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Insights/Opinion

Promoting Urban Studies and Practice with Emerging Technologies: City Laboratory, New City, and Future City Exploration

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The Fourth Industrial Revolution, marked by emerging/disruptive technologies like mobile internet, big data, robotics, artificial intelligence (AI), immersive media (VR/AR/MR), and the Internet of Things (IoT), is transforming cities and promoting urban development. This paper argues that these technologies foster urban studies and implementation in three pathways: methodology, epistemology, and practice. First, the new data environment offers a foundation for quantitative and objective urban studies, enabling researchers to treat cities as laboratories and conduct city experiments worldwide. Second, emerging technologies are reshaping contemporary urban life and space, promoting the update of urban theories. Third, these technologies are expected to be applied as new elements in the urban planning and design processes to create smart urban spatial forms that cater to contemporary needs. Overall, this paper highlights the potential significance of emerging technologies for urban research and development in terms of research methods and data support, theoretical updates and iterations, and practical urban planning and design.

Keywords: Fourth Industrial Revolution; disruptive technology; big data; smart city; data-driven.

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1. Introduction

The Fourth Industrial Revolution has been profoundly reshaping economics, societies, and individuals, and transforming cities through the integration of a range of emerging technologies, represented by mobile internet, big data, robotics, artificial intelligence (AI), immersive media (virtual reality/augmented reality/mixed reality), and the Internet of Things (IoT) (Moffitt 2018; Schwab 2017). The fusion and interaction of these technologies are not only playing an increasingly essential role in reshaping urban daily life and space but also creating unprecedented opportunities to accurately depict and understand cities, thereby further supporting more refined-scale urban planning and management practice (Long and Zhang 2021; Engin *et al*. 2020).

The state-of-the-art studies examining how technology shapes urban development revolve around three key aspects. Some scholars acknowledge the merits of big data derived from Information and Communication Technology (ICT) in providing unprecedented opportunities to sense fine-scale socioeconomic activity and mobility (Liu *et al*. 2015), explore the new science of cities (Batty 2013a), and enhance decision making and management (Karimi *et al*. 2021). Some scholars emphasize the pivotal role played by emerging technologies, such as the internet, mobile devices, and IoT, in reshaping individual behaviors and influencing the structure of urban spaces based on observations and prospects (Mitchell 2000), case studies (Ghonimi 2021), and simulations (Czamanski and Broitman 2017). Additionally, some scholars focus on identifying the practical applications of cutting-edge technologies to aid urban planners and designers in enhancing resource utilization efficiency, improving the quality of life, achieving a higher level of transparency and openness (Al Nuaimi *et al*. 2015; Kitchin 2014), and creating smarter and more sustainable cities (Deakin and Al Waer 2011), emphasizing advancements in technology as key drivers for city development progress.

Various terms have been proposed to characterize the transformative changes occurring in cities. These include the concepts of the Digital City (Ishida 2000), Smart City (Neirotti *et al*. 2014), and Digital Twin (Batty 2018a), which emphasize the integration of digital technologies into urban environments and leverage data and devices to enhance efficiency and quality of life to make cities more intelligent. The notions of the Connected City (Neal 2012) and Sharing City (Agyeman and McLaren 2017) emphasize the essential role of networks, particularly those derived from ICT, in shaping modern metropolises and connecting individuals. Moreover, some terms are proposed to underline the impact of emerging technology in shaping individuals' lifestyles and behaviors, such as 5G City (Marabissi *et al*. 2018), which evaluates the capability of the 5G network to support innovative services, and Robot City (Tiddi *et al*. 2020), which underscores the interaction between emerging robots and urban ecosystems. To enhance urban science, urban design, planning, management, and government, phrases such as Urban Computing (Zheng *et al*. 2014), Computational Urban Science (Kontokosta 2016), Data-Augmented Design (Long and Zhang 2021), Data-Driven Design (Bokolo 2023), Computational Design (Cantrell and Mekies 2018) have been proposed to emphasize the crucial role of data generated from ICT and the progress in computing and algorithms. In addition, there is also a global trend toward leveraging emerging technologies to improve various aspects of society such as efficiency, sustainability, and quality of life. These attempts include Singapore's Smart Nation initiative, Germany's Industry 4.0, Japan's Society 5.0, China's Made in China 2025, South Korea's Manufacturing Industry Innovation 3.0, the UK's Future Cities Catapult initiative, and the US's Smart Cities Challenge.

