Beyond Twinness and Twinning: Reflections on Urban Digital Twinnation from the Namur 3D Project

Hadrien Macq [1], Imane Jeddoub[2], Roland Billen [2]

[1] F.R.S. FNRS - SPIRAL, UR Cité, University of Liège, 4000 Liège, Belgium, Hadrien.Macq@uliege.be
[2] GeoScITY, Spheres Research Unit, University of Liège, 4000 Liège, Belgium, (i.jeddoub, rbillen)@uliege.be

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Abstract

The current burgeoning of urban digital twin projects is leading to a proliferation, and sometimes confusion, about what exactly a digital twin is. Analyses tend to develop in two directions. First, efforts are being made to define typologies and debates are taking place on the *twinness* of digital twins' projects: the specific state and qualities of something called a digital twin. Second, research has been carried out into the empirical analysis of the *twinning* process, not to judge what is or is not a 'twin', but rather how the process of creating something called a 'twin' actually takes place. We argue that these two directions are not sufficient to fully understand the current phenomenon of the development of digital twin projects and its implications for the transformation of urban governance in the digital age. We therefore introduce the notion of *twinnation* to capture the gradual process of broader transformations in the representation and governance of a city brought about by the development and use of digital twins. Using the Namur 3D Project as an illustrative empirical case, we show that the notion of twinnation allows us to grasp the role of a larger number of social and technical entities and raises new fundamental issues both for empirical analyses of digital twin projects and for reflections on the development of digital twins better adapted to their development and use contexts. This work should be an initial step toward fostering both transdisciplinary research and collaborations involving stakeholders in the development of data-driven infrastructures of urban governance.

1. Introduction

Urban digital twins (UDTs) are increasingly central to the visions and strategies of smart cities, governments, and technology developers holding immense promise and challenges to bring cities to the next level of sustainability and management (AlBalkhy et al., 2024). The burgeoning of digital twin projects for urban governance has led to a proliferation of terms being used to describe the projects developed and the technologies associated with them: they are sometimes referred to as Urban Digital Twin, Digital Urban Twin, City Digital Twin, Local Digital Twin, and so on. This proliferation of terms and labels goes hand in hand with uncertainty about the concrete realities to which they refer; a central question in the literature concerns twinness: what actually is a digital 'twin'? Although discussions around the definition of digital twins have emerged prominently since the late 2010's, this remains both a challenge and a subject of ongoing interest and debates (Ketzler et al., 2020). A large part of these debates focuses on the more or less precise match between the reality of what is concretely developed through so-called 'digital twin' projects and a strict definition of what would correspond to the standard of a 'digital twin'. For example, some authors debated the very relevance of using the term 'twin' itself (Batty, 2018), with some concluding that the metaphor of a "digital twin" should be replaced by that of a "brain" in an organism (Tomko & Winter, 2019).

Linked to these debates are efforts to establish typologies, either to distinguish 'twins' from other entities, or to distinguish different types of 'twins'. One of the most frequently invoked of these typologies is the one that distinguishes between digital 'model', 'shadow' and 'twin', which has been developed in the context of manufacturing industries (Kritzinger et al., 2018). In this typology, a digital 'model' is a one-shot digital representation of a physical object that does not use any form of automated data exchange between the physical object and its digital counterpart. A digital 'shadow' is a model that is augmented with an automated one-way data flow between the physical object and the digital one. In this situation, a change of state in the physical object leads to an automated update in the digital object, but not vice versa. The digital representation is said to be a 'twin' when data flows between the physical object and its digital counterpart are automated in both directions. In such cases, the digital counterpart could also automatically control the physical object, via actuators. Transferred into the urban realm, this model/shadow/twin typology proved delusional for some scholars. Indeed, most projects that bear the name 'digital twin' are actually quite far from approaching a 'true' twin in terms of synchronized interconnection. This is what is described by Kitchin and Dawkins (2025, p. 623), who therefore speak of a 'model' rather than a 'twin': "some changes in the real world can be reflected into the model, such as the display of real-time sensor data, but this is limited in nature with significant alterations to the urban landscape only being updated in the model infrequently". Other typologies were developed to move beyond a strict, universal definition of what should constitute an urban digital twin and to better grasp the evolving definitions and core components of digital twins. Abdelrahman et al. (2025), focusing on the perceptions of scholars and experts on digital twins developed in the built environment sector, distinguished between two main representations of UDTs: Long-Term Decision Support (LTDS) DTs and High-Performance Real-Time (HPRT). Haraguchi et al. (2024), in an attempt at assessing how technologically and functionally advanced different UDTs are, developed a 'maturity model' to understand the governance implications of digital twins and forecast their future.

