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From Smart Cities to Territorial Digital Twins: A Critical Essay with Evidence from Flanders' DUET

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1. *Smart Cities or Technological Enclaves? The Challenges of Digitalization between Inclusion, Gentrification, and Sustainability. Critical Introduction to Smart Cities: Beyond Technological Rhetoric*

The idea of hyperconnected cities, where traffic lights, street lamps, and garbage bins communicate in real-time with citizens to optimize urban services, fits into a utopian technological vision often associated with smart cities. However, this dominant narrative, grounded in a perspective where advanced technologies like the Internet of Things, 5G, and artificial intelligence promise to radically transform cities, making them more efficient, sustainable, and livable, requires critical analysis that goes beyond technological enthusiasm to examine the socio-spatial implications and power dynamics that characterize these urban transformation processes (Hollands, 2008).

The critical literature on smart cities has highlighted how behind the promise of efficiency and innovation lies a series of profound challenges related to social inclusion, equity, and sustainability (Paradiso, 2013). The concept of "smartmentality," introduced by Vanolo (2013), offers a fundamental analytical lens for understanding how smart cities operate not only as urban development models but as actual disciplinary strategies that shape behaviors, expectations, and modes of citizenship through technological devices. This critical perspective reveals how the rhetoric of smartness can mask processes of exclusion and social control, transforming technology from an empowerment tool into a mechanism of neoliberal governance (Vanolo, 2015).

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As observed by Paradiso (2013), it is necessary to develop a critical geography of smart cities that takes into account the spatial and social implications of these urban transformation processes. The primary challenge that cities face is therefore not merely technological but deeply involves the impact that this digital transformation has on different social strata and urban spatial configurations. While 5G, artificial intelligence, and other advanced technologies represent significant progress, the debate around smart cities increasingly focuses on who truly benefits from them and how these benefits are distributed in urban space, reproducing or amplifying existing inequalities (Murgante, Borruso, 2013).

Digitalization, while offering new tools to improve urban efficiency, can also generate new forms of exclusion, particularly for those who lack the resources or skills to quickly adapt to innovations. This digital exclusion is not uniformly distributed in urban space but follows specific geographical patterns that reflect and amplify pre-existing socio-economic inequalities. Low-income individuals, the elderly, and those living in rural or peripheral areas are among the most affected groups, configuring what Angelidou (2014) defines as a spatial approach to smart city policies that tends to privilege urban centers at the expense of peripheries.

The World Economic Forum has highlighted that while about 60% of the global population has access to the Internet, around 3.7 billion people remain excluded, unable to fully benefit from smart city technologies, and thus left on the margins of a transformation meant to improve everyone's lives (World Economic Forum, 2020). A study conducted by the Oxford Internet Institute found that in the UK, one of the most technologically advanced countries, 18% of adults lack basic digital skills, a figure that translates into a large number of citizens unable to access the city's smart services, such as digital public transport management or social service platforms (Helsper et al., 2021).

According to the 2023 ITU report, globally, 79% of people aged 15 to 24 use the Internet, a percentage that is 14 points higher than the rest of the population (65%). This generational gap has remained stable over the past four years and can be observed across all regions, but takes on specific spatial connotations when considering the geographical distribution of these digital skills. In high and upper-middle-income countries, near-universal Internet access has already been achieved for this age group, with a penetration rate of 95% or higher.

In low-income countries, young people aged 15 to 24 are nearly twice as likely to use the Internet compared to others in the same country. Although this is the largest usage gap across income groups, it has narrowed since 2019, when young people in this age group were 2.5 times more likely to be online compared to the rest of the population (ITU, 2023).

This digital divide exacerbates existing inequalities, creating a distinction between citizens who are able to access the benefits offered by technology and those who are excluded. The critical nature of the digital divide is reflected in what some scholars refer to as digital darwinism. Only citizens with advanced

technological skills thrive in increasingly digitalized urban environments, while those lacking these skills risk being left behind. This is particularly evident among the most vulnerable groups, such as the elderly and low-income individuals (fig. 1), who often lack the resources needed to keep up with technological advancements.

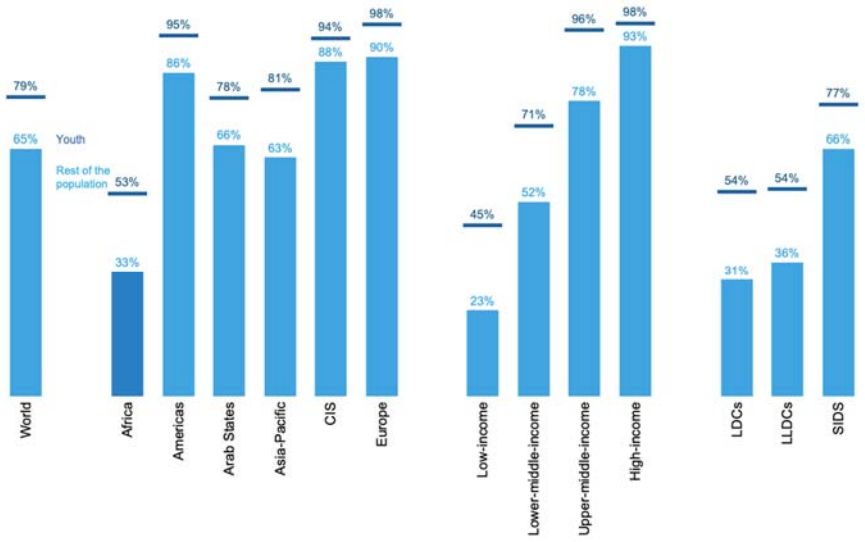

Fig. 1 – Percentage of individuals using the Internet by age group (2023).

