these AIs have in common is that they all operate independently. Human actions do not dictate their actions. Independent AIs proactively come up with their own agenda and implement it without humans leading the way.

The above categories constitute what is commonly referred to as 'artificial narrow intelligence'. This is the AI level that we have reached to date in practice, and that is becoming a common sight in contemporary cities and societies. However, R&D efforts are constantly leading to bolder and more innovative theories such as the 'theory of mind AI', which pictures an AI system that has beliefs, desires, and emotions [98]. A 'self-aware AI' is likely to be the next level of AI, thereby producing machines which actually function like us [99]. We call this level 'Mindful AI' (Level 3) to denote artificial intelligences which not only have a mind and are capable of thinking. They are also conscious of their own mind and thoughts which they apply to multiple domains of knowledge. This is the level of 'artificial general intelligence' at which machine behavior is almost indistinguishable from human behavior.

Mindful AIs, and artificial general intelligence more in general, are hypothetical stages of development, which could become the steppingstone to further technological progress in the field of AI. The ultimate level of AI that has so far been imagined is the 'artificial super intelligence'. Here at the 'Super AI' level (Level 4), the AI does everything and anything better than us humans [100]. The opinions of scholars on superintelligence are mixed. While some believe that this could be mankind's last invention leading to the end of human civilization, others posit that this technology could be the

beginning of a new era as our only chance of leaving this planet and establishing an interplanetary or interstellar civilization [101–103].

As urbanists interested in the present and near future of urban development, we deal with those existing technologies that are already in the process of altering the sustainability of cities. The rest of the viewpoint will, therefore, focus on artificial narrow intelligence. This vast field of AI includes technologies with at least one of the following capabilities: (a) *perception* including audio/visual/textual/tactile (e.g., face recognition); (b) *decision-making* (e.g., medical diagnosis systems); (c) *prediction* (e.g., weather forecast); (d) *automatic knowledge extraction and pattern recognition* (e.g., discovery of fake news); (e) *interactive communication* (e.g., social robots or chat bots); (f) *logical reasoning and concept extraction* (e.g., theory development from premises) [104]. Mapping out the state of the art in AI is highly useful to better understand the capacities and impact of artificial narrow intelligence. Figure 4 illustrates the key AI problem domains and paradigms.
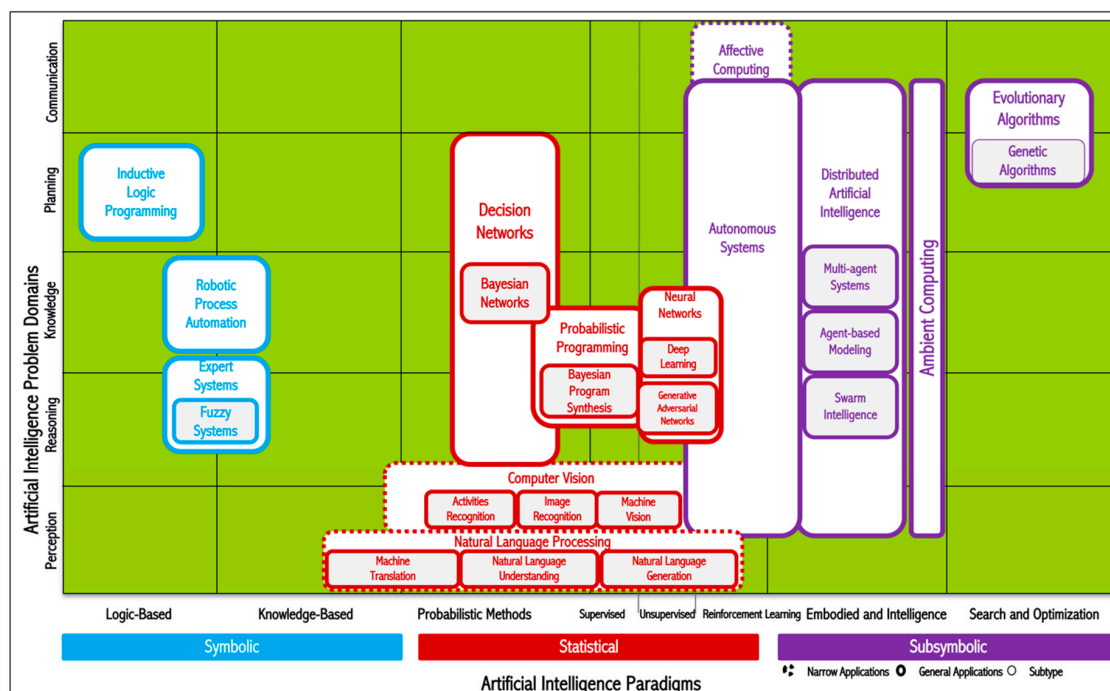

Figure 4. Artificial intelligence knowledge map, derived from [105].