These definitional debates and typologies are necessary and relevant in that they shed light on the reality of what is developing through the current spread of UDTs' projects. However, we see three main limitations to them, that need to be overcome to better grasp what the spread of UDTs means for transformations in urban governance. First, regardless of their alignment with strict definitions of a twin, so-called 'digital twin' projects continue to proliferate. However useful they may be in clarifying a posteriori the names of the technologies being developed, efforts at

definition and typology do not allow us to take seriously projects that actors call "digital twins", even if this does not correspond to a given definition of a twin in the existing literature. It is therefore important to develop more empirical approaches that allow us to take the actors and their discourse seriously and to study projects in the making, so as not to miss an important part of the dynamic that is developing through the proliferation of so-called "digital twin" (DT) projects. Second, the definitional debates and typologies tend to focus on the technical dimensions of digital twins: the technologies involved in creating the twin and what the twin can technically do, for example in terms of synchronization, the data produced and processed, the greater or lesser integration of different layers of information about the city, and so on. However, the dominant technology-driven approach to UDTs does not take sufficient account of non-technical aspects (Lei et al., 2023). Indeed, the development and use of UDTs are eminently socio-technical phenomena (Nochta et al., 2021): they involve constant and evolving interactions between technical entities and social entities (actors, institutions, values, interests, etc.). The technical focus resulting from definitional debates and typologies therefore runs the risk of failing to understand a large part of the dynamics that are developing with the proliferation of UDT projects. Third, because they focus on the 'twin' as a final product, definitions and typologies are not well equipped to grasp the dynamic processes of development and use of UDTs within broader urban governance ecosystem. However, the emergence of the term 'digital twin' among economic, political, and academic circles leads to significant transformations in the conceptions of how cities can and should be represented, known, and governed (Knopf et al., forthcoming). To better grasp these transformations, we need to move beyond typologies, take a step back, and adopt a broader perspective on the development and use of UDTs for urban governance.

To overcome these limitations, we must zoom out and examine how UDTs interact with the socio-technical environment in which they are developed and used. We need an approach that considers both the technical architecture and components of UDTs, and the fact that the latter are evolving in a relation of mutual influence with the social, institutional, and political ecosystem in which they are deployed. Such an approach would help us reflect on the real-world impacts, governance implications, and long-term sustainability of UDTs, as well as develop transdisciplinary research on the ongoing burgeoning of UDTs. To develop such an approach, we introduce the notion of urban digital 'twinnation'. In Section 2, we develop what we mean by 'twinnation', how it diverges from the often-used notion of 'twinning', and reflect on what it allows us to analyze exactly. Then, in Section 3, to illustrate the potential of an approach in terms of twinnation, we present an empirical case: the Namur 3D project. In section 4, we reflect on several core dimensions that must be analyzed when we take twinnation into account. Finally, we conclude by summarizing our arguments and hitting to avenues for further research.

2. From Twinning to Twinnation

2.1. Twinning: Analyzing the Processes of Creating DTs

A first step beyond definitional debates has been taken by scholars developing empirical analyses of digital twins' initiatives through the notion of 'digital twinning'. Scholars from engineering and related fields often use the term 'twinning' to refer to the process of creating a cycle between the physical and the virtual states (Jones et al., 2020; Saeed et al., 2022). More specifically, twinning is the process of measuring the state of the physical entity and realizing that state in the virtual entity: in other words, it is the "act of synchronization between the two entities" (Jones et al., 2020, p. 39).

From this definition, research that discusses and analyzes the process of digital twinning often focuses on technical issues related to how this process is carried out: e.g., the twinning rate (the frequency in which the coupling of physical and virtual entities occurs), the collection and analysis of data, the artifacts of measurement (e.g. sensors), the integration of data, etc. (Jeddoub et al., 2023; Jones et al., 2020; Saeed et al., 2022). Other scholars, this time from urban, environmental studies and social sciences, have extended the technical-centered approach to twinning and argued that digital twinning is essentially a sociotechnical process (Nochta et al., 2021). This approach led scholars to argue that twinning is not exclusively a technical process but involves a number of human dimensions that need to be studied alongside the technical ones. For example, a number of studies showed that the process of digital twinning can be more or less participatory, that is, including or excluding a range of actors from the private sector, research and civil society, in the design of a digital twin (Calzati & van Loenen, 2023; Nochta & Oti-Sarpong, 2024). Other scholars building on this 'socio-technical' approach have described twinning as an active process of governance by design (Solman et al., 2022). In their perspective, the process of twinning is influenced by technical issues (data, sensors, etc.) as well as by regulation, the values and interests of human actors, and the resulting decisions of expert 'twinners'. In such a perspective, the focus is on "how boundaries are set for determining which aspects (technical, societal and environmental) are twinned, and thus how these boundaries influence the design and function (…) technologies over time" (p. 273).

