# A Tale of Three Cities: On Digital Twins

**Book Chapter**

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ABSTRACT

Cities are multidimensional, multiagent, and multiobjective artifacts with a complex, convoluted, and unexpected life hard to disentangle. Open and participatory approaches to city-making face the challenges of coordinating divergent opinions and agendas, informing all parties effectively, and avoiding manipulative legitimacy misappropriation. Computers can help in this endeavour to create more sustainable and resilient built environments. However, it involves issues of representability and accuracy, trust and accountability, and accessibility and applicability. Here, the aim is to combine the navigational capabilities of computer models with a sociotechnical focus on the complexity of cities and their dwellers embedded in the visionary thinking of architecture and urban planning to evoke alternative scenarios. These urban simulations can expand human capabilities and explore alternative sustainable and resilient futures of cities collaboratively. They can enhance participation by transparently and comprehensively informing us about the effects of our choices to help behavioural change. Instead of relying completely on machine automation, natural intelligence is complemented with machine intelligence to take account of the difficult-to-quantify factors of complex socio-technical systems in urban life. This chapter illustrates this future through three tales about reformulating the way we occupy, design, and use space at different scales, based on new realizations of urban digital twins not as deterministic predictors, but as exploratory and participatory tools.

*KEYWORDS*

*urban digital twins; cities simulation; citizen participation; cities speculative design; design fiction; hybrid intelligence.*



# *Chapter 22*—A Tale of Three Cities: On Digital Twins

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We approach our cities in contradictory ways. On one hand, we aim to control, predict, and design them top-down (Gaffron et al., 2005). On the other hand, cities are complex entities (Portugali, 2000) in constant change whose functioning is extremely hard to grasp.

## MOTIVATION

This means that they are ill-suited to traditional control approaches. Problems and conditions are always evolving with every single change or after a solution is provided. Understanding the manifold interactions between the built environment and its inhabitants requires powerful tools (Fink, 2018) beyond traditional practice and purely human skills.

Digital abundance (Hovestadt et al., 2017) enables the most recent iteration of incorporating computational tools for city-making: smart cities. However, their promise of hyper-efficient management of cities (Picon, 2015) falls short (Greenfield, 2013). They are mostly disconnected, ad hoc, utilitarian, and technical single-dimension optimization processes (Wilson, 2018) with very limited impact on the expected overall quality of life in our environment (Batty, 2020). They focus mainly on the 'high-frequency' city. Its changes we experience in real time, at the scale of seconds, minutes, days, and months (Batty, 2018; Wildfire, 2018), while disregarding longer-term planning. Simultaneously, the abundance of data and digital resources enhances participation and commoning processes (Cardullo & Kitchin, 2019; Mainka et al., 2016) that counterbalance top-down and technocratic visions for the production of cities (Lefebvre, 1974). But such a counterbalance cannot be taken for granted, as unbalanced power and information-sharing capabilities among parties may hinder the quality of this participation (Pateman, 1970).

Underlying both approaches is the inherent difficulty of grasping and measuring the components of urban life (De Nadai et al., 2016): from geometric and physical features of space to interactions and cognitive processes that are hard to quantify, as is the case with the qualitative aspects of any human-related system (Helbing et al., 2021).

This situation suggests a need to reformulate the role and scope of city planning (Cuthbert, 2006; Ratti & Claudel, 2015), as already anticipated by more open-ended dynamic, systemic, and participatory approaches such as those embedded within planning support systems (pSS) (Geertman & Stillwell, 2020). In contrast to the postulates of the end-of-history (Fukuyama, 1992) and end-of-science (Anderson, 2008; Carpo, 2014), which assume the steadiness of our world in combination with some sort of technological determinism (Lanier, 2013), the constant changes in our environmental conditions require permanent revision and adaptation. Crises cause our planned cities to come apart at the seams. Rigid functional planning proves to be segregating and detrimental to cities and leaves little room for change and adaptation (Jacobs, 1961; Mäntysalo, 2005; Verebes, 2014). Unsurprisingly, this shortcoming permeates everywhere in the built environment: homes are too inflexibly designed to cope with the changing needs of their dwellers, and streets are forced to cope with peak hour traffic while hindering any alternative or unplanned uses (Bereitschaft & Scheller, 2020; Southworth & Ben-Joseph, 1997). We barely give a chance to people to determine their own preferences and use these preferences for the benefit of spatial planning. Hence, we need to find ways of embedding adaptability and resilience in city-making processes by design.