Artificial narrow intelligence is increasingly becoming part of our lives, and an integral element of our cities. For instance, in many parts of the world, states are trialing AI-driven cars to prepare their cities and citizens for the disruptions that autonomous driving will generate [97,106–108]. Robotic dogs are employed in places like Singapore for monitoring social distancing in the era of COVID-19 [109]. A couple of years ago, Dubai has started robot police services meant to stop petty crime [110]. Hospitals in a number of countries, such as Japan, are employing robot doctors [111]. Many homes are getting safer and more energy efficient due to smart home technology and services, and home automation, or *domotics*, is becoming a big part of the construction industry [112]. Websites of both major corporations and ordinary companies have now chatbots to respond to clients' inquiries [113]. In China and Malaysia, large-scale urban artificial intelligences called *city brains* are managing the transport, energy and safety systems of several cities [15].

Additionally, AI is an integral part of environmental research in a number of countries such as Australia, where autonomous drones are detecting via machine learning environmental hazards and animals in danger of extinction [114,115]. Today, most smart phones offer an AI as a personal assistant [116]. Overall, these examples are only the tip of the AI iceberg, as the largest application of AI technology is in analytics. Many of the decisions impacting our life are being made as a result of

descriptive, predictive, and prescriptive analyses of data collected and processed by AI [117,118]. In other words, AI-aided urban data science is being extensively used today in cities across the globe, to address the uncertainties and complexities of urbanity [119,120].

5. The Symbiosis: Towards an Artificially Intelligent City?

AI is one of the most powerful and disruptive technologies of our time, and its influence on urban settlements and activities is growing rapidly, ultimately affecting everyday life [121,122]. Given that cities are the main hubs and drivers of most socioeconomic activities, political actions, and environmental transformations, it is important to understand how the development of AI and the development of the city are intertwining [123]. This brings up the question of whether there is or could be a symbiotic relationship between them, and if this revolutionary technology could offer novel sustainability solutions feeding into new urban models. After all, AI has already entered our cities, and it is therefore essential to critically examine and question its urban sustainability potential [15].

A study by Yigitcanlar et. al. [124] investigated these questions through a thorough systematic literature review—99 peer-reviewed research articles concentrating on both smart cities and AI. The study arranged the findings under four smart city domains, as shown in Figure 2—i.e., economy, society, environment, governance.

In terms of the 'economy' domain of smart cities, the AI focus is predominately on technological innovation, and business productivity, profitability and management. Some of the most typical contributions of AI to this domain include [124]:

- Enhancing firm productivity and innovation by automating data management and analysis processes;
- Increasing the efficiency and effectiveness of existing resources, and reducing additional costs through pattern recognition;
- Supporting decision-making by analyzing large volumes of data—e.g., big data analytics—from multiple sources;
- Drawing conclusions to facilitate informed decisions based on logic, reason, and intuition via deep learning.

In terms of the 'society' domain of smart cities, the AI focus is predominately on the public health, wellbeing, and education areas. The COVID-19 pandemic is particularly accelerating the use of AI in these areas. The main contributions of AI to this domain include [124]:

- Improving community health monitoring via smart sensors and analytics tools embedded in homes and/or workplaces;
- Enhancing public health diagnoses through medical imaging analytics, particularly in radiology and healthcare services;
- Providing autonomous tutoring systems to teach algebra, grammar, and other subjects to pupils and adults;
- Offering personalized learning options to facilitate students' progress and expand their curriculum.