Source: International Telecommunication Union, Measuring Digital Development. Facts and Figures 2023.

Smart cities, while designed to make services more accessible and efficient, risk creating new forms of exclusion and inequality. In cities like San Francisco and Seattle, access to digital services is essential to fully participate in urban life, yet not all citizens have the necessary skills to do so. As a result, smart cities may turn into technological enclaves reserved for those with the resources and knowledge to fully exploit them (Metropolis, 2022).

Additionally, the persistent divide in Internet usage between urban and rural areas remains a significant issue. In 2023, 81% of the urban population used the Internet, compared to 50% of the rural population, see figure 2 (ITU, 2023). This gap is most pronounced in low-income countries, where people living in urban areas are three times more likely to use the Internet than those in rural areas.

The gap between urban and rural areas varies significantly across different income groups. Analyzing data from 2020 to 2023 reveals that in high-income countries, the gap is nearly closed (a ratio of 1.1). In contrast, in low-income countries, the divide remains profound: less than one in five people (17%) in rural areas use the Internet. People living in urban areas are almost three times

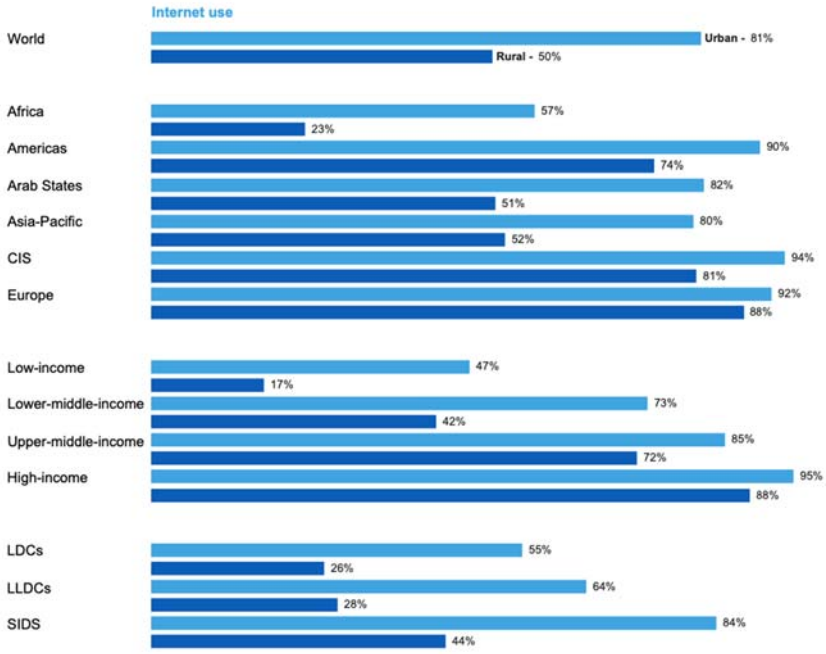

Fig. 2 – Percentage of individuals using the Internet in urban and rural areas (2023).

Source: International Telecommunication Union, Measuring Digital Development. Facts and Figures 2023.

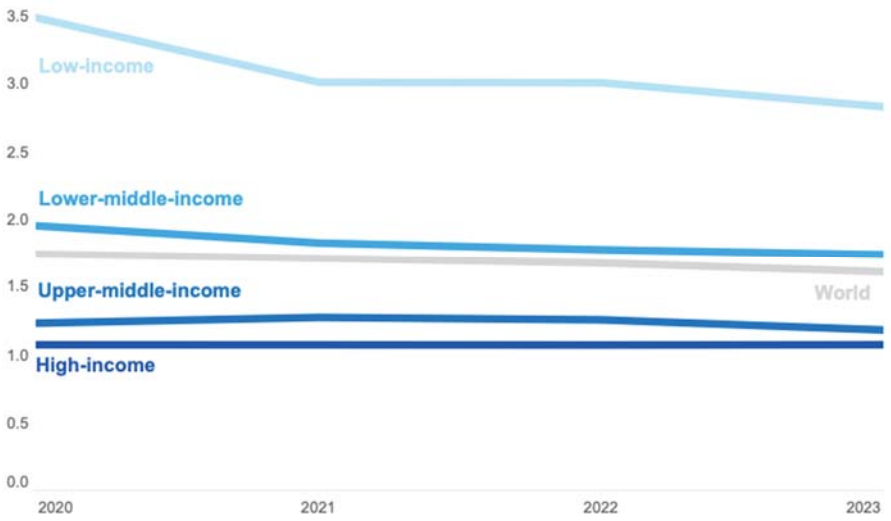

Fig. 3 – Internet usage between urban and rural areas.