In this paper, we argue that emerging technologies are transforming the field of urban studies and implementation in three significant ways: methodology, epistemology, and practice. Pathway 1 emphasizes the vast amounts of data generated by emerging technologies that allow for quantitative and objective urban research. With the use of ICT-based sensors, questionnaires, and devices, cities can now be studied as laboratories where researchers can conduct experiments. Pathway 2 recognizes the profound impact of technological advancement on urban life and space, leading to the updating of urban theories. Pathway 3 highlights the potential of emerging technologies to be integrated into urban planning and design practices to create smarter and more adaptable urban spaces that meet the changing needs of contemporary society. These three pathways highlight the significance of emerging technologies in advancing research methods, updating urban theory, and transforming urban planning and design. The following three sections provide detailed elaboration on the three pathways separately, and the challenges that cannot be ignored and a potential future research agenda are discussed in the last section.

2. Urban Laboratory: Data-Driven Urban Science Discovery

Urban studies experienced a slow development period due to difficulties in acquiring large-scale and high-precision data for built and social environments. Fortunately, recent advancements in ICT and advanced analytic methods have gradually been introduced to urban studies, giving rise to a new urban science (Batty 2021, 2013b). The increasingly diverse, massive, and rapidly updating urban data, benefiting from navigation and positioning technology, multiple Remote Sensing technology, and social sensing technology, provides vast research prospects for studying human behavior and spatial form at fine spatiotemporal

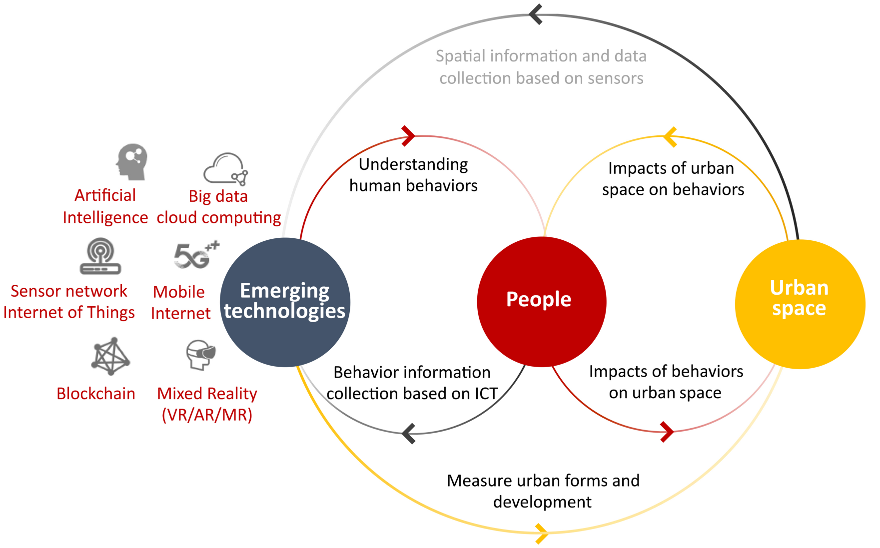

Figure 1. Empowering Urban Research Through Emerging Technologies

scales, and presents critical opportunities for understanding the mechanisms behind the interaction between urban space and human activities (see Figure 1). In particular, the availability of high-frequency and long-term urban data, presented by mobile phone signaling data and Location-Based Service (LBS) data, provide a perspective closer to cities' real operating frequency (Batty 2018b). In this context, the time and space dimensions of urban research have been expanded, which can support quantitative analysis and complement and update urban theories, providing unprecedented opportunities to enhance the scientific rigor of urban research.