In terms of the 'environment' domain of smart cities, the AI focus is predominately on the transport, energy, land use, and climate areas. Some of the key contributions of AI to this domain include [124]:

- Operationalizing smart urban transport systems via mobility-as-a-service (MaaS)— integration of various transport services into a single on-demand mobility service;
- Optimizing energy production and consumption via domotics—home technologies with a focus on environmental issues, energy saving, and lifestyle improvement;
- Monitoring changes in the natural and the built environment via remote sensing with autonomous drones—used for multiple-object detection and tracking in aerial videos;

- Predicting the risks of climate change via machine learning algorithms combined with climate models—employed to foresee potential disastrous events in specific geographical areas and act in advance.

Moreover, beyond urban environmental issues, AI is also being used for addressing planetary environmental challenges. Overall, as Vinuesa et al. [104] have argued, AI applications can potentially contribute to achieving 17 Sustainable Development Goals (SDGs). Below, we provide a summary of the application areas touched by AI technologies, specifically in relation to environmental sustainability.

- AI application areas for *climate change/crisis mitigation* include: research, urban, and regional planning, land use, home, mobility, energy production and consumption [125–127];
- AI application areas for *ocean health* include: sustainable fishery, pollution monitoring, reduction and prevention, habitat and species protection, and acidification reduction [128–130];
- AI application areas for *clean air* include: pollutant filtering and capture, pollution monitoring, reduction and prevention, early pollution and hazard warning, clean energy, and real-time, integrated, adaptive urban management [131–133];
- AI application areas for *biodiversity and conservation* include: habitat protection and restoration, sustainable trade, pollution monitoring, reduction and prevention, invasive species and disease control, and natural capital enhancement and protection [134–136];
- AI application areas for *clean water security* include: water supply quantity, quality and efficiency management, water catchment control, sanitation, and drought planning [137–139];
- AI application areas for *weather and disaster resilience* include: prediction and forecasting, early warning systems, resilient infrastructure and planning, and financial instruments [140–142].

In terms of the 'governance' domain of smart cities, the AI focus is predominately on national and public security, urban governance and decision-making in government. Some of the principal contributions of AI to this domain include [124]:

- Deploying smart poles as digital sensors, and providing technological tools for citizen scientists to act like human sensors, for making informed decisions—smart poles and volunteer citizens equipped with smart tech, generate big data that is processed by AI;
- Aiding management, planning, and operations related to disasters, pandemics and other emergencies via predictive analytics—using AI to make predictions about future events;
- Enhancing the operability of surveillance systems via smart poles with AIoT (although due to cyber-attacks and privacy issues, benefits exist together with major concerns);
- Improving cybersecurity by analyzing data and records on cyber incidents, identifying potential threats, and providing patches and options to improve cyber security.

Nonetheless, the above list of benefits should not obscure that of the many problems that AI is bringing. AI is a double-edged sword. This sentient sword can be used to fight against global sustainability issues, but it can also cause much collateral damage as well as harm those who wield it. The drawbacks of AI are equal to its potentials [143]. Below, we provide a summary of prospects and constraints of AI according to different smart city domains [144]. As pointed out earlier, we need more than *technology* to achieve urban sustainability. Particularly *policy* and *community*, which are the other two drivers of smart and sustainable cities (see Figure 2), should be refined and operationalized to neutralize the technological shortcomings of AI.

- On the one hand, the *prospects* of AI in the *economy* domain include: enhancing productivity and innovation, reducing costs and increasing resources, supporting the decision-making process, automating decision-making [145–147]. On the other hand, the *constraints* of AI involve: making biased decisions, having an unstable job market, losing revenue streams and employment, and generating economic inequality [148–150].

- On the one hand, the *prospects* of AI in the *society* domain include: improving healthcare monitoring, enhancing medical diagnoses, increasing the adaptability of education systems, personalizing teaching and learning, and optimizing tasks [151–153]. On the other hand, the *constraints* of AI involve: making biased decisions, making misdiagnoses, having an unstable job market, losing employment, and undermining data privacy and security [154–156].

- On the one hand, the *prospects* of AI in the *environment* domain include: assisting environmental monitoring, optimizing energy consumption and production, optimizing transport systems, and assisting the development of more environmentally efficient transport and logistic systems [157–159]. On the other hand, the *constraints* of AI involve: making biased decisions, increasing urban sprawl, leading to more motor vehicle kilometers traveled, destabilizing property values, establishing heavy energy dependency due to intensive use of technology, and increasing carbon footprints [160–162].