Source: International Telecommunication Union, Measuring Digital Development. Facts and Figures 2023.

more likely to use the Internet. This shows that the digital divide between income groups is amplified in rural areas. These differences are clearly visualized in figure 3, which compares Internet usage between urban and rural areas across income groups. The gap in Internet usage between urban areas in low-income countries and those in high-income countries is 48 percentage points, while the gap between rural areas in the two groups is 71 percentage points (ITU, 2023).

This spatial pattern of the digital divide demonstrates how income inequalities are amplified in rural areas. As highlighted by de Falco, Angelidou and Addie (2018), it is necessary to move from the concept of "smart city" to that of "smart metropolis," recognizing the importance of building resilience in urban peripheries and rural areas.

Another major critique of smart cities is linked to technological gentrification. This phenomenon, similar to traditional urban gentrification, occurs when the introduction of advanced technologies in certain urban areas raises the cost of living, driving out lower-income populations. Smart cities, with their advanced digital infrastructures and high development costs, risk becoming cities for the wealthy, where only those who can afford to live in highly digitalized environments can fully benefit from technology.

This process of technology-mediated spatial exclusion is not simply an unwanted side effect but can be interpreted, following Vanolo's analysis of smartmentality (Vanolo, 2013), as part of a broader disciplinary strategy that uses technology to redefine who has the right to the city and under what conditions. Smartmentality operates through the creation of "smart" subjects who are able to navigate and benefit from urban technological environments, while excluding those who do not possess the skills, resources, or cultural disposition necessary to adapt to these new urban paradigms.

In cities like San Francisco, the introduction of advanced technologies and the influx of highly specialized tech workers have contributed to skyrocketing housing prices, exacerbating the housing crisis and influencing the city's demographic composition (Colding *et alii*, 2024). A striking example is the Mission District, located south of downtown San Francisco in the Bay Area, which represents a paradigmatic case of technological gentrification. As shown in figure 4, this neighborhood, historically home to many Latin American immigrants, has undergone significant changes with the arrival of tech workers attracted by the area's technological development.

The installation of high-speed fiber optics, smart sensors, and automated transport systems has contributed to increased property values. However, it is important to recognize that the increase in property values is likely the result of a combination of factors, including high wages in tech jobs in the Bay Area and high housing demand. Technological investments in homes and neighborhoods are probably a consequence of specific requests from high-income workers in the area, but it appears complex to establish direct causal relationships between smart technology alone and the creation of divides with low-income workers.

It is not only the presence of tech companies but also the smart infrastructure that has made the neighborhood more attractive to high-income workers, contributing to the urban transformation process. The district has become an example of how technological innovations can alter the social and cultural composition of an urban area, influencing property values and residential distribution.

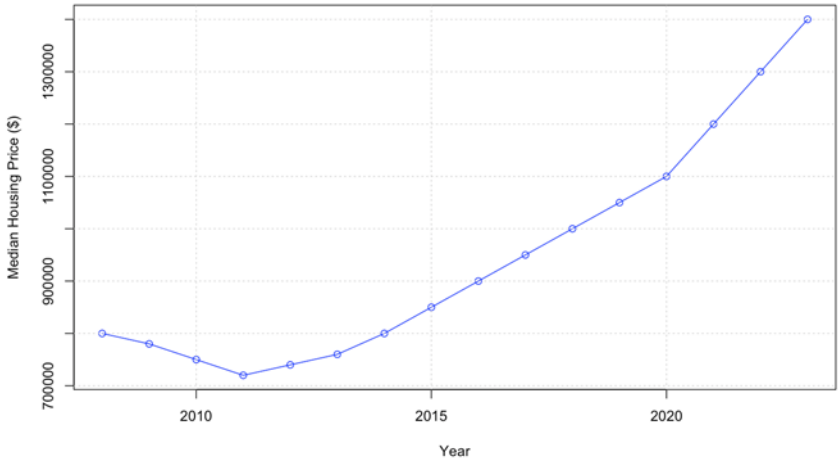

Fig. 4 – Housing Prices in Mission District (2008-2023).

Source: Author's analysis based on Redfin data - Mission District Real Estate Market.

This phenomenon highlights a trend in which smart cities, instead of being inclusive spaces, risk transforming into enclaves reserved for the technological elite, progressively excluding the most vulnerable citizens. This dynamic reflects what Paradiso (2013) identifies as the need to develop a critical geography of smart cities that takes into account the spatial and social implications of these urban transformation processes[1].

2. *Collaborative Governance as a Possible Solution: From Participatory Platforms to Urban Digital Twins*

To overcome the challenges associated with smart cities, such as social exclusion, the digital divide, and technological gentrification, it is essential to adopt a

[1] It should be noted that these are just some of the critical issues associated with smart cities, with many other challenges remaining unresolved, such as those related to privacy and environmental sustainability, which cannot be addressed in detail here due to space constraints. For further insights, refer to: Kitchin, R. (2020), Goodman, E.P., Powles, J. (2020), Zuboff, S. (2019) for issues concerning data protection, and Kim, J., Choe, S. (2022), Shahat, E. et al. (2021), Hollands, R.G. (2015) regarding environmental sustainability challenges.