The notion of 'twinning', especially when understood through a socio-technical approach, is of great help in overcoming debates about the greater or lesser concordance of digital twin projects with typologies of what a twin is. This notion allows us to grasp not only the final product, but also the entire process by which it was developed: all the operations involving human actors and technologies that contributed to the creation of an entity known as a "digital twin". However, by focusing on the process of creating a twin, the notion of "twinning" leaves in the shadows a large part of the story that takes shape when a digital twin project is developed. In particular, 'twinning' fails to take into account the insertion of digital twins into a gradual process of transformation in the way cities are represented and governed. Yet these broader transformations in the way cities are represented and governed are linked to digital twins in two ways: (1) they influence their development, and (2) they are influenced by their development. In other words, digital twins are in a relationship of mutual influence with transformations in the way cities are represented and governed. For example, in a recent article, Knopf et al. (forthcoming) showed that processes of digital twinning in urban governance both draw on and transform three core dimensions of urban governance that merge together technical and social aspects: the ways in which cities can be represented digitally, the specific epistemic promises attached to digital twins, and ideas about what a desirable urban governance should be. To extend the notion of 'twinning', and to capture the interactions between processes of digital twinning and broader transformations in urban governance, we introduce a new notion: that of 'twinnation'.

2.2. Twinnation: Capturing Broader Urban Governance Transformation

In introducing the notion of twinnation, we want to move beyond a focus on how the process of twinning unfolds to also capture its

inscription in broader transformations in how urban spaces are represented and governed. Going from twinning to twinnation is essentially a linguistic operation based on the use of the suffix -tion. The latter is close to the suffix -ing, but is broader: a word in -tion denotes both a process, an action, and a result, a state. It is a suffix that links an action to a state, i.e. the result of that action. We use this suffix to create a word that emphasizes the links between the process of creating a twin and the interactions of this process with the emergence of a particular state of urban governance. This leads to the following definitions: while (1) twinning is the process of creating a digital twin, (2) twinnation is the inscription of the process of creating a digital twin within the broader process of transforming the way a city is governed.

To make it clearer, and since our aim is to develop an approach to urban twinnation, we can make a parallel between the terms "Twinning/Twinnation" and "Urbanizing/Urbanization". The term urbanizing describes a dynamic process: it denotes the transformation of entities (spaces, institutions, or societies) as urban ones. Urbanization, on the other end, encompasses the full socio-spatial, economic, and political transformations associated with the growth of cities and urban systems. Crucially, it implies not only spatial expansion but also systemic integration, infrastructural scaling, and changes in governance. The shift from twinning to twinnation is closely related to the shift from urbanizing to urbanization. While twinning is the (sociotechnical) process of creating a virtual representation of the physical parts of the city and synchronizing the physical and the virtual entities, twinnation is the ongoing, systemic transformation of an urban environment through the integration, coordination, and scaling of digital twin technologies across sectors, institutions, and infrastructures. It reflects a systemic, integrated transformation: an entire city, region, or institution coming to be structured by the logics, affordances, and epistemologies of digital twinning. Like urbanization, twinnation involves a reconfiguration of how urban space is conceptualized, governed, and experienced.

To summarize our argument so far, Table 1 shows how notions of 'twinness', 'twinning', and 'twinnation' differ which regard to the central questions they deal with:

Twinness	What is a digital 'twin'?
Twinning	How is a digital twin created?
Twinnation	How do the twin and its broader urban governance context influence each other?