- On the one hand, the *prospects* of AI in the *governance* domain include: enhancing surveillance system capacity, improving cyber safety, aiding disaster management planning and operations, and assisting citizen scientists with new technologies in producing crowdsourced data/information [163–165]. On the other hand, the *constraints* of AI involve: making biased decisions including racial bias and discrimination, suppressing public voice/protests/rights, violating civil liberties, causing privacy concerns, using technology unethically, risking the spread of misinformation, and creating cybersecurity concerns [166–168].

The above prospects and constraints should be evaluated in relation to the five different levels of autonomy that characterize the decision-making power of AI [15,169]. Level 0 corresponds to no autonomy—meaning full human control on every decision. Levels 1 and 2 correspond to assisted decision-making, where in Level 2 AI offers moderate assistance or recommendation. In Level 3, decisions require human approval, whilst in Level 4 only human monitoring or human oversight is needed, to step in in case of a problem. Level 5 is equal to complete autonomy, meaning that decisions are taken by an AI in an unsupervised manner. As we progress to Level 5, both the magnitude of disruption and opportunity will become greater. With this greater power, AI will have to assume greater responsibility, and it will be thus crucial to develop 'responsible and ethical AI' before we get to Level 5 [170–172]. From an urban point of view, AI technology is progressing fast, thereby gaining more and more autonomy in cities. Especially in experimental cities, where the pace of technological innovation is usually rapid, we can already see parts of the built environment that are not *automated* but rather *autonomous*.

The key difference between *automation* and *autonomy* is that an automated technology repetitively follows patterns previously established by a human intelligence, while an autonomous technology establishes its own patterns, seldom repeating the exact same action [15]. Simply put, this is the difference between an elevator always going up or down stopping at invariable floors, and an autonomous car which can traverse entire cities and never follow the same route twice. The difference is critical because autonomous AIs operate in real-life environments where the life of real people is at risk. Not in a confined elevator shaft but in, for example, an urban road shared by hundreds of individuals. Here unsupervised, AIs have to make important decisions and take actions that can actually kill. This is the case of the first pedestrian fatality caused by an autonomous car in Tempe (Arizona) in March 2018. An autonomous Uber was incapable of dealing with the uncertainty that is typical of unconfined urban spaces, and its incapacity killed a woman that was crossing a road outside the designated crossing lane [173]. The greater the autonomy of AI is, the greater its constraints are, given that, to date, we do now have urban artificial intelligences that can fully understand what is right or wrong (the issue of ethics) and then answer for their behavior (the issue of responsibility).

Furthermore, it is important to recognize that both the fields of smart and sustainable cities and AI are in constant evolution. As Sections 3 and 4 have illustrated, numerous smart-city projects have been implemented and an even larger number is under development, while the evolution of AI has reached only two levels out of four. This means that we have seen only a small part of what smart urbanism

and AI can potentially offer. Whether the best or the worst is yet to come, is an open question. For sure, at the moment there is neither an ideal AI system, nor an ideal smart and sustainable city that can serve as a universal model of development and, given the many geographical differences that exist in the world, the very idea of having a global paradigm is questionable in the first place [68,174,175]. This is to say that we need to continue researching both conceptualizations and practical applications of AI and smart and sustainable cities, across geographical spaces and scales [176]. Only then will we be able to analyze and fully evaluate the symbiosis between AI and the city and understand whether this can give birth in particular places to 'artificially intelligent cities' [144].

Lastly, there is the critical issue of how we define and construct artificially intelligent cities. In its current conceptualization, an *artificially intelligent city* "is a city where algorithms are the dominant decision-makers and arbitrators of governance protocols—the rules and frameworks that enable humans and organizations to interact, from traffic lights to tax structures—and where humans might have limited say in the choices presented to them for any given interaction" [177]. For such type of cities to achieve a condition of sustainability, the issues of transparency, fairness, ethics, and the preservation of human values need to be carefully considered. These unresolved issues are intrinsic to AI and thus hinder its sustainability. In other words, in order to improve the chances that the city of artificial intelligence becomes a sustainable city, we need better AI, and this will be the topic of the next section.