With the deepening of ICT use, the widespread availability of the internet and real-time data has facilitated urban computing, allowing for more efficient data acquisition, integration, and analysis, enabling the creation of innovative solutions for improving urban life, optimizing urban space, and enhancing city operations (Zheng *et al*. 2014).

2.1. *Urban dynamic sensing based on big data and open data*

As urban socioeconomic activities increasingly depend on the internet, many online platforms — including social media, search engines, and thematic websites and mobile applications — generate substantial volumes of data and information. In particular, LBS data generated by various mobile apps in the mobile internet era provide crucial spatiotemporal information for social sensing (Liu *et al*. 2015). Additionally, emerging active urban sensing methods based on various sensors offer fundamental support for urban planning, design, management, and operation by enabling urban planners, designers, and governors to collect large-scale, low-cost, and human-scale data from built, natural, and social environments for specific research questions (Townsend 2013; Adams *et al*. 2021; Cuff *et al*. 2008).

As advocated in "The Fourth Paradigm: Data-Intensive Scientific Discovery", there is a shift in research paradigms toward a data-driven fourth-generation approach, which is transforming our methods and perspectives for understanding cities (Hey *et al*. 2009). This paradigm is replacing the traditional research paradigm that relied on observation, summarization, and simulation with a data-driven paradigm centered around data exploration. With the improvement of spatiotemporal data and the emergence of new data, there is a surge in research on individual behavior and human-scale urban form (Long and Ye 2019). The combination of basic spatiotemporal data analysis, urban planning modeling, and new social sensing data analysis can facilitate a more comprehensive understanding of urban life and the dynamics of urban space. Ultimately, this approach can lead to more effective and sustainable urban development and the application of "people-centered" principles in urban planning and design. This trend could enhance and enrich "Urban Informatics", which is a multidisciplinary approach that integrates urban science, geomatics, and informatics to comprehensively understand, manage, and design cities (Shi *et al*. 2021).

2.2. *Experiment based on active urban sensing and internet platform*

In addition to acquiring data generated as a byproduct of activities, the dynamics of built, social, and natural environments can be comprehensively captured and enhanced through active urban sensing and experiments, utilizing available and matured data collection technologies. Therefore, the field of urban science has started to embrace the idea of regarding cities as laboratories, utilizing various ICT facilities to intervene, experiment, and observe in cities. Several laboratories and institutions are at the forefront of developing innovative approaches for conducting experiments in urban environments, advancing our understanding of the complex systems that underlie cities. For example, the Senseable City Lab at MIT has conducted experiments to collect data on traffic patterns by equipping taxis in New York City with sensors[1] and to reveal bike theft in Amsterdam by deploying

[1] http://senseable.mit.edu/hubcab/

GPS-traceable bikes.[2] The Beijing City Lab at Tsinghua University launched the "Nudging populations towards healthier eating behaviors" project with the World Health Organization (WHO), the Chinese Centers for Disease Control and Prevention, and Alibaba's Ele.me, using the Ele.me app as an experimental platform to observe the impact of different salt reduction interventions on consumers' choice of low-salt takeout food through a randomized controlled trial.[3]

ICT plays a crucial role in these experiments, providing a basis for information dissemination and service practice, collecting relevant experimental data and information, and enabling monitoring and analysis of the investigation. It also provides an avenue for receiving participant feedback (Slota *et al*. 2022; Rodrigues *et al*. 2022). This active data collection from urban researchers can further extend the scale and precision of human behaviors and built environment studies, steering urban studies toward a more scientific dimension.