Therefore, this text introduces three visions of how future policy and decision-making for city co-creation could use comprehensive urban simulations. More than for their predictive, deterministic power, in these visions, urban digital twins (Batty, 2018) are valuable because they enhance the collaborative exploration of 'what-if' scenarios (Dembski et al., 2020) that could inform more resilient and adaptable cities through unbounded multiobjective optimization (Deb, 2014). This means identifying alternatives that effectively consider several goals simultaneously. At different scales, components, and cycles, (Gaffron et al., 2005), three future cities are described where computational approaches and machine intelligence are merged with human preferences and skills to articulate new strategies of urban planning able to cope with the complex interplay of stakeholders' agencies involved (Quan et al., 2019) in an unpredictable and changing world. This means, altogether, more informed, more diverse, more uncertain, and more flexible cities existing after our time.

## THE CITY OF UNBOUNDED STREETS

It is 8 am. In this city, the streets leading to transit stations, offices, and schools show a calm, packed, and incessant stream of vehicles of different shapes and sizes for those who are not working remotely today. They do not necessarily move fast (Gershenson & Helbing, 2015), but in an intertwined, satisfactory, and coordinated fashion, avoiding stop-and-go waves and making the most of the space available on streets. They leave just enough room for opposing traffic and pedestrians heading somewhere else while seamlessly merging with them when needed as converging flocks (Jiang et al., 2006).

At 10 am, as the morning hustle and bustle comes to an end, street life diversifies. Fewer vehicles are around, and they move differently and more unpredictably: some of them stop here and there to pick people up or to drop goods off. Small delivery vehicles squeeze between larger cars and people (Camara et al., 2020) to accomplish their last-mile service. A group of school students crosses the street and the traffic rapidly adapts, slows down, avoids them, and keeps running.

At 5 pm, kids play on the street after school while people enjoy some after-work gatherings in front of bars and restaurants. The vehicles of those who need to return home or go somewhere else sense the environment: they detect where the people are, anticipate their movements, and know how humans react in their presence to neither scare



*Figure 1* →
The city is a result of the active, collaborative, and co-learning process between physical (in red) and virtual agents (in green) (visualization by the authors).

them away nor hamper traffic flow (Ackermann et al., 2019; Millard-Ball, 2018).

At 6 pm, there is enough space on the street for people to sit outside, grab some drinks, and meet family, friends, and strangers, for kids with their parents to take a walk, and for the evening traffic of people doing the last chores before dinner (Ruiz-Apilánez et al., 2017).

After midnight, the streets, mostly empty, show their real backbone. There is no signage, marking on the surface, or obvious sidewalks, just a flat, step-free (Meyboom, 2018) surface and some greenery, where traffic directions, lanes, and rights-of-way can be created, removed, adapted, and reversed on demand (Papageorgiou et al., 2021; Rieland, 2018). The streetscape becomes a whiteboard that adapts dynamically to diverse occupation patterns and uses at different moments of the day. There are no more fixed segregations between different uses and speeds throughout the day, and no more roadways oversized inefficiently only for peak times or for parking spaces (Norton, 2008). It results simply in a new social contract on the use of the public domain with different sensorial, behavioural, and semantic rules (Fernández-Abascal & Grau, 2019).

This city, its streets, and its 'inhabitants' have been simulated endless times before. Its artificial city dwellers can anticipate what humans are going to do. They leave room for people and find the best way of adapting their behaviour while leveraging efficient movement with perceived and measured safety. These prosthetic urban inhabitants have learned from simulations in virtual worlds how to be simultaneously efficient in their tasks of transport, assistance, and maintenance and to be social machines able to interact safely and usefully with humans (Bauer et al., 2009). In fact, humans in this city have simulated the interactions of heterogeneous groups of artificial and natural city dwellers using virtual environments as safe sandboxes (Fujii et al., 2017). These immersive simulations have captured the cognitive and emotional responses of people facing thousands of different situations (Dubey et al., 2016; Liu et al., 2017). It means that they have simulated, anticipated, and tested virtual worlds before implementing them for real. Even further, they have led people to change how they behave for more coordinated and efficient use of common resources (Theodorou et al., 2019). Each time an artificial city dweller, whether a full-size car, a bus, a small delivery vehicle, or a droid-like personal assistant, goes along a street, it senses its physical environment. Then, the artificial city dweller projects its physical environment into a full digital twin that simulates possible scenarios to anticipate the appropriate and safe behaviour that, ultimately, will apply in reality. And it repeats this procedure again and again, hundreds and thousands of times (Brooker & Van Patten, 2017).

