Application of Digital Technologies in Controlling Urban Sprawl

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Abstract. Urban sprawl has been defined as an excessive conversion of rural land into urban land or excessive increase of the city beyond the optimal city size. Urban sprawl became a hot topic first in the United States, where the low-density city the problem emerged in the late 70s and early 80s. In Europe, urban sprawl wasn't an issue until very recently, predominantly due to the structure of the European cities, which are traditionally more concentrated and densely populated, in contrast to the US cities. However, today we observe signs of urban sprawl in European cities, such as excessive decentralization, road congestion, lack of open space, overpopulation, etc. Recently urban city planners started using contemporary digital technologies to measure and control urban sprawl. This study discusses modern digital technologies used in present-day city planning.

1 Introduction

The rapid growth of urban areas has been a defining characteristic of the modern era, bringing with it numerous opportunities and challenges. One of the most pressing challenges associated with urbanization is the phenomenon of urban sprawl, a sprawling expansion of cities and their suburbs that often leads to inefficient land use, increased traffic congestion, environmental degradation, and a diminished quality of life for residents. As cities continue to expand and populations rise, the need for effective strategies to control and manage urban sprawl becomes paramount [1].In recent years, a promising solution has emerged in the form of digital technologies. The digital revolution has permeated nearly every facet of our lives, and urban planning is no exception. The integration of digital technologies into urban planning and development processes offers a unique opportunity to not only mitigate the negative impacts of urban sprawl but also to foster more sustainable and livable cities [8,9].This article delves into the application of digital technologies in addressing the challenge of urban sprawl. We will explore how cutting-edge tools such as digital mapping, geographic information systems (GIS), smart city solutions, urban planning simulations, transportation innovations, and community engagement platforms are being used to reimagine urban development. By leveraging these technologies, cities around the world are finding innovative ways to shape their growth trajectories and create more harmonious urban environments [1]. Through a comprehensive examination of the role of digital technologies in controlling urban sprawl, this article aims to shed light on the transformative potential of these tools. By using the power of data, connectivity, and

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citizen engagement, urban planners and policymakers are navigating the complex landscape of urbanization with greater precision and insight. The remainder of this article will deal with specific areas where digital technologies are making a significant impact, showcasing real-world examples and discussing both the opportunities and challenges that lie ahead [2].

2 Urban sprawl as a contemporary issue

The phenomenon of urban sprawl has become a defining challenge of contemporary urbanization. As cities expand outward and encroach upon surrounding rural and natural areas, a host of interconnected problems arise that impact both the environment and the well-being of residents. Some of them are:

Land Fragmentation and Inefficient Land Use: Urban sprawl often results in fragmented and inefficient land use patterns. Low-density development leads to the conversion of open spaces, farmland, and natural habitats into sprawling housing subdivisions, commercial centers, and road networks. This fragmented development makes it difficult to create cohesive communities, increases infrastructure costs, and diminishes the availability of green spaces for recreation and conservation [4].

Traffic Congestion and Air Quality: The unchecked expansion of urban areas contributes to increased traffic congestion and longer commuting times. This not only leads to frustration for residents but also has significant environmental implications. Traffic congestion results in higher emissions of greenhouse gases and pollutants, deteriorating air quality and exacerbating public health concerns [4].

Traffic Congestion in the Context of Urban Sprawl

Traffic congestion stands as one of the most visible and immediate consequences of urban sprawl, illustrating the intricate relationship between urban development patterns and transportation challenges. As cities sprawl outward, several factors contribute to the exacerbation of traffic congestion:

- Longer Commute Distances: Low-density suburban developments often lead to longer commuting distances between residential areas and major employment centers. This results in extended travel times and increased traffic volume on roadways, especially during peak hours.
- Dependency on Automobiles: Sprawling urban layouts typically prioritize automobile usage, with limited emphasis on public transportation and pedestrian-friendly infrastructure. This promotes car dependency and places more vehicles on the road, adding to congestion [5,3].
- Inadequate Public Transit: In many sprawling areas, public transit systems may be underdeveloped or insufficiently integrated. This leaves residents with few viable alternatives to driving, further contributing to congestion.
- Induced Demand: Expanding Road networks to accommodate sprawl can inadvertently encourage more people to drive, a phenomenon known as induced demand. As roads are widened or new highways are built, they often attract additional drivers, counteracting any immediate congestion relief [4,7].
- Cascading Effects: Congestion doesn't just impact individual commuters. It has cascading effects on economic productivity, air quality, and overall quality of life. Slow-moving traffic increases travel times for deliveries, affects businesses, and degrades air quality due to prolonged vehicle idling.
- Environmental Impacts: Congestion leads to increased emissions of greenhouse gases and pollutants, contributing to air pollution and environmental degradation. This has both local health implications and broader consequences for climate change.

- Stress and Quality of Life: Prolonged periods spent in traffic can lead to stress, frustration, and decreased quality of life for commuters. Additionally, time spent commuting detracts from time that could be spent on leisure, family, or other activities [4].

Addressing traffic congestion within the context of urban sprawl requires multifaceted solutions that consider both transportation and urban planning:

- Enhanced Public Transit: Developing efficient and accessible public transit systems can provide an alternative to driving, reducing the number of vehicles on the road.
- Mixed-Use Development: Promoting mixed-use development, where residential, commercial, and recreational areas are interwoven, can reduce the need for long commutes and decrease traffic [3,4,2].
- Walkability and Cycling Infrastructure: Creating pedestrian-friendly environments and dedicated cycling lanes encourages non-motorized modes of transportation, reducing congestion.
- Transit-Oriented Development (TOD): Concentrating development around transit hubs encourages residents to use public transportation, decreasing reliance on private vehicles.
- Congestion Pricing: Implementing congestion pricing, where motorists pay a fee to access certain congested areas during peak hours, can incentivize carpooling and public transit use [3,4,7].

By incorporating digital technologies, such as real-time traffic monitoring, predictive analytics, and smart traffic management systems, cities can gain insights into traffic patterns and make informed decisions to alleviate congestion. These technologies enable adaptive traffic signal control, rerouting options, and data-driven infrastructure planning [3,4].

As urban planners and policymakers deal with the challenges of traffic congestion induced by urban sprawl, the role of digital technologies becomes increasingly pivotal in creating more efficient, sustainable, and livable urban environments [3,4].

Loss of Agricultural Land and Biodiversity: The conversion of agricultural land into urban developments poses a threat to food security and biodiversity. As urban sprawl consumes fertile land, the capacity for local food production diminishes, leading to a greater reliance on distant sources. Additionally, the loss of natural habitats due to sprawl contributes to the decline of native plant and animal species, disrupting ecosystems and compromising local biodiversity [5,6].

Infrastructure Strain and Service Provision: Expansive suburban development requires the extension of utility networks, transportation systems, and public services. This places a strain on municipal budgets and resources, potentially leading to inadequate infrastructure maintenance and service provision. The cost of extending utilities and services to sprawling areas can divert funding from other essential municipal projects [9].

Social Isolation and Reduced Quality of Life: The design of sprawling suburbs often prioritizes automobiles over walkability and public spaces, leading to social isolation and a sedentary lifestyle. Residents may spend more time commuting and less time engaging in community activities. The lack of accessible amenities and public spaces can contribute to feelings of isolation and a diminished sense of community.

As urban sprawl continues to present these complex challenges, there is a growing recognition of the need for innovative approaches to urban planning and development. This is where digital technologies step in, offering a range of tools and solutions to address the negative impacts of sprawl and foster more sustainable, connected, and vibrant cities [4,9].

3 Application of digital technologies in contemporary urban planning

Digital urban planning is a relatively recent phenomenon, which came into being when emerging innovative technologies—such as Artificial Intelligence, Big Data, the IoT, and Digital Twins, providing rich datasets and advanced computational understandings of human behavior, became widely available and affordable enough to be used on a large scale [10].