3. New City: Technology-Guided Urban Life and Urban Space

Pathway 1 not only supplements the data sources for urban research but also reveals the changes in individual lifestyles and resulting changes in spatial use within cities. Therefore, Pathway 2 emphasizes the impact of the technological revolution on urban life and space. Figure 2 illustrates the specific pathway of

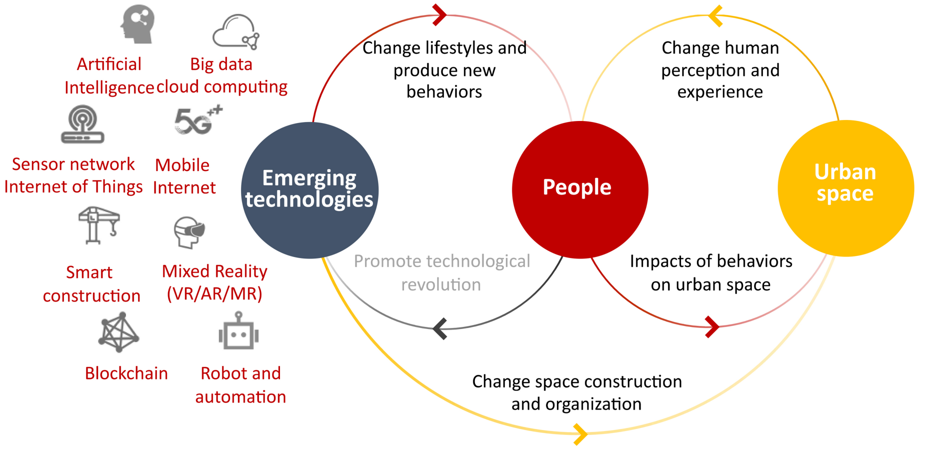

Figure 2. The Role of Emerging Technologies in Reshaping Urban Life and Urban Spaces

[2] https://senseable.mit.edu/bike-trafficking/
[3] https://www.who.int/publications/i/item/9789290620242

urban transformation influenced by emerging technologies. In this paper, the term "new city" refers to a city that exhibits new behavioral patterns and spatial organization modes influenced by emerging technologies such as mobile internet, big data, artificial intelligence, smart manufacturing, and automation (Kitchin 2014).

3.1. *Urban life is being reshaped*

As noted by Mitchell (2000), the digital revolution, characterized by global digital networks, is changing the way we access, use, and share information. Castells (1996) proposed the concept of "The Space of Flows" to highlight the flow of society and emphasize the significance of ICT in influencing the fundamental dimensions of human life, time, and space. Building on this, Batty (2013b) further proposed that in this communication-dominant world, the relationships and interactions between people are the basic principles of urban life. Thus, the essence of location is a comprehensive entity of interactions.

Nowadays, ICT has quickly become the most influential technology affecting the urban spatial structure. Its impact has penetrated all aspects of urban life as the internet and mobile devices become increasingly pervasive. Individuals are becoming digitized, leading to a blending of their online and offline behaviors (Wang *et al*. 2021). As a result, people's activities are becoming fragmented, diversified, and liberated in terms of time and place (Ben-Elia *et al*. 2014). Urban functions are significantly shaped by ICT, which is evident in the emergence of flexible working formats like teleworking, coworking, and on-demand working (Yu *et al*. 2019). Additionally, online services are abundant, including online shopping, remote education, online entertainment, online-to-offline (O2O) services, and on-demand food delivery (Bauriedl and Struever 2020). Residents' daily lives are already intertwined with the digital network. As Zhou (2016) pointed out, the carbon-based civilization represented by the physical world will coexist with the virtual, computational, and shared silicon-based civilization for a long time.

3.2. *Urban space is being transformed*

Analyzing the historical evolution of the Industrial Revolution unveils that technological advancements have not only induced transformations in urban production and lifestyle but have also resulted in changes in the organization of urban space (Ratti and Claudel 2016; Mitchell 2003). Although the pace of change in urban form is relatively slower compared to the rapid iteration and change in urban lifestyle, as Batty (2018b) noted, the technological revolution is also subtly influencing urban morphology. On the one hand, with increased flexibility in time and space utilization, the spatial functions tend to be mixed and fragmented, represented by shared offices and residences (Lenz and Nobis 2007). Due to the inherent virtuality of ICT, the tie between urban activities and the built environment is loosening, resulting in spatial dispersion, decentralization, and placelessness (Dadashpoor and Yousefi 2018). On the other hand, technologies can influence cities' scale, organization, and structure. For example, studies on Autonomous vehicles reveal the appearance of commuting lanes for vehicles used for commuting between surrounding households and CBD work, land used for parking (Zakharenko 2016), and the reduction of daily parking costs and space (Harper *et al*. 2018). The examination of the influence of automation on industrial assets suggests that automation has the potential to address density concerns and optimize operations, thereby alleviating operators' space requirements (Nuckel 2023).