6. Discussion: Better Artificial Intelligence for Better Cities

Makridakis [178] asks the question of whether the AI revolution creates a utopian or dystopian future, or somewhere in between. The answer to this question fully depends on how we are going to tackle the drawbacks of AI, and how we are going to utilize AI in our cities, businesses and, more in general, lives. As Batty [179] remarks, it is hard to predict the exact future of cities, while it is possible to build future cities, meaning that we can actively work in the present to improve contemporary cities and our results will ultimately be the cities of the future. Following this line of thought, if we focus on the pitfalls of AI, we can then search for ways to actually make AI better. *Better* in the sense of more useful to make our cities and societies more sustainable. The key areas of improvement to reach AIs that are conducive to sustainability, are illustrated in Figure 5, and further elaborated below.

Figure 5. Areas of improvement for artificial intelligence (Source: Authors).

The first issue to consolidate a sustainability-oriented AI is *stakeholder engagement*. In general, AI technologies are created exclusively by technology companies without any or much consultation with wider interest groups or stakeholders. Active collaboration among a wide and inclusive range of stakeholders—ideally in the form of quadruple helix model participation of public, private, academia and community—in the development and deployment stages, in particular, will improve the caliber of the sustainability potential of AI [180,181]. This is, in essence, a matter of inclusion and democracy. Given that the ethos of sustainability is about achieving a *common future*, we argue that no common future can be envisioned and realized unless proper forms of democratic governance are in place. Specifically, in relation to AI, this means that each AI technology affecting cities should be discussed by all urban stakeholders, instead of being imposed in a top-down manner by influential tech companies.

The second issue is the *trust* problem. The blackbox nature of the decisions taken by AIs without much transparency (which, at times, are wrong), the possibility of AI failing in a life-or-death context, and cybersecurity vulnerabilities all limit public trust. AI technology needs to earn the trust not only in the public and the way people perceive it, but also in the minds of companies and government agencies that will be investing in AI [182–184]. This is a challenging problem because, as Greenfield [121] notes, AI is an arcane technology meaning that, although it is already part of the everyday of many people, its mechanics and actual functioning are understood by only a few.

The next area of improvement concerns the *agility* issue. AI systems should be competent enough to deal with complexity and uncertainty, which are extremely common features of contemporary cities [185]. Besides, AI systems should focus on the problem to be solved, rather than just on the data whose collection is arguably meaningless from a sustainability point of view, unless it serves the purpose of addressing a previously identified SDG. In addition, AI technology needs to be as frugal and affordable as possible. This is critical for a wider uptake of AI across cities through public sector funds [186,187]. Expensive AIs are ultimately elitist AIs, which only a rich minority can afford. Elitist AIs can only be unevenly distributed, thus creating a divide among richer and poorer cities, as well as internal fractures within individual cities where small premium enclaves coexist next to disadvantaged districts.

The fourth issue is the *monopoly*. A monopolistic structure behind technology development and deployment is problematic as a lack of competition limits technological variation. Avoiding AI monopolies can make AI technologies more affordable and support current efforts in 'open AI' development. This, in turn, would also promote the democratization of AI research and practice, as well as decrease the risk of the formation of a *singleton* [188,189]. According to Bostrom [4], a singleton is a world order in which one super intelligent agent is in charge. This is an unlikely situation when it comes to Level 1 and 2 AIs, but it might not be a remote possibility if only one tech company in the world has the capacity to build an artificial super intelligence.

Another critical issue is *ethics*. We need to develop AI in a way that it respects human rights, diversity, and the autonomy of individuals. The European Commission's recent ethical guidelines for AI development offer a good starting point [190]. However, as stated by Mittelstadt [191], principles alone cannot guarantee the development of an ethical AI. Hence, we need to develop globally an AI ethics—a multicultural system of moral principles that takes the risks of AI seriously—together with a mechanism to monitor ethics violations. Ethics should ensure the design of AI technologies for human flourishing around the world [192,193], but this is a very complex matter given that, as the work of Awad et al. [194,195] clearly demonstrates, universally valid and accepted ethical principles do not exist.