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multidimensional and holistic approach that takes into account not only technology but also the needs and rights of all citizens. Solutions must aim to ensure equitable access to technology, promote an inclusive and transparent environment, and develop policies that balance technological innovation with social and ecological sustainability.

One of the first solutions to address the digital divide is investing in digital literacy programs accessible to all segments of the population. As highlighted by the World Economic Forum, a large percentage of the global population is excluded from access to the Internet and digital technologies. Therefore, to ensure that citizens can benefit from smart city infrastructure, it is crucial to create initiatives that teach basic digital skills, especially to the elderly, low-income individuals, and those living in rural areas. These programs must be free and accessible, with special attention to the linguistic and cultural diversity of urban communities. Cities should collaborate with schools, public libraries, universities, and non-governmental organizations to promote widespread digital literacy, ensuring that no one is left behind.

To tackle the issue of technological gentrification, cities should develop affordable housing policies and incentivize the creation of inclusive neighborhoods. The rising cost of housing in highly digitalized areas can be mitigated through regulations promoting affordable housing, such as rent caps and tax incentives for real estate developers who create affordable housing units. Singapore, for instance, has successfully experimented with public housing initiatives to ensure that even low-income populations can continue to live in the most digitalized areas of the city, reducing the risk of exclusion due to high property costs.

In all cases, one solution would be to adopt collaborative governance models. This means actively involving citizens and stakeholders in the design and management of smart cities, ensuring that technology serves people and not the other way around (Barnes, 2018).

To facilitate this process, participatory platforms should be more widely used, allowing citizens to contribute ideas and proposals on how to improve their city. Platforms like Decidim in Barcelona and Participatory Budgeting in Helsinki have shown how it is possible to actively engage citizens in political decision-making and resource allocation. These open-source platforms are designed to facilitate participatory democracy through digital tools that enable citizens to propose, discuss, and vote on public policies, initiatives, and collective decisions. In particular, Decidim represents one of the most advanced open-source platforms for participatory democracy, used internationally to facilitate collaborative governance in a variety of institutional, municipal, and civic contexts.

The platform was conceived with a technopolitical framework, where technology serves as a means to redefine democratic participation and build a transparent infrastructure to manage decision-making processes. Decidim oper-

ates by leveraging algorithms that structure interaction between citizens, policymakers, and other actors involved in governance processes. At the heart of this infrastructure is a deliberative model that allows participants to propose, discuss, vote, and co-create public policies. One of the key mechanisms is the preference aggregation algorithm, which organizes citizens' choices in an equitable and transparent manner during consultations or participatory budgets (Barandiaran et al., 2024).

However, these platforms are not without challenges. They need to be further developed and adapted to become more user-friendly and accessible to people with limited technological skills. One potential solution could be the integration of voice interfaces, allowing people to interact with the platforms using voice commands, making access easier for groups who may struggle to use computers or smartphones. Additionally, cities should ensure that participatory platforms are accessible through public devices, such as interactive kiosks or access points in community centers, enabling those without personal devices to actively participate. It is crucial that citizens' voices are heard and their feedback is genuinely integrated into decision-making processes. This would not only increase trust in institutions but also lead to better resolution of urban issues, promoting greater social cohesion.

Therefore, overcoming the challenges of smart cities requires implementing solutions that integrate technology and social inclusion. Cities must ensure that all citizens, regardless of their socioeconomic background or digital skills, can participate in and benefit from the opportunities offered by urban digitalization. Only through inclusive, participatory, and sustainable policies can smart cities truly fulfill their promise of improving life for everyone, not just a select few.

In this context, urban Digital Twins represent an emerging technology that can address many of the key challenges faced by smart cities, including social inclusion, sustainability, resource management, and governance. Defined as dynamic, real-time digital representations of physical cities, urban Digital Twins allow for the monitoring and simulation of a wide range of activities and infrastructures, improving operational efficiency and enabling decision-makers to predict future scenarios to optimize city management. If implemented correctly, this approach can be a powerful tool for reducing inequalities and improving the quality of life for citizens, as highlighted by Batty et al. (2018). However, for Digital Twins to fully realize their potential, they must be designed with careful attention to the needs of all social groups, ensuring equitable distribution of technological benefits.

One of the main advantages of Digital Twins is their ability to integrate data from a wide range of sources (IoT sensors, satellite data, mobile data, etc.) to create a real-time virtual urban model that can be used to simulate the effects of various policies or infrastructural interventions.

Digital Twins could offer a solution to tackle the digital divide and social inequality in smart cities. Cities can use these tools to identify areas with limited

access to digital services and develop targeted strategies to improve connectivity and access to technology. For example, through the analysis of data collected from urban sensors, Digital Twins can reveal patterns of digital public service usage, allowing administrations to identify underrepresented communities and develop specific interventions to increase digital inclusion.