Table 1. Core questions of Twinness, Twinning, Twinnation

2.3. Implications

Two important precisions should be made at time point. First, the study of twinnation does not imply a complete abandonment of the study of twinning. In fact, twinnation refers to broader dynamics than the processes of twinning but includes the latter. In other words, twinning is a component – and an important one – of twinnation. An understanding of twinnation requires an understanding of twinning placed in the context of broader transformations of the urban environment, thus considering more elements: the social and technical elements involved into processes of twinning but also the actors, practical operations, rationales, institutions, regulations, epistemologies, etc. that make up the context in which twinning is enacted and which twinning contributes to shape. Translated into research questions, while studying twinning essentially concerns questions of 'what' is twinned and 'how' is it twinned, studying twinnation is about adding questions such as 'why is twinning happening at all?', 'how is it connected to the political and economic ordering of the city?', and 'how is twinning both shaping and shaped by transformations of urban governance?'. Second, just as 'twinning' (see section 2.1.), twinnation is never either social or technical: it is always a socio-technical phenomenon. In essence, what the notion of 'twinnation' points to is the inherently intertwined nature of social and technical elements: data are crafted by humans operating within technical possibilities and constraints; digital twins projects are shaped by technological and social incentives and limits, etc. In other words, twinnation points to the mutual shaping of technological and social orders. The study twinnation therefore requires that all elements, social and technical, be considered simultaneously to capture the dynamics of mutual influence: it requires transdisciplinarity to be studied and taken into account.

To help further position the notion of twinnation and its implications alongside the notions of twinness and twinning, Figure 1 provides an overview of the different notions and approaches that have been discussed thus far.

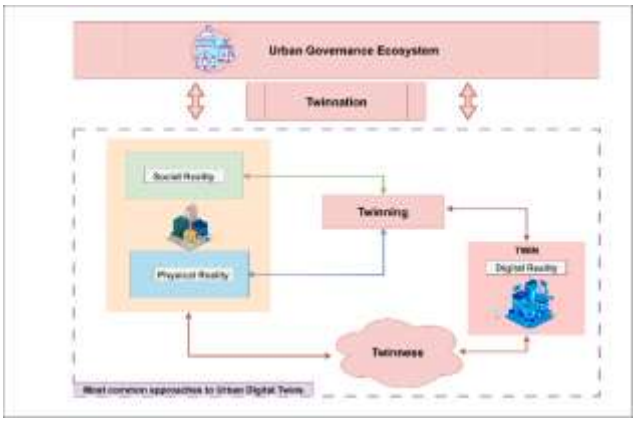

Figure 1. From Twinness and Twinning to Twinnation: highlighting the mutual influences between physical/social and digital realities within broader urban governance contexts.

3. Illustrative Empirical Case: Namur 3D

In this section, we illustrate our argument with an empirical case: the 'Namur 3D' project (see also Knopf et al., forthcoming). One of us analyzed Namur 3D as a case study and conducted fieldwork based on semi-structured interviews and document analysis. We approached relevant interview participants by identifying actors involved with this project, mainly employees in the public sector. Six interviewees were met between November 2022 and April 2023. All names and affiliations were anonymized to ensure confidentiality. This empirical material was approached through inductive analysis. Data were systematically coded, looking for patterns across the different interviews and documents. As the analysis progressed, emergent and recurring themes were identified and led to the establishment of categories for structuring the analysis and refining the different component of 'twinnation' in this specific case. By triangulating our findings with supplementary information such as news media articles, public statements and websites, we developed a comprehensive understanding of how Namur 3D functions as a governance tool.

By analyzing the way in which the Namur 3D project developed and was part of an objective to transform the way in which the city of Namur is represented and governed, we show (1) what can be analyzed of this project by focusing on the process of 'twinning' and (2) what can be analyzed of this project by focusing on the broader process of 'twinnation'.

3.1. Twinning Elements

Namur 3D digitally represents the 3D geometries of the approximately 45.000 buildings of the city, as well as the textures of the buildings' fronts. Each building is also associated with different layers of information, such as its postal address, year of construction, photovoltaic potential, and thermographic imaging of the roof. The private companies[1] that were task to conduct the twinning process had to cope with a set of specifications established by policy-makers and the public administration of the city: it had to cover the whole commune, it had to be 3D and it had to model a set of specific elements: all textured 3D geometries of the building; the calculation of roof photovoltaic potential; the aerial thermography of the entire municipal territory. Additionally, the minister and his cabinet wanted a 3D web visualization platform to make all data accessible to citizens.