The sixth issue relates to *regulation* and regulatory challenges. AI cannot achieve sustainability and the common good if it is not regulated. In a situation in which different AI users (or potentially different mindful and super intelligent AIs) can do whatever they want, it is extremely unlikely that the common good will be achieved. Different actors will follow diverse trajectories and reach heterogenous (and not necessarily mutually beneficial) outcomes. This poses a big risk for society—particularly for disadvantaged groups, historically-marginalized groups, and low-income countries. Thus, we

need well-regulated and responsible AIs with disruption mitigation mechanisms in place. Such regulation should also protect public values [196,197], and extent to the built environment. It is well documented in urban studies that, when urban development is unregulated, key sustainability themes (such as justice and environmental preservation) get neglected and overshadowed by economic interests [198,199]. Therefore, the regulation of AI and the regulation of the built environment should go hand in hand as a dual policy priority.

The last issue concerns the development of AI for *social good*, and for the benefit of every member of society [200]. AI and data need to be a shared resource employed for the good of society, rather than for serving the economic agenda of corporations and the interests of political elites. An *AI for all* would require establishing AI commons [201] and a similar attempt has been previously made to establish digital commons [202]. AI commons are supposed to allow anyone, anywhere, to enjoy the multiple benefits that AI can provide [203]. AI commons should be studied and pursued to enable AI adopters to connect with AI specialists and AI developers, with the overall aim of aligning every AI towards a shared common goal [204]. From an urbanistic perspective, this is arguably the biggest challenge, because opening up AI as a common good requires also opening up urban spaces, thinking about the city as a truly public resource rather than a territory balkanized by neoliberal ambitions.

7. Conclusions: The Next Big Sustainability Challenge

This viewpoint has explored the prospects and constraints of developing and deploying AI technology to make present and future cities more sustainable. The analysis has shown that, while AI technology is evolving and becoming an integral part of urban services, spaces, and operations, we still need to find ways to integrate AI in our cities in a sustainable manner, and also to minimize the negative social, environmental, economic, and political externalities that the increasingly global adoption of AI is triggering. In essence, the city of AI is not a sustainable city. Both the development of AI and the development of cities need to be refined and better aligned towards sustainability as the overarching goal. With this in mind, the viewpoint has generated the following insights, in the attempt to improve the sustainability of AI and that of those cities that are adopting it.

First of all, AI as part of urban informatics significantly advances our knowledge of computational urban science [205]. In the age of uncertainty and complexity, urban problems are being diagnosed and addressed by numerous AI technologies. However, from a sustainability perspective, the quality of our decisions about the future of cities heavily depends on this computational power (technology), *and* on the inclusivity of decision-making and policy processes. The greater computational power offered by AI, therefore, is not enough to achieve sustainability, unless it is coupled with systems of democratic governance and participatory planning.

Second, AI is being exponentially used to improve the efficiency of several urban domains such as business, data analytics, health, education, energy, environmental monitoring, land use, transport, governance, and security. This has a direct implication for our cities' planning, design, development, and management [206]. Yet, the different uses of AI tend to be fragmented, in the sense that heterogeneous AIs are targeting heterogeneous issues and goals without a holistic approach. Coordinating the many AIs present in our cities is thus necessary for a sustainable urbanism, given that sustainability is about thinking and acting in terms of *the whole* rather than single parts. On these terms, artificial narrow intelligences working on narrow tasks are missing the broad spectrum of social, environmental, and political issues, which is essential to achieve sustainability. We cannot and should not expect a hypothetical future artificial general intelligence to fill this lacuna [207]. Human initiative and coordination are needed now.

Third, the autonomous problem-solving capacity of AI can be useful in some urban decision-making processes. Still, the utmost care is needed to check and monitor the accuracy of any autonomous decisions made by an AI—human inputs and oversight are now critical in relation to artificial narrow intelligence, and they would be even more important should innovation reach the stage of artificial general intelligence [208]. AI can help us optimize various urban processes and can

actually make cities smarter. We can move faster towards the goal of smart urbanism, but if we want to create smart *and* sustainable cities, then human intelligence must not be overshadowed by AI.

Fourth, AI can drive positive changes in cities and societies, and contribute to several SDGs [104,209]. Nonetheless, despite these positive prospects, we still need to be cautious about selecting the right AI technology for the right place and ensuring its affordability and alignment with sustainability policies, while also considering issues of community acceptance [210]. AI should not be imposed on society and cities, but rather discussed locally at the community level, taking into account geographical, cultural, demographic and economic differences. Sustainability can only be achieved with a healthy combination of technology, community and policy drivers, hence the urgent need to develop not only technologically, but also socially and politically.