Furthermore, Digital Twins can facilitate more transparent and participatory governance. Through user-friendly interfaces, citizens can access real-time information about their city and actively participate in decision-making processes. The Virtual Singapore project, for example, has demonstrated how a Digital Twin can be used to engage citizens in urban planning, allowing them to visualize the impact of proposed projects and provide feedback before implementation. This type of engagement can increase public trust and ensure that urban decisions reflect community needs and preferences. As demonstrated by Kitchin (2020), if properly regulated, a Digital Twin can promote more responsive and inclusive governance.

Regarding the issue of technological gentrification, Digital Twins could offer a solution by allowing administrations to simulate the economic impact of new policies or technologies before implementation. For example, in London, the Centre for Digital Built Britain is using a Digital Twin of the city to study the impact of new technologies on the cost of living and wealth distribution in urban areas. This has enabled planners to identify neighborhoods most vulnerable to gentrification and adopt preventive measures, such as introducing affordable housing policies or promoting social inclusion initiatives, to prevent technological transformation from leading to the economic exclusion of weaker groups (Bolton et al., 2018).

Another clear benefit of using Digital Twins is their ability to improve urban resilience. Cities are often exposed to risks such as natural disasters, climate change, traffic congestion, and health crises. Digital Twins allow for real-time monitoring of urban conditions and the simulation of emergency scenarios to better prepare for potential crises. In New York, for instance, urban planners are experimenting with a Digital Twin to simulate the impact of flooding caused by rising sea levels. Thanks to these simulations, the city has been able to identify the most at-risk areas and implement mitigation measures, such as installing barriers and building resilient infrastructure (Bolton et al., 2018). This predictive capacity offers cities a crucial tool to adapt to climate change and enhance the safety of citizens.

Using this framework, the digital model tool appears to have significant potential beyond the urban realm, particularly for monitoring and governing territorial areas at regional and metropolitan scales, which are often more vulnerable to environmental and other risks, leading to the development of models known as Territorial Digital Twins (TDT).

3. *Case Study: The DUET Flanders Twin Project – a Territorial Digital Twin for Regional Policy Making*

The DUET (Digital Urban European Twins) project is a significant case study for analysing the implementation of Territorial Digital Twin (TDT) technologies at the regional scale. The FlandersTwin, developed within the DUET initiative, focuses on Belgium's Flanders region, a network of interconnected cities which, together with Brussels, forms a large metropolitan area. Flanders alone can be considered a single smart region of 6.7 million inhabitants, making it an ideal testbed for territorial-scale Digital Twin implementation (DUET Consortium, 2022). In simple terms, the regional twin is a decision-support environment where policy makers can test "what-if" scenarios before acting (that is, ask: "if we close this bridge, introduce a Low Emission Zone, or change the bus network, what happens to traffic, air quality and noise?") and immediately see the expected effects as maps and charts (see fig. 5). The project was conceived to address the specific challenges of regional governance in a highly urbanised and interconnected territorial context. The Smart Flanders network brings the region together to reach the necessary scale for smart-city solution and data providers, showing how territorial Digital Twins can operate beyond municipal boundaries, encompassing entire regional ecosystems. In practice, this means connecting local and regional data/models so that decisions taken in one municipality can be assessed for their spillover effects across the wider territory (centre–periphery, urban–rural).

Fig. 5 – DUET (Flanders) regional twin — illustrative image from official materials*.

* This is a non-cartographic illustration used for communication purposes; no scale, compass or CRS is provided or implied.

Source: DUET Project - Digital Urban European Twins.

FlandersTwin was developed with four primary objectives that reflect the core principles of Territorial Digital Twins: (1) creating a Smart Region in which all actors can access available services and data; (2) supporting cross-silo cooperation between sectors; (3) involving citizens and businesses in policy-making processes to improve decision quality and acceptance of outcomes; (4) defining transferable services and data standards to maximise efficiency and open the market (DUET Consortium, 2022). The platform serves as a tool to collect, analyse and visualise real-time data across multiple domains, creating an interface that helps manage territorial resources efficiently at the regional scale. In other words, the twin is a regional "control room" for evidence-based planning (a single place that ingests live and historical data and runs scenario simulations). Unlike traditional urban Digital Twins, FlandersTwin integrates data from multiple cities and rural areas across the region, creating a comprehensive territorial model capable of simulating policy impacts at different geographical scales and across administrative boundaries. To achieve this, the twin combines traffic models with environmental/health models and then overlays the results in an interpretable way (maps, time series, dashboards), so that trade-offs and co-benefits are visible before decisions are taken. The architecture of FlandersTwin brings together, in a single regional "control room", data on mobility, air quality, health and the environment; based on these, it translates mobility scenarios (e.g., road closures or low-emission zones) into estimated pollution and noise maps, with street-by-street detail. In addition to official sensor networks, it combines bottom-up data produced by citizens (e.g., neighbourhood traffic counts), thus covering less-monitored areas and making before/after comparisons more robust. The infrastructure is modular: different "building blocks" activate only when needed and exchange information automatically, returning maps and dashboards in moments that make visible the trade-offs and co-benefits of policy alternatives[2].