## THE CITY OF PRUNING STREETS

In this city, not every street is designed to make the circulation of vehicles easier, faster, and safer. When traffic jams happen, they do not build new roads (Duranton et al., 2011). They do just the opposite: they close roads or reduce the number of lanes. Over the years, the traffic in this city has not worsened, and the environmental quality of the streets has improved while making space for other activities and alternatives for mobility (Rueda, 2018).

People in this city rebelled against how things were decided before. First, they learned. They could not ignore the complex counterintuitive effects (Braess, 1969; Roughgarden, 2005) of planning decisions made by experts around the world (Cairns et al., 2002; Chung et al., 2012; Kolata, 1990, 25 December). Second, they changed citizens' roles. They were not satisfied with simply being consulted about predefined plans designed by experts (Jones et al., 2005). People wanted to be informed and participate, not be persuaded (Cardullo et al., 2019).

It took them some time to tune their city-making processes and combine

*Figure 2* ▸ p. 306



*Figure 3* ▸ p. 306

the understanding of urban complexity with people's desires and preferences to inform decisions in actionable, effective ways. Their planners became coordinators, facilitators, and systems designers and not mere makers of visionary prescriptions (Ratti & Claudel, 2015). They leveraged the knowledge and goals of the various people and organizations involved in the wicked problem of designing their city (Rittel & Webber, 1973) by expanding techniques of planning support systems (Geertman & Stillwell, 2020) into hybrid human-machine simulations (Licklider, 1960; Negroponte, 1970) with the support of artificial intelligence (Lock et al., 2021). They brought people into the loop. Everybody in this city can now experiment with their future simulated visions in such a way that they can reflect on and inform their opinions and images of their city (Lynch, 1960) and let the computer intelligence learn to help them.

Planning in this city is a serious game (Beirão, 2012; Dodig & Groat, 2019). Its citizens, developers, investors, and designers, among other stakeholders interact with highly accurate simulations of their environment in a safe sandbox. There, they explore alternatives, learn from the outcomes of their own actions, and sometimes adapt their opinions and preferences according to their experience (Burr et al., 2018). The use of artificial intelligence in this interactive decision-making system expands the capabilities of this city's inhabitants to know, share, negotiate, and agree (Engelbart, 1962). They can communicate their preferences, aggregate them with fellow citizens, update possible scenarios, and hybridize them to offer new alternatives. More importantly, this system allows people's opinions to be elaborated and coordinated in an actionable way. This framework is a collaborative development environment whose best versions are deployed for updating the real city as needed, as if it were an operating system (Marvin & Luque-Ayala, 2017).

In this creative generative loop, people experience and experiment through simulations of their desired city while the computer intelligence learns from them and helps to coordinate these human preferences in actionable ways to configure the new city (Koenig et al., 2018). In a sense, it is much closer to a continuous, augmented, collaborative, and AI-mediated, even generative, dev-ops scheme with many humans-in-the-loop (Chirkin & Koenig, 2016; Scott et al., 2002; Veloso & Krishnamurti, 2021). This city's people have replaced their previous rigid and static planning with new dynamic city operations based on hundreds of cities simulated and wished for by humans in almost real time. Nowadays, they can adapt to the very rapidly changing conditions of their world, hit by overheated extreme weather and unstable ecosystems. What is more impressive, they can maximize their strategies with minimal intervention. They get more done by doing less.

## THE CITY OF REMOTE(D) STREETS

Alex and Lynn moved with their children 3 hours' journey away from the city. They still keep the same jobs that they had when they met for the first time, by chance in a hyped cafe in the city centre. Now, with a family, they have other needs: additional expenses, a bigger house to maintain, and more time together. The possibility of working remotely and visiting the headquarters of their employers once or twice a month allows them to live outside the city and use the train for the occasional 3-hour commute. Now, they can spend more time at home, spend less money on transport, and revitalize a sparsely populated area far from the dynamic urban centres (Johnson, 2003; Zenkteler et al., 2019).