4. Future City: Digital Innovation Enabled Smart City

With the development of Pathway 1, urban space designers have begun to embrace emerging technologies to enhance individuals' perceptions, collect users' feedback, and improve their interactions with space (Costa and Menezes 2016). These findings can be used to guide detailed spatial intervention and to improve place-making. Specifically, the digital twin based on the sensors and actuators could continuously sense and replicate social and physical space in the City Information Model (CIM) and facilitate self-feedback management of space (Irshad and Rambli 2014). Some virtual means like digital platforms, mixed reality devices, and mobile applications (APPs) could enhance place-making among individuals and relocate their time and space arrangement. Moreover, human–computer interaction devices installed in physical space could also promote the interaction and experience of users (Figure 3). Therefore, the term "future city" describes smart cities aiming to involve these digital innovations with place-making and spatial intervention to make the city more convenient, self-adaptive, and efficient.

4.1. *Cooperation between multiple participants*

The emergence of digital innovation in urban planning and design is expected to merge traditional spatial intervention, social-level place-making, and public participation with interactive facilities, management platforms, and supporting technologies. This integration will involve multiple stakeholders in future cities' design, construction, operation, and ongoing development. Planning and design experts will provide innovative ideas, specific planning and design proposals, and guide design and construction implementation. Community planners and

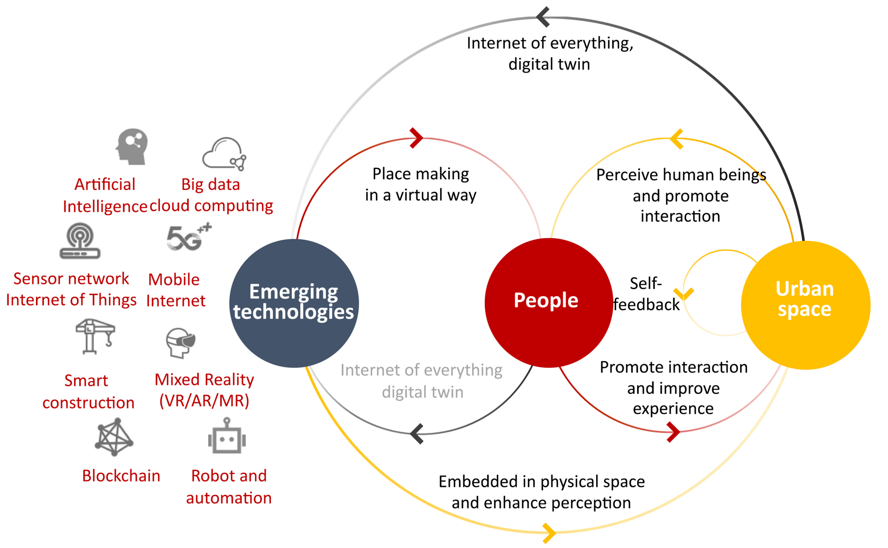

Figure 3. Potential Application of Emerging Technologies in Future Urban Space Design, Management, and Operation

managers will encourage public participation, create a sense of community, and provide a multi-party negotiation and discussion platform. Technology providers will offer interactive facilities and supporting technologies throughout the design and implementation process, and assist in the continuous tracking and operation of the design site through management platforms. Additionally, stakeholders such as space retailers, internet companies, and government departments will work together in city construction and operation.