[2] FlandersTwin employs TNO's "Urban Strategy" models -TNO is the Netherlands Organisation for Applied Scientific Research; Urban Strategy is a policy tool-suite that turns traffic scenarios into estimated air-pollution and noise maps) which combine the Dutch SRM1 method (a "street-canyon" approach for dense urban streets where buildings trap pollutants) and SRM2 (a "gaussian plume" approach for open roads and motorways- to produce NO_2 and PM10/PM2.5 surfaces and Lden noise maps computed at dense "receptors" -calculation points on façades/along streets; up to ~3 million receptors over ~30 km², allowing street-by-street detail-. On the mobility side, the twin fuses heterogeneous feeds through CityFlows -a "data blender" that unifies telecom/Wi-Fi/ANPR cameras/speed radars/bike-sharing into comparable multimodal densities, with an accuracy score- and incorporates Telraam -a citizen-science network where residents count passing traffic from their windows; this adds neighbourhood-level granularity that fixed sensors may miss-. The components talk to each other via a message broker (Apache Kafka, i.e., a real-time event "switchboard"), with models packaged as Docker containers (portable software bundles) and started by an orchestrator (the controller that launches models, passes parameters and collects outputs) over REST APIs (standard web interfaces); DUET refers to this modular layout as the "T-Cell" architecture (by analogy with T-lymphocytes that connect with external agents on demand).

FlandersTwin focuses on the design of new measures, their implementation, and the evaluation of results as set out in the Flanders Regional Mobility Plan and the Flanders Environment Plan. These plans aim to make mobility smoother through actions that are more environmentally friendly and less harmful to human health, representing a concrete application of territorial digital-twin technology to regional policy challenges (DUET Consortium, 2022). Flanders is currently recognised as a European hotspot for air pollution, making it a crucial testbed for assessing the effectiveness of TDT approaches to environmental and mobility challenges. The platform has been used to test and implement digital-twin capabilities, helping the region and stakeholders explore correlations between mobility patterns, health outcomes and air-quality data at different territorial scales. This is where the twin's value is clearest: it allows authorities, ex ante, to see how a road closure or a low-emission policy changes traffic volumes and, through the coupled models, how those changes propagate to NO_2/PM and noise exposure at both district and regional scales.

Two main use cases have been developed and tested: (1) mobility-flow analysis to better understand patterns across Flanders, Flemish cities and neighbourhoods, providing a comprehensive view of mobility's impact on citizens' lives in urban and rural areas; (2) public-safety applications to anticipate appropriate safety measures in areas with higher offence or crime rates, improving citizens' safety through predictive territorial analysis. In both, the emphasis is on comparability across spaces and options: the same inputs/assumptions generate like-for-like delta maps, making alternatives discussable with non-experts and easing cross-department coordination.

The DUET FlandersTwin project offers valuable insights into the benefits and limitations of TDTs at the regional scale. The platform has shown the ability to democratise available smart-city data for citizens, businesses and service providers across an entire region, facilitating cross-silo cooperation between sectors and administrative levels that is often difficult within traditional governance structures. Evidence reported in DUET materials also concerns adoption/usability (e.g., high shares of testers and professional users willing to use the platform) and the breadth of datasets/models/scenarios integrated; these are organisational outcomes rather than measured environmental effects. It is nonetheless important to adopt a cautious approach when evaluating results. While it has improved data accessibility and facilitated regional policy coordination, the complexity of implementing territorial Digital Twins at this scale presents significant challenges. The project has shown that creating interoperable standards across multiple cities and administrative boundaries requires substantial coordination and technical expertise that may not be available in all regional contexts. In short, scaling a regional twin requires sustained data governance (stable rules, roles and funding), not just well-designed software.

The platform's ability to integrate data from multiple sources and simulate policy impacts at different territorial scales represents a significant advance in

regional governance capabilities. The focus on correlations between mobility, health and environment has provided regional policy makers with unprecedented insights into the interconnected nature of territorial challenges that extend beyond city boundaries. At the same time, public DUET documents do not present ex-post causal impact metrics (for example, "NO_2 −x% after measure y"); the twin should therefore be read as enabling infrastructure for transparent, evidence-based choices, with actual outcomes to be verified through independent monitoring after implementation.

The FlandersTwin project demonstrates both the potential and the challenges of implementing TDTs at the regional scale. The success in creating a unified digital representation of an entire region with 6.7 million inhabitants, encompassing multiple cities and rural areas, is a significant achievement in TDT development. The project has shown how TDTs can facilitate evidence-based policy-making at the regional scale, enabling decision makers to understand complex territorial relationships and make more informed decisions on mobility, environmental and health policies. The platform's capacity to simulate policy impacts across different geographical scales has proved particularly valuable for regional planning processes. However, the project has also highlighted the technical, organisational and financial challenges associated with implementing TDTs at such a scale. The need for extensive data integration, cross-administrative coordination and ongoing technical maintenance represents substantial barriers that must be carefully considered in future implementations. The FlandersTwin experience suggests that, although TDTs offer promising tools for regional governance, their success requires sustained political commitment, adequate technical resources, and effective coordination mechanisms across multiple administrative levels. Future research should focus on more scalable and cost-effective approaches to TDT implementation, particularly for regions with limited technical and financial resources. Overall, the Flanders case clarifies what a territorial twin can and cannot do on its own: it connects local and regional evidence, surfaces trade-offs before acting, and structures participation; it cannot, by itself, guarantee redistribution or pollution reductions—those depend on the policies chosen and on how rigorously they are implemented and monitored.