Meanwhile, in the city centre, the original large headquarters, over 47,000 square metres, of Lynn's employer, a finance company, was built to cope with its rapid growth. Now, it is a constantly reconfigurable architecture (Steen-

“There are alternative futures to be explored in this conversational relationship with virtual versions of our environment.”



son, 2017) comprising small offices and rooms to rent by the hour for local workers and occasional commuters, apartments with transparent views over the city's roofs, hydroponic farms, gardens on the rooftop, stores, and restaurants. And space is still available for any unexpected need that might arise in the area (Schneebeli, 2021).

The dwellers of this city have very different needs, ways of thinking, and modes of behaviour now from when this massive headquarters building was opened. They adapted their lifestyle following several public health shocks, economic crises, increasing energy costs, and various aspects of deprivation that led to restrictions on daily habits (Bradley & Altizer, 2007; Dobkowski & Wallimann, 2002; Meadows et al., 1972). Separating working from living no longer makes sense for many of them. Neither is it sustainable nor even the most resilient alternative (Belzunegui-Eraso & Erro-Garcés, 2020). They can contact anybody and retrieve any information from anywhere. They can project themselves and meet remotely in virtual environments (Townsend, 2013). They still move, meet, and travel (De Abreu e Silva & Melo, 2018; Zahavi, 1974), but they prioritize when and where to move. They live in hybrid cities, distributed physically but united and connected via the digital realm (Lim et al., 2022). Their focus is not solely or even mainly on productivity and efficiency but on care and well-being (Amann Alcocer, 2005; Dominoni & Scullica, 2022). This new focus does not mean neglecting physical reality (Geraci, 2010) but prioritizing how to make better use of its resources.

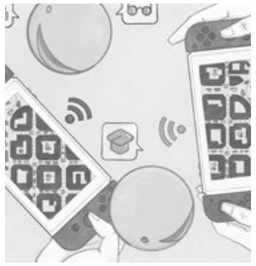
*Figure 4* ▸ p. 307

Living in the centre of the large city does not pay off for many of them. What is valuable is being able to access it physically or virtually as needed. Concurrently, the city becomes more accessible for those who need or decide to stay. It dissolves the concentration and rise in costs of services, resources, and housing (Bettencourt et al., 2007). Technology and the freedom to be remotely present counterbalance the distance rule. The former infrastructure and buildings designed for crowds needed to be repurposed like Lynn's employer's headquarters, giving more room for larger, more flexible, and more affordable spaces for housing and changing activities (Pask, 1969). Rather than large central facilities, people prefer a distributed, flexible network of small units for working, shopping, gathering, and leisure close to their homes (Camocini, 2011; Garavaglia, 2020; Moreno et al., 2021; Zenkteler et al., 2019).

This city's inhabitants plan and design it very differently than they used to. They have transformed a modernist, segregated, and functional territory. They have taken into consideration these pre-existing facilities, buildings, and infrastructures and retrofitted this construction stock to the new demands of fragmented spatiotemporal habits. To avoid pushing suburbia even further (Nilles, 1991) across every hinterland around the world (Brenner & Schmid, 2012), they decide on policies and urban strategies with a dynamic model (Acheampong & Silva, 2015; White et al., 2015) fed by data gathered continuously from the inhabitants' preferences and needs for transportation, the affordability of the environment, available floor space, economic flows, and so on. The citizens influence the model that is designed to raise awareness about, and then avoid, inequalities and inefficiencies from social, energetic, economic, spatial, and environmental perspectives.

## DISCLAIMER FOR AN UNCERTAIN POSSIBILISTIC FUTURE

The future is hard to predict. Most likely, it will be different from any of these tales. Some of the elements will resonate in future cities, but in different ways and with different interactions and implementations. Each of these new technologies will have effects on culture, society, and ultimately the environment that are hard to anticipate (Berkhout & Hertin, 2004; Gao et al., 2014). Some of them will be undesirable too. They are not complete visions either, as they do not lay out every detail. Nevertheless, all of these visions agree on the importance of the exploration of 'what-if' scenarios as planning tools to envision more resilient cities supported by conversations and discovery processes with computer intelligence. These approaches match architecture and urban planning aims to change the way we think about how things work and how things could be in alternative scenarios rather than how they are now (Doucet & Cupers, 2009; Simon, 1969). There are alternative futures to be explored in this conversational relationship with virtual versions of our environment (Pask, 1976) beyond purely physical-digital interactive feedback for management (Fuller et al., 2020), endless detailed 1:1 mirrors (Borges, 1946), solely data-driven approaches (Arcaute et al., 2021; van Dijck, 2014), and transhumanist escapes from the physical realm (Kye et al., 2021).