As the result of the process of twinning, Namur 3D is publicly accessible via a web platform[2]. When accessing it, the user lands on a map of the city which invariably shows the view of the Town Hall, with every built volume modelled in 3D. A banner at the top of the screen allows direct navigation to various urban planning projects already completed or underway in the municipality. On the lower left section of the screen are different tools relating to the data available in the 3D cartography, including a tool for downloading data via the city's Open Data platform and a list of available data layers which allows users to display or remove the various layers on the map. The web visualization platform is integrated to the 'Namur Smart and Sustainable' (NSS), a space that seeks to put 'citizens at the heart of the debate on the future of Namur' and that 'questions the role of cities in the face of current and future challenges', as described on the NSS website. Namur 3D is accessible via the NSS' website and is also integrated into a physical building in the city centre (see also section 3.2.3). To provide a clearer overview, Figure 2 gives a view of the Namur 3D web platform. It shows the platform's main features, including the city map with 3D modeled buildings, navigation tools, and data layers. As shown in this section, a twinning perspective enables us to understand how the 3D model was produced, which players were involved, how they worked, what data flows are produced and pass between the physical and virtual entities, what is actually represented, etc. Based on the analysis of Namur 3D, here a number of elements specific to this particular twinning process: represented material elements and associated information; actors (both conducting and commissioning the twinning process); choices about what and how to represent; outputs (e.g. visualization platform); data acquisition techniques (e.g., sensors, photogrammetry, LIDAR), data bases, data flows. However, focusing on the twinning process tells us little about the interactions between this project and its wider environment: why it was developed, how it fits with other policy objectives in terms of governance and knowledge production, etc. To grasp these issues, we need another perspective in terms of twinnation.

3.2. Twinnation Elements

When analyzing Namur 3D through the lens of 'twinnation', several new elements appear in the picture that relate to the links between Namur 3D and broader political and administrative dynamics; its specific objective and its links to the urban governance ecosystem; its uses once developed.

Figure 2. Namur 3D - web visualization platform.

Several elements can help understanding the emergence of 'Namur 3D' within the political and administrative dynamics of the city. First, it is related to a wider history of data-driven urban planning within the administrative services of the city. A department for cartography and urban geography was created within the administration in the late 1980s. Since then, it has been working on the collection, treatment and use of data for urban planning purposes. Namur 3D is therefore seen by members of the administration as a continuation of previous efforts in terms of developing forms of data-driven urban governance. Second, in 2012, local public authorities set out in their municipal policy statement the goal of making Namur a so-called 'smart city'. The smart city initiative in Namur was centered around the idea of fostering the sustainable development of the city, using digital technologies to tackle issues of mobility, cleanness, employment, housing, environment and social cohesion. It is at this nexus of digital technologies and environmental objectives that the 'Namur 3D' project emerged. Third, by creating this tool, the Namur city government also sought a way to address a perceived deficit in public awareness of sustainability issues. The origins of Namur 3D lie in the will and influence of the municipal minister for regional planning, urban development and energy (Ecologist Party). This minister was in office from 2006 to 2018 and developed several important projects for the city in terms of regional planning and urban development. These projects were all linked to the ambition of tackling climate change at the urban level by turning Namur into an ecologically sustainable city. To achieve this overarching goal, the minister and his cabinet developed policies to reduce energy consumption in the city, notably by improving energy efficiency of private homes. They then identified a problem: 'How can we reach everyone? How to raise awareness? How do you visualize such abstract things as insulation etc.? I am a teacher by training, I am obsessed with pedagogy' (Minister, Interview, April 2023). The Namur 3D project therefore shows different ways of conceiving the development of a twin and its relation to what is deemed a good governance of the city.

3.2.1. Purposes and Connections to the Urban Governance Ecosystem

First, Namur 3D was conceived as a tool to raise citizens' awareness through the visualization of the energy condition of their home. In a way, Namur 3D was about nudging homeowners: by providing them with a way to visualize the level of insulation (with the aerial thermography) and the photovoltaic potential of their home, the idea was that they would be more aware of what they could do to renovate the building and then act accordingly. Second, 3D technologies are supposed to give a 'more realistic' view on a given territory. The inclusion of the third dimension to traditional 2D cartography is said to give 'greater consistency to technical studies carried out' (Press kit, 2018). Namur 3D was

[1] Two private firms were selected to work on the project: Walphot, a private company based in Namur, was charged of everything except the Web platform, for which ESRI Belux was selected.

[2] The platform is accessible online via this link: https://www.le-nid.be/3d

therefore seen as a way to gain new knowledge of the city for policy purposes. It was seen as a tool to objectivate material elements or phenomena that remained little known before. The idea was that the 3D makes it much easier to apprehend the current state of territory or how it might evolve. Several actors met during the fieldwork took the example of the simulation of projected shadows. The latter, according to them, makes it possible to see something that was unseen before, and hence to gain so-called 'objective' knowledge on an important component of a city's urban planning (Members of the administration, Interview, April 2023). Third, and directly linked to the help it was supposed to provide in decision-making processes, the minister insisted that the model was also a tool that reinforced the public sector's vision vis-à-vis private actors. By 'showing things in a transparent, non-arbitrary manner' (e.g. shadow projection) thanks to data, the 3D model provides public authorities with a tool to 'hold their political line loud and clear' in bargaining with private companies about urban planning projects (Minister, Interview, April 2023). Overall, the development of Namur 3D is therefore deeply entrenched in three different dimensions of urban governance that are undergoing a twinnation dynamic: the kind of representation that a made possible by digital twin technologies, the epistemic promises that these representations bring about, and the ideas of desirable governance that are rearticulated through digital twins. To better understand how Namur 3D aligns with broader urban transformations, we now examine how it engages with these three key dimensions of governance.