4. *Critical Discussion, Limitations, and Future Directions*

Smart cities, while representing a promising evolution towards urban efficiency, resource optimization, and improved quality of life, must confront a series of complex challenges that include social exclusion, the digital divide, technological gentrification, and concerns related to privacy and democratic governance. As highlighted by the critical analysis conducted in this study, the adoption of advanced urban technologies is not a neutral process but involves significant

socio-spatial implications that require careful consideration of power dynamics and existing inequalities.

The analysis of the concept of "smartmentality" proposed by Vanolo (2013) has revealed how smart cities operate not only as urban development models but as actual disciplinary strategies that shape behaviors and modes of citizenship through technological devices. This critical perspective demonstrates the need to go beyond technological rhetoric to examine how urban digitalization can reproduce or amplify pre-existing socio-spatial inequalities, particularly evident in the center-periphery relationship analyzed through Angelidou's spatial approach (Angelidou, 2014).

Urban Digital Twins emerge in this context as a potentially innovative technology to address many of the key challenges of smart cities, including social inclusion, sustainability, resource management, and participatory governance. Defined as dynamic, real-time digital representations of the physical elements of the city, Digital Twins enable the monitoring, simulation, and optimization of urban infrastructures and services, with the potential to address many of the challenges faced by smart cities. However, it is important to emphasize that the success of these technologies does not depend exclusively on their technical capabilities but on the participatory and inclusive approach with which they are implemented.

When Digital Twins are designed with active citizen participation mechanisms, through open and accessible platforms, it is possible to contribute to reducing inequalities in the distribution of technological benefits. However, it is necessary to adopt a cautious approach in evaluating the effectiveness of these tools, avoiding deterministic claims about their impacts. The experience of the Virtual Singapore project, for example, suggests that the integration of data from different sources can improve transparency and civic engagement, but the actual democratization of decision-making processes depends on complex factors that go beyond the simple availability of advanced technologies.

Regarding the issue of technological gentrification, Digital Twins could offer tools to simulate the economic impact of new policies or technologies before their implementation. The example of the Centre for Digital Built Britain in London illustrates how the use of a city's Digital Twin can be utilized to study the impact of new technologies on the cost of living and wealth distribution in urban areas. However, it is important to recognize that identifying neighborhoods vulnerable to gentrification and adopting preventive measures require political and social commitment that goes beyond the technical capabilities of Digital Twins themselves.

Another potential benefit of Digital Twins is their ability to improve urban resilience through real-time monitoring of urban conditions and simulation of emergency scenarios. New York's experience in experimenting with a Digital Twin to simulate the impact of flooding caused by rising sea levels demonstrates how these tools can contribute to identifying at-risk areas and imple-

menting mitigation measures. However, the effectiveness of such interventions depends on local administrations' ability to translate simulations into concrete policies and adequate infrastructure investments.

Urban Digital Twins face several significant challenges that limit their adoption and effectiveness. One of the main limitations is implementation complexity, which requires advanced technological infrastructures, extensive IoT sensor networks, data management platforms, and specialized technical expertise. This represents a significant barrier for many cities, especially small and medium-sized ones, which do not have the necessary resources to undertake projects of such scope. As observed by Batty et al. (2018), the initial development cost and the burden of ongoing maintenance can hinder the adoption of Digital Twins, creating a divide between technologically advanced cities and those less equipped.

Another significant limitation is platform interoperability. Since many cities use different providers to manage their digital infrastructures, it can be difficult to integrate data from various sources into a single Digital Twin platform. This leads to inefficiencies and limits cities' ability to fully harness the potential of Digital Twins. Bolton et al. (2018) observed that the lack of international standards for urban data management is a significant barrier to the widespread adoption of Digital Twins, forcing cities to develop ad hoc solutions that may not be scalable.

Finally, another issue to consider is data accessibility and democratic participation. Although Digital Twins have the potential to increase transparency and civic engagement, many citizens may lack the technical skills to understand and use these tools. This underscores the need to invest in digital literacy, ensuring that all citizens have the opportunity to access the benefits of Digital Twins and actively participate in decisions affecting their urban environment.

Extending the analysis beyond the urban context, Territorial Digital Twins (TDTs) represent a significant evolution that applies Digital Twin principles to broader territorial scales, including regional areas, metropolitan regions, and distributed territorial systems. TDTs focus on broader issues such as regional resource management, environmental risk mitigation at territorial scale, and overall territorial sustainability, offering potentially effective tools to address the challenges of regional governance and territorial coordination often neglected by traditional smart city policies.

The experience of the DUET FlandersTwin project offers valuable insights into the potential benefits and limitations of TDTs at regional scale. The project developed a comprehensive territorial Digital Twin covering the entire Flanders region with 6.7 million inhabitants, demonstrating the feasibility of implementing Digital Twin technologies beyond individual city boundaries to encompass entire regional ecosystems.