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*Figure 2*
*The streetscape is a tabula rasa (blank canvas) whose digital layer enables simultaneous uses and interactions learned from digital mirrors of the environment* (**visualization** *by the authors).*

*Figure 3*
*Physically distributed, virtually connected* (**visualization** *by the authors).*



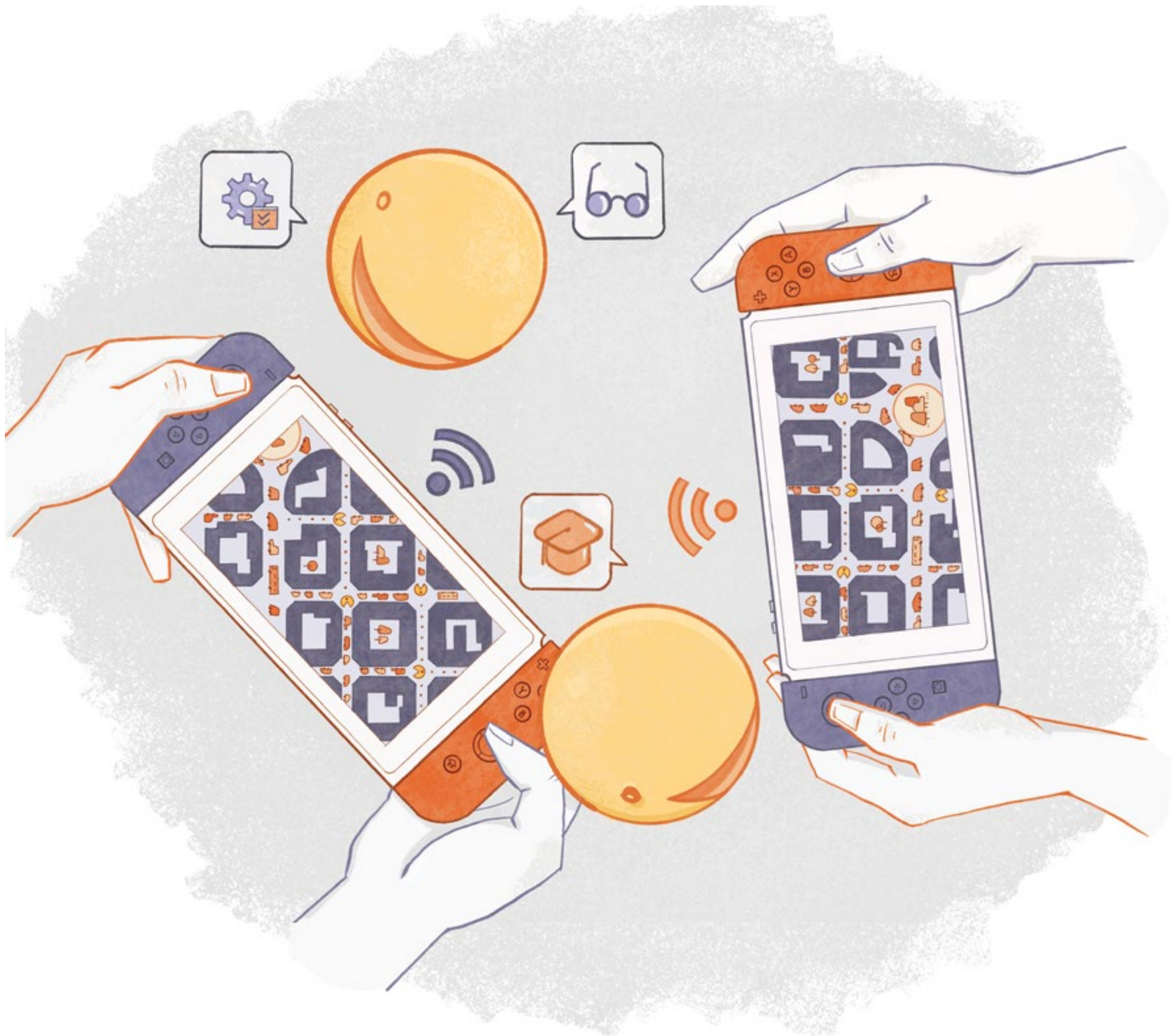

*Figure 4*
*Computer intelligence pairs with people and enhances communication and coordination* (**visualization** *by the authors).*