Representation: The Namur 3D model incorporates detailed information about buildings' photovoltaic potential and thermographic imaging of roofs, aiming to educate citizens on energy efficiency and climate-related issues. This approach reflects the city's goal of fostering ecological sustainability. By providing visualizations of energy conditions, the UDT nudges homeowners toward making environmentally friendly renovations. This emphasis on public engagement and education highlights a different aspect of representation, where the UDT serves as a tool for both governance and citizen involvement.

Epistemic Promise: The UDT promises to enhance public engagement and promote sustainability by providing detailed and accessible information about the city's energy efficiency and climate-related initiatives. By integrating data on buildings' photovoltaic potential and thermographic imaging, the UDT aims to educate citizens on energy conservation and environmental issues, fostering community-wide understanding and commitment to sustainability. This visualization capability is designed to make abstract sustainability concepts tangible, encouraging homeowners to undertake environmentally friendly renovations. The UDT in Namur seeks to bridge the gap between governance and citizens, using data-driven insights to motivate public action and support the city's ecological goals.

Ideas of desirable governance: The UDT is supposed to allow for a governance that can produce transparent, objective data on sustainability-related issues and communicate them in a pedagogical manner to citizens, who are expected to act accordingly. The governance that should result is therefore one in which public authorities can benefit from their capacity to twin the city through the production and treatment of data so that they raise citizens' awareness and engage them in the realization of pre-existing urban policies. Moreover, by giving hard facts to public authorities (e.g. buildings' shadow projection), the UDT is also expected to make governance more transparent and, hence, empower public actors in their relations to private ones.

3.2.2. Challenges Regarding the Use of Namur 3D

In terms of uses, Namur 3D shows a nuanced picture for the actors we interviewed. Current authorities do not ask the relevant administrative services to further develop the model, to go further with the data and their processing. Neither are they using the model as an instrument of urban knowledge and decision-making. This lack of success of the model and the digital twin idea in Namur is attributed by administration members to a number of factors: a lack of political will since the departure of the minister coupled to a lack of funds and manpower to further develop the tool, as well as the administration's wider lack of the digital culture needed for a twin to be developed and used in city services. Moreover, the few projects that were developed around Namur 3D and that were initially supposed to be integrated to it (e.g. a smart transport system) known their own problems. It results that very little data is updated in real time in Namur because the sensors have been installed but are not working. The sensors exist, but the data is incomplete, or the sensors have broken down altogether. And sometimes there are blockages because the owner of the sensors is a private company that doesn't agree to share its data: "And so, unfortunately, all this data that could enable us to set up much more intelligent things, for example in terms of flooding or traffic, we don't have it. So, we are not able to automate things". (Head of geomatics and urban planning Department, interview, April 2023). Among the people that are still working close to the project, the Head of the city's Department of Geomatics and Smart City laments that something closer to what he would consider as a proper digital twin of the city still does not exist. To him, in order to have a true digital twin, it is necessary to automate data transfer and to have some degree of real-time flows of data. Only this automation of data transfer would allow to reach a critical mass of data that is cross-referenced, leading to a major improvement in the knowledge one can have of the territory. As he observes, Namur 3D is currently not really used by specific services within the administration, as situation he sees as a pity and upon which – provided that he has access to more resources – he would like to act through re-developing the project in the future and making it a mainstream tool that out cross-cut administrative services.

Currently, although not widely used by administrative services and elected representatives, Namur 3D is available to the general public. The web visualization platform is integrated to the "Namur Smart and Sustainable" (NSS) via its website, where the platform is accessible, and the physical building in the city center. The NSS is a space that seeks to put "citizens at the heart of the debate on the future of Namur" and that "questions the role of cities in the face of current and future challenges" (website). The NSS has developed a permanent exhibition entitled "Hatching the city of tomorrow" to show how cities, and in particular Namur, can enter into transition and prepare a better future for their citizens. Namur 3D can be viewed and navigated via a giant touch-screen, in the center of the exhibition room. It is therefore used to "discover various themes closely linked to urban planning in a fun and educational way" (website). Here, then, 3D is essentially used to show things, to raise visitors' awareness of the issues at stake in the exhibition.