The FlandersTwin has shown how territorial Digital Twins can facilitate evidence-based policy making at regional scale, enabling policymakers to understand complex territorial relationships and make more informed decisions

about mobility, environmental, and health policies that transcend individual city boundaries. The platform's capacity to integrate data from multiple cities and rural areas within the region and simulate policy impacts across different geographical scales represents a significant advancement in regional governance capabilities.

However, it is important to adopt a cautious approach in evaluating the results of the DUET FlandersTwin project. While the project has certainly contributed to improving data accessibility and facilitating regional policy coordination, the complexity of implementing territorial Digital Twins at such scale presents significant challenges. The project has revealed that creating interoperable data standards across multiple cities and administrative boundaries requires substantial coordination efforts and technical expertise that may not be readily available in all regional contexts.

The project's focus on mobility, health, and environmental correlations has provided regional policymakers with unprecedented insights into the interconnected nature of territorial challenges. However, the translation of these insights into effective policy interventions requires sustained political commitment, adequate technical resources, and effective coordination mechanisms across multiple administrative levels that go beyond the technical capabilities of the Digital Twin platform itself.

In conclusion, both urban Digital Twins and Territorial Digital Twins represent promising tools for addressing the challenges of urban and territorial digitalization, but their success critically depends on adopting inclusive, participatory, and spatially aware approaches. Data management, transparency, and direct community involvement in decision-making processes are essential elements to prevent smart cities and smart regions from becoming technological enclaves reserved for a few. Only through constant commitment to social equity, environmental sustainability, and democratic governance will it be possible to realize the transformative potential of these technologies without reproducing or amplifying existing inequalities.

Future research should focus on developing more robust methodologies to evaluate the social and territorial impact of these technologies, identifying best practices for the inclusive implementation of Digital Twins and TDTs, and creating regulatory frameworks that ensure equitable access to the benefits of urban and territorial digitalization. The experience of projects like DUET FlandersTwin provides valuable lessons for scaling territorial Digital Twin approaches while addressing the technical, organizational, and financial challenges that limit their widespread adoption. Only through this multidisciplinary and critical approach will it be possible to build truly smart, sustainable, and inclusive cities and territories for all citizens.

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From Smart Cities to Territorial Digital Twins: A Critical Essay with Evidence from Flanders' DUET

The rhetoric of smart cities has portrayed urban digitalization as a promise of efficiency and sustainability, yet in practice these processes often generate new forms of exclusion, deepen digital divides, and trigger technological gentrification. This essay adopts a critical perspective to question the smart city model and proposes a shift in scale: from Urban Digital Twins (UDTs), focused on the technical management of urban space, to Territorial Digital Twins (TDTs), capable of encompassing peripheries and regional systems. Through a review of the literature and the examination of the DUET project in Flanders, the paper shows how TDTs can strengthen political and institutional coordination and open new spaces for participation, while also highlighting that their effectiveness depends on inclusive governance choices and a sustained commitment to social equity and sustainability.

Dalle smart cities ai Gemelli Digitali Territoriali: un saggio critico con evidenze dal DUET delle Fiandre

Le retoriche delle *smart cities* hanno presentato la digitalizzazione urbana come promessa di efficienza e sostenibilità, ma la realtà mostra come tali processi possano produrre nuove esclusioni, accentuare i divari digitali e innescare forme di gentrificazione tecnologica. Questo saggio adotta una prospettiva critica per interrogare il modello della città intelligente e proporre un passaggio di scala: dai Gemelli Digitali Urbani (Urban Digital Twins, UDT), centrati sulla gestione tecnica dello spazio urbano, ai Gemelli Digitali Territoriali (Territorial Digital Twins, TDT), capaci di includere periferie e sistemi regionali. Attraverso un'analisi della letteratura e l'esame del caso DUET nelle Fiandre, si mostra come i TDT possano rafforzare la capacità di coordinamento politico-istituzionale e aprire spazi di partecipazione, ma anche come la loro efficacia dipenda da scelte di governance inclusive e da un impegno costante verso l'equità sociale e la sostenibilità.

Des villes intelligentes aux jumeaux numériques territoriaux : un essai critique avec des éléments probants issus du DUET des Flandres

Les rhétoriques des smart cities ont présenté la numérisation urbaine comme une promesse d'efficacité et de durabilité, mais dans la réalité ces processus peuvent produire de nouvelles formes d'exclusion, accentuer les fractures numériques et déclencher des dynamiques de gentrification technologique. Cet essai adopte une perspective critique pour interroger le modèle de la ville intelligente et propose un changement d'échelle : des Jumeaux Numériques Urbains (Urban Digital Twins, UDT), centrés sur la gestion technique de l'espace urbain, aux Jumeaux Numériques Territoriaux (Territorial Digital Twins, TDT), capables d'inclure les périphéries et les systèmes régionaux. À travers une analyse de la littérature et l'examen du projet DUET en Flandre, l'étude montre comment les TDT peuvent renforcer la coordination politico-institutionnelle et

ouvrir de nouveaux espaces de participation, tout en soulignant que leur efficacité dépend de choix de gouvernance inclusifs et d'un engagement constant en faveur de l'équité sociale et de la durabilité.