The process of availability and affordability is already evident in our post-COVID reluctance to return to a mainstream urban office environment. During the pandemic, people interacted and collaborated on projects through extended realities, such as AR and AU, made telephone/Teams/Zoom calls, and participated in 'normal' activities on digital platforms. Acquiring and mastering innovative technologies is critical in reducing energy consumption by automobiles and reducing resources used in constructing workplace infrastructures, extensive transport networks, and others that directly or indirectly support the work environment [10].

By definition, digital urban planning emerged as a decision-making process to facilitate the simulating process of the physical environment based on precise and up-to-date sensor-fed data [11].

Digital urban planning relies heavily on the concepts of digital city and digital twin in terms of recreating a real-life environment in the virtual space and placing the ICT infrastructure in the focus of the long-term development of the actual city.

Digital urban planning goes in two phases. The first phase includes physical and social planning, function division, spatial pattern, physical infrastructure, urban land use, and construction density. The second phase comprises technical information: planning, components and structure, system functions, information structure, spatial database, and management system. It includes the city infrastructure, its spatial attributes, and functional departments of the city administration and depends on acquiring data from multiple sources (sensors, cameras, IoT devices, meters), processing it (conversion, validation, summarization, aggregation), and turning it into meaningful insights that end users can access through online platforms [11].

3.1 The key technologies that make digital city planning possible

Digital urban planning substantially relies on the concept of a digital twin. Digital twins are accurate virtual representations or copies of physical objects or locations based on data collected from vast arrays *by sensors*, cameras, and devices monitoring the physical infrastructure. The essence of this technology is to enable the collected data to create simulations to model, test, and predict how a given product, process, or service would perform in the real world. It provides assessment capacity and solutions, offering immediate real-time visual representations of development or interventions. Thus, the users benefit from reduced costs of testing and modeling. Every digital city twin is a variety of underlying technologies constituting the digital urban planning process.

The dominant digital technologies used in digital urban planning are:

3.1.1 Online Open Data Sources and the Associated Data Analytics

Online open data sources typically include administrative data derived from the "open government" initiatives across developing and developed countries, social media data, online communities (e.g., themed forums), job posting sites, and service records of smart-device applications. These new online data are usually "big data" and come with detailed timestamps and geo-location information, which provide valuable information for urban planning professionals to understand the dynamics in cities that are difficult to capture in structured statistics. Use cases of online open data for urban planning include mapping the spatial structure of cities, verifying the population and employment in fast-growing cities, and identifying the commuting patterns of formal and informal jobs [12].

3.1.2 GIS-Based Data Visualization and Integration

Three levels categorize the use of geographic information systems (GIS) for urban planning: visualization, data integration, and automation. The first level is to visualize geospatial data from a single source. For centuries maps have been used to visualize the correlation of different variables to geographical locations by layering these variables over the maps. The second level is integrating data from multiple sources to enable better decision-making. Data integration will likely be the mainstream application of GIS-based data analytics for urban planning in the next few years. The third level is the automation of tasks in urban planning, to a great extent enabled by artificial intelligence (AI) through machine learning. This level represents a qualitatively different paradigm of data and algorithm use and raises questions about issues related to the regulation, accountability, and ethics of algorithm-based decision-making. These questions provide an opportunity for contemplation about what processes in urban planning can and should be automated and the future role of urban planning within the ecosystem of a city [12].

3.1.3 City-Scale Data-Sharing Schemes

ATIS (automatic terminal information service) and Microsoft Ignite (an annual conference for developers and IT professionals) launched a new initiative to enable cities to share data with other cities. The organizations are working on a data-exchange specification which includes a data-sharing framework, data formats and protocols, security and privacy requirements, and simple APIs. This new data-centric, open approach to promoting urban economic development encourages citizens and businesses to conceive innovative solutions to immediate urban challenges [12].

3.1.4 City-Level Digital Twin

The worldwide smart-city initiatives have accumulated new knowledge on how digital technologies can help cities deliver better political and socioeconomic outcomes. The digital twin model will optimize the use of resources (e.g., energy and water), improve efficiency at a system level, and inform policy-making on planning and managing infrastructure. It also relates to the issue of mediating short-term urban management measures (e.g., smart-traffic lights) and medium-to-long-term policy goals (e.g., productivity growth and sustainability). The city-level digital twin explores digital technology as an intermediary for sharing intelligence across disciplinary and professional boundaries. It links different policy timescales, enabling the identification of system-level inefficiencies and risks, otherwise difficult to discover. The integrated intelligence may stimulate new collaborative approaches to policy research and practice and strengthen public debate [12].