4.2. *Enhanced interactions between physical and social space*

Through the digital twin of the social and physical space, the future city can enhance the interactions between the virtual and real worlds (Figure 4). In recent years, various sensors and wearable devices have provided essential data support for digital twins, enabling the flow of information in different physical and social spaces. Sensors embedded in physical space can capture real-time urban activities and problems in physical space, promoting the adaptation and self-regulation of urban space to meet people's timely demands (Figure 4(a) and 4(b)) (Batty 2018a). The interaction between people and space is also enhanced. For example, the AR/VR/MR game enables the characters in twin social spaces to interact with actual physical space, and people interact with augmented and virtual space, meanwhile stimulating or

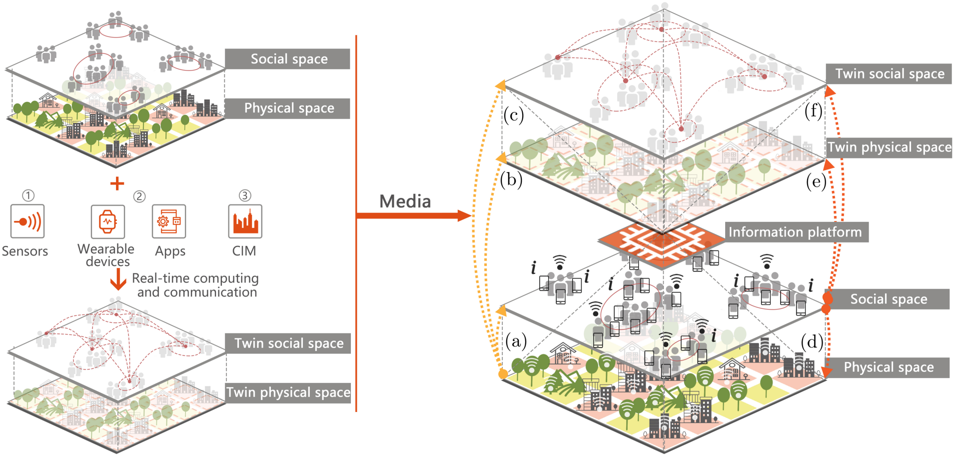

Figure 4. Conceptional Prototype of the Future City (a) the Sensing of Human Beings in the Physical Space; (b) The Digitalization and Virtualization of Urban Space in the Twin Space; (c) The Interaction Between Urban Space and Virtual Community; (d) The Enhanced and Changed Urban Activities in Urban Space; (e) The Interaction Between People and Virtual Space; (f) People's Communications in the Virtual Community

replacing the people's offline activities in the real world (Figure 4(c)–4(e)) (Mokhtarian *et al*. 2006). In addition, the interaction between the twin and real social space also redefined the community and the transmission of information, which can influence the people's demand and choice of activity venues (Figure 4(f) and 4(d)).

5. Conclusions and Discussion

Emerging/disruptive technologies in the Fourth Industrial Revolution have profoundly impacted urban research and practice, presenting new opportunities and challenges. This paper provides a comprehensive summary of the effects of emerging technologies on cities while focusing on three key aspects: urban laboratories, new cities, and future cities. The three pathways offer unprecedented opportunities for urban study and implementation, including enabling the analysis of data generated from digital devices, the transformation of urban life and space, and the facilitation of design and implementation processes.

Each of these pathways is interrelated and mutually supportive (Figure 5). For instance, data and methods from Pathway 1 can aid in investigating changes in urban life and space (Pathway 2), informing urban planning and design by precisely identifying space problems and needs and supporting adaptive adjustments (Pathway 3). In turn, the insights gained from studying urban life and space in