3.3. Summary of the Case

Analyzing Namur 3D beyond the twinning process provides a broader and more complex picture of the project. In particular, it shows that the twinning project is linked to a broader governance project that aims to strengthen public authorities in relation to private actors, while developing modes of governance that are more open to citizens, who are seen as key actors in the city's sustainability transition. We can therefore understand how the

form taken by the project (a publicly accessible 3D model focusing on the energy characteristics of the built environment) relates to the objectives and networks of actors in the field of urban governance. We can also understand how a particular production of knowledge about the city was considered useful for the governance of an area within a broader political strategy of environmental sustainability enabled by digital technologies. Based on the analysis of Namur 3D, here a number of elements specific to this particular twinnation dynamics: actors involved in the governance of the city; policy strategies; administrative services and organization; power relations within the governance ecosystem (e.g. between public and private actors); rationales; ideas of desirable governance; ways of knowing the city; uses (and absence of use). To compare approaches in terms of twinning and twinnation, Figure 3 shows the elements associated with each of these notions in the specific empirical analysis of Namur 3D.

Figure 3. Key elements of the Namur 3D Case: A Comparison Between Twinning and Twinnation.

As appears in Figure 3, analyzing a project through the lenses of twinning or twinnation have implications in terms of what can be analysed empirically, with the notion of 'twinnation' broadening the horizon of understanding the development and use of UDTs compared to that of 'twinning'. But it also has implications for the thinking behind the development of UDTs. Indeed, the notion of 'twinnation' makes it possible to consider a number of issues related to the way in which the development of UDTs can be better aligned with the contexts of transformation of urban governance in which they are developed and used, for example in terms of public sovereignty of data, citizen participation, opening up of platforms, and so on. In the following section, we return to some of these key issues, grouped into five main dimensions.

4. Discussion

As argued in Section 2 and illustrated throughout Section 3, twinnation allows us to grap on the interactions of digital twins' projects with the general ecosystem of governance in which they are developed and used (i.e. policymakers, institutions, privates companies, research centers, citizens, etc.). Twinnation encompasses the processes of twinning but also reconfigures what it means to represent and govern the city, including ways of knowing, deciding and participating in urban governance. Through such reconfiguration, twinnation produces new practices of urban governance, new subjectivities (e.g. involved, 'smart' citizens, 'data-driven' policymakers), and new objects of public debate (e.g., digital models, data-driven policies, modes of governance). In this section we present some issues that emerge as key when we consider the dynamics of twinnation. Each of the dimensions listed in this section is important both for the empirical analysis of existing digital twins' projects and for the development of future projects and technologies that would be more robust and better adapted to their context of development and use. The following list of key dimensions is not exhaustive but should be seen as an exploratory set of considerations for future thinking, research and development.

4.1. Twinnation's Dimensions

4.1.1. Purposes

In section 2, we argued that twinnation asks the fundamental question of why projects of so-called 'digital twins' are promoted and developed. In this perspective, seizing dynamics urban twinnation requires going beyond definitional debates and adopting a pragmatic approach that takes seriously the full range of actors and institutions involved in efforts to develop technologies that are as "twin" as possible, even though they are aware that a full-fledged digital 'twin' stricto sensu is not ultimately produced.

The central assumption here is that digital twin projects are assigned objectives, and that these objectives reflect conceptions of what constitutes 'good' governance and/or 'good' knowledge of the city that are pre-existing and transcend the boundaries of digital twins projects. These objectives strongly influence the way in which these projects are developed and may evolve over time, reflecting socio-technical changes specific to the project, but also to the context in which it is developing. This raises a number of questions both for the analysis of twinning projects and for their development, including, but not limited to:

- To whom does the label 'digital twin' matter, and why?
- How is the idea of a 'digital twin' linked to ideas of an improved urban governance?
- How do digital twin projects fit into broader political strategies (e.g., promoting the 'smart city', involving citizens into governance, producing new knowledge on the city, etc.).
- How are digital twin projects concretely adapted to fit into these broader strategies? How do these strategies affect the way digital twins are developed?
- How do the purposes attached to a given digital twin project change throughout the process of development and use of the twin?