Other digital technologies used for urban planning are:

- 3D visualization, including AR and VR
- Cloud-based services that aggregate, process, and store relevant data
- User-facing portals and mobile applications
- Cybersecurity tools
- IoT infrastructure capturing and feeding data to multiple destinations
- Advanced GIS services

- Big data management and analysis tools

These and other relevant technologies do not exist in isolation. There is a lot of interplay and cross-pollination between every aspect of the digital twin approach to urban planning. From building a complex and reliable communication network capable of withstanding high loads to properly managing massive volumes of incoming data, the process requires the utmost attention to detail and a forward-thinking attitude at every step.

As more innovations like driverless cars and fully autonomous, AI-based city management systems arrive, they will inevitably blend into the existing digital urban planning paradigm and be treated as their integral parts [11].

Within the context of the Metaverse, the concept of digital twin will have unparalleled impact on simulating and modelling events such as floods, bushfires, energy demands in view of changing urban population, traffic movements, climate change variables, and other pertinent concerns for the urban planning [10].

4 Conclusion

Urban sprawl, as defined, is an excessive conversion of rural land into urban land or an excessive increase of the city beyond the optimal city size. Although urban sprawl became a hot topic in the United States in the late 70s and early 80s, that was not an issue in Europe until recently due to the structure of the European cities. However, today we can observe symptoms of urban sprawl in European cities, such as excessive decentralization, road congestion, lack of open space, and overpopulation. Modern municipalities use the help of digital technologies to control urban sprawl and minimize its side effects. Through digital technologies, city planners can predict the speed and direction of city growth and supposedly prevent the city from sprawling. Even better, digital technologies help urban planners to envision a modern, technologically developed, and eco-friendly city. The transformative simulations are efficient tools for engaging citizens and investigating their future interactions with the environment. However, the use of digital twins as accurate virtual representations or copies of physical objects or locations is still in its early stages. For example, the Metaverse and research in this area are still in their infancy. There is little understanding of this global platform's substantive opportunities and implications. Yet, it has already raised concerns about risks and impacts on human, ethical, and social values. The technological development should not let go unhinged, and the formation and dissemination of new socio-humanitarian rationality is a necessary condition for the successful development of the Metaverse.

References

1. K. Williams, E. Burton, M. Jenks, Achieving sustainable Urban Form (New York: Taylor & Francis, 2000)
2. W. H. Parry, M. Walls, W. Harrington, JEL **45**, 2, 373–399 (2007)
3. T. Nechyba, R. Walsh, JEP **18**, 4, 177–200 (2004)
4. J. K. Brueckner, IRSR **23**, 160-171 (2000)
5. J. Geoghegan, L. A. Wainger, N. E. Bockstael, Ecol. Econ. **23**, 3, 251–264 (1997)
6. A. O'Sullivan, J. Urban Econ. **18**, 235–250 (1985)
7. G. Acharya, L. Bennett, J. Real Estate Finance Econ. **22**, 221–237 (2001)
8. M. Kahn, JPAM **19**, 4, 569–586 (2000)

9. A. Bertaud, *The Spatial Organization of Cities: Deliberate Outcome or Unforeseen Consequence?,* Working Paper, Institute of Urban and Regional Development, University of California , Berkeley (2004)
10. Z. Allam, A. Sharifi, S. E. Bibri, D.S. Jones, J. Krogstie, Smart Cities **5**, 3, 771–801 (2022)
11. V. Haydin, Digital Urban Planning Today and Tomorrow, (2020), Blog Post, [Online] https://intellias.com/digital-urban-planning-today-and-tomorrow/
12. A. Parlikad, L. Wan, T. Nochta. The Technological Transformation of Urban Planning in the Age of "Smart Cities", Policy Brief (University of Cambridge, 2021)