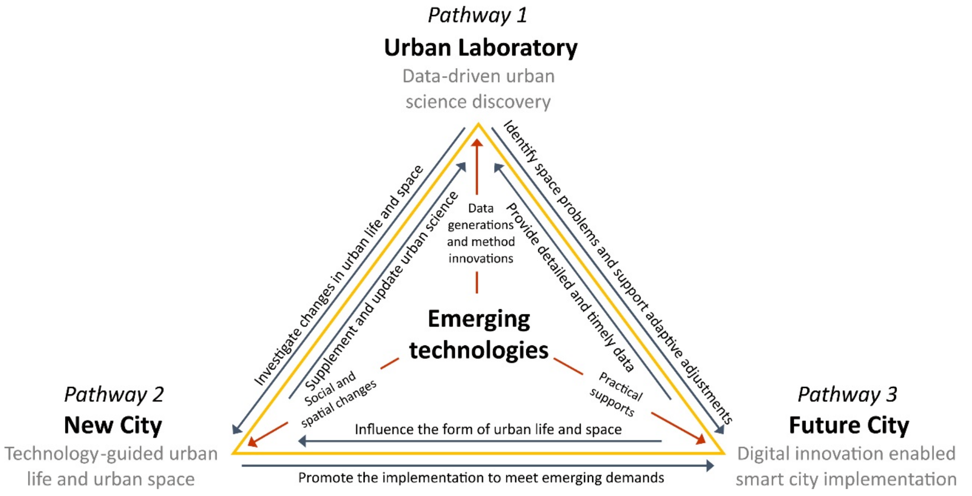

Figure 5. The Interactions Among the Three Pathways

Pathway 2 can supplement and update our understanding of urban science (Pathway 1), and promote the design and implementation to better meet emerging demands (Pathway 3). Moreover, data generated from Pathway 3 can provide more detailed and timely information, which can support research in Pathway 1. These new interactions can result in an iterative process that influences the form of urban life and space in Pathway 2.

To better harness the opportunities emerging from the Fourth Industrial Revolution, we propose several future research agendas. First, developing innovative methodologies and models rooted in AI technology is crucial to effectively handle and integrate multi-modal data from remote, social, and active urban sensing sources. This, in turn, contributes to enriching the new science of cities. Second, there is a need to explore new mechanisms and theories capable of describing the evolving phenomena in individual behaviors and urban spaces. The transformative impact of ICT, AI, robots, and autonomous vehicles necessitates a deeper understanding, and adapting theories to these changes is paramount. Furthermore, a concerted effort should be made to enhance the processes and objects of urban planning and design. This involves seeking technology-empowered solutions to address urban challenges and improve the resilience of cities (e.g., climate change, city shrinkage, natural disasters, and public health risks) and cater to emerging demands (e.g., low carbon, flexible working, healthy lifestyle, and O2O services). By embracing these advancements, we can effectively tackle the complexities of urbanization and pave the way for creating sustainable cities for future generations.

However, these pathways also present potential crises or new challenges. Therefore, it is essential to not only focus on the positive effects of the technological revolution on urban development but also be alert to its potential negative impacts. Pathway 1 utilizes information and communication technology to expand urban research boundaries and enable individual participation. However, this raises concerns about data privacy, acquisition, usage, and ownership, as well as the management of research data. In Pathway 2, technological progress can create new urban crises, such as unemployment, spatial inequality, and control by internet giants. Pathway 3 focuses on smart city construction, but funding and operational models pose challenges to sustainability and social benefits. The challenges mentioned are intrinsic to the technological revolution in urban research and practice. Therefore, there is a pressing need for elevated standards in policies, laws, systems, norms, and management to tackle privacy concerns, employment issues, and potential monopolies and find solutions to smart city construction.

Whether in urban research or planning and design, it is necessary to comprehensively consider the opportunities and challenges brought by the technological revolution. One cannot expect technology to be benevolent and become a proponent of technological determinism, nor can one become a resistant critic of technological innovation and the unstoppable trend of technological development. As Mitchell (2000) claimed, a new technical system is a fairly complex social structure; therefore, we need to understand the various choices that are constantly emerging, carefully select our goals, and build them. Our effort is to design and create the future we need, not to predict the road it must take. This paper summarizes three pathways of how the technological revolution promotes urban development, not to predict the impact of the technological revolution on cities but to showcase the various choices it presents and provide new perspectives for more people-centered urban development.

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