Fifth, we need to be prepared for the upcoming and inevitable disruptions that AI will create in our cities and societies. The diffusion of AI will not be a black and white phenomenon. Many shades of grey will characterize the deployment of heterogeneous AIs in different parts of the world. Even in an optimistic scenario in which a 'benign AI' is promoting sustainability, somewhere someone/something will still be suffering. It is thus imperative to develop appropriate policies and regulations, and to allocate adequate funds, in order to mitigate the disruption that AI will cause to the most disadvantaged cities and social groups, and nature [211]. As we mentioned earlier, sustainability is not about single parts, but rather about the whole. Any form of development that fractures cities, societies, and the natural environment, producing winners and losers, is not sustainable. Like a hurricane, AI is likely to shake everything that we see, know, and care about. It should not be forgotten that we are only as strong as the weakest member of the society.

Sixth, a symbiotic relationship between AI and cities might become a concrete possibility in the future. Combined with progress in public policy and community engagement, progress in AI technology could mitigate the global sustainability challenges discussed in Section 2 [212]. In so doing, while the city might benefit from AI technologies and applications, AI might also benefit from the city to advance itself. This is a key aspect of the intersection between the development of AI and the development of the city. As we explained in Section 4, a key AI skill is learning. AIs learn by sensing the surrounding environment, thereby gaining and accumulating knowledge [15]. Learning is also how AIs improve themselves. AI is a technology that learns from the collected data, from its errors as well as from the mistakes made by other AIs and human intelligences. On these terms, the city represents the ideal learning environment for AI. Cities are the places where knowledge concentrates the most, where a wide-range of events occur, where numerous actors meet and where the biggest mistakes and greatest discoveries of mankind have been made. It this in this cauldron of ideas and experiences that we call *city* that contemporary artificial narrow intelligences can learn the most, potentially evolving into artificial general intelligences.

Seventh, we need to further decentralize political power and economic resources to make our local governments ready for the AI era that is upon us. While planning for a sustainable AI uptake in our cities is crucial, presently, almost all local governments in the globe are not ready—in terms of technical personnel, budget and gear—to thoroughly plan and implement AI projects city-wide [213,214]. Most AI technologies are expensive and it is therefore important to make them affordable, in order to avoid an uneven distribution and ultimately injustice. If AI is to become part of the city, then we need to think of AI not as an elitist technology, but rather as a common good on which everybody has a say. This is, in turn, a question of urban politics and a matter of politicizing AI so that its deployment in cities is discussed and agreed as inclusively and as democratically as possible, instead of being dictated by a handful of influential tech companies. Sustainability will not be achieved in a technocracy.

Eighth, some of the changes triggered by AI might be invisible and silent and, yet, their repercussions are likely to be tangible and loud from an urban perspective. For example, AI is clearly impacting on the economies of cities [215]. This impact will get deeper and wider as innovation keeps improving and expanding the capabilities of artificial narrow intelligences. *What is the role of humans in an economy in which artificial narrow intelligences, artificial general intelligences and artificial*

super intelligences can cheaply perform human tasks faster and better? This is a recurring question in AI studies, to which we add a complementary urban question: *What is the role of cities as economic hubs in the era of AI?* A key reason why cities exist is that they provide the spaces that are necessary to perform and accommodate human labor and to train humans in many work-related fields. However, AI is undermining this *raison d'etre*. If human labor decreases or, worse, ceases to exist in cities, then cities are likely to decline and cease to exist too [1]. Now more than ever it is therefore vital to reimagine, replan and redesign cities in a way that their function and shape are not dictated by and dependent on human economies. This is both a matter of rethinking the economic dimension of cities and galvanizing the social, cultural, psychological, political, and environmental dimensions of urban spaces.

Lastly, in the context of smart and sustainable cities, AI is an emerging area of research. Further investigations, both theoretical and empirical, from various angles of the phenomenon and across disciplines, are required to build the knowledge base that is necessary for urban policymakers, managers, planners, and citizens to make informed decisions about the uptake of AI in cities and mitigate the inevitable disruptions that will follow. This will not be an easy task because AI is a technology while the city is not. Cities are primarily made of humans and are the product of human intelligence. The *merging of artificial and human intelligences in cities* is the world's *next big sustainability challenge*.

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