4.1.2. Actors

By broadening the focus of twinning, the concept of twinnation makes it possible to take into account all the actors who are *de facto* involved in the governance of a city using a digital twin. These actors therefore go beyond those involved in the process of creating the twin to include those who will use it directly or indirectly for governance purposes: elected representatives, policy makers, urban planners, members of the administration, private companies using the twin to develop services, citizens, etc. The key assumption here is that the emergence of a digital twin in a governance ecosystem is dependent on pre-existing configurations of this ecosystem but also produces effects, redirects practices, gives power to certain actors rather than others, requires reorganization within the administration, and so on. A number of key questions therefore arise:

- Who actually uses the digital twin? How? And for what purpose?
- Who is not using it, voluntarily or involuntarily? Why?
- How are power relations between actors affecting the development and use of a twin?
- How are power relations between actors affected by the use of a twin?
- How are citizens invited or not to participate in urban governance through the digital twin?
- Who controls the data, its storage, processing and use?
- How are the administrative departments responsible for managing and using the digital twin organized?

- How does the digital twin generate collaborative urban governance practices?

4.1.3. Maintenance

Once we consider not only the development but also the use of digital twins, the question of their maintenance over time emerges as central. This follows in part from the previous points: the different objectives and actors involved lead to specific maintenance requirements, for example in terms of updating databases, repairing data collection systems, patching algorithms, etc. Maintenance operations are therefore central throughout the lifetime of a digital twin. More than a set of simple technical operations that would simply extend the life of the digital twins, maintenance allows us to understand how the governance ecosystem and its connections to the digital twin evolve over time, bringing to light issues that may not have been foreseen initially. Again, a number of key questions can be considered:

- What types of issues, both technical and social, emerge as the digital twin is used?
- How do these issues affect the life cycle and use of the twin?
- Who is in charge of updating the twin?
- How does maintenance practices change what the twin is and how it can contribute to urban governance?

4.1.4. Scalability

'Scalability' is often presented as a key characteristic of (big) data: data sets are expected to expand in size rapidly and to be translated to new settings. While often assumed to be a smooth process, scalability is in fact profoundly instable and uncertain: it depends on the specific configurations of data, actors and institutions that seek to bring things to a different scale, and it involves identifying both scalable and unscalable elements. Digital twins are no exception: they are often developed as pilot projects with the aim of being scaled up. This scaling up can be on a sectoral basis (e.g. a twin focusing on mobility in a city is extended to air quality in the same city) or on a territorial basis (e.g. a twin for a district of a city is extended to the whole city, or a twin for a city is extended to all cities in a country). There are also initiatives that aim to scale up by integrating different local digital twins that are linked together to form a single large twin. In its various forms, scalability raises a number of key issues that need to be considered when analyzing and developing UDTs:

- What is effectively scaled-up? Why? And How?
- How are technical components of the twin made scalable?
- What does scaling-up require, both in terms of technologies and of human interventions?
- How are different components of the twin shared and standardized into scaled-up technologies (e.g. commercialized platforms, new standards for database, etc.)?
- How the perspective of being scaled-up and the imperative to be relevant at wider levels shape the development of UDTs in the first place?

4.1.5. Responsibility

Responsibility raises questions about who is accountable for what, under what terms, and with what implications. As a key-element of twinnation, responsibility must be tackled in a systemic way, encompassing technical, ethical, political, institutional, and civic dimensions. In fact, in addition to the technical responsibility for ensuring, for example, that the various functions of the digital twin operate correctly or that data is kept up to date, there are other aspects to consider. For example, (1) decision-making responsibility: who is responsible for decisions taken on the basis of simulations or predictive models? But also (2) ethical responsibility: how are concerns about surveillance, bias and unequal access taken into account? Who is ensuring that digital twins do not reinforce existing socio-spatial inequalities? (3) Institutional responsibility: Are existing governance structures equipped to integrate the twin? Are new institutions or roles being created, and how are they legitimized? And finally, (4) civic responsibility: how are citizens empowered (or burdened) by digital twins? Should they be expected to become co-developers, observers, data providers?
Moreover, responsibility is not static. As digital twin projects evolve their governance frameworks must adapt to accommodate new uses, users, and stakes. This calls for anticipatory mechanisms that foster accountability not only retrospectively but also proactively, ensuring responsible innovation and inclusivity over time. Key questions include:

- Who is held accountable when decisions based on digital twins lead to undesirable outcomes?
- How are responsibilities distributed among technical teams, public officials, private partners, and civil society actors?
- How are questions of transparency and explainability addressed within the twin's ecosystem?
- What mechanisms are in place to enable ethical oversight, public scrutiny, or institutional correction?
- How does the existence of the digital twin reshape notions of urban accountability?

4.2. Structuring Twinnation's Dimensions

While each of the five dimensions, Purposes, Actors, Maintenance, Scalability, and Responsibility, captures a key aspect of twinnation, they are not conceptually equivalent nor analytically independent. These dimensions form an interdependent system that can be structured to both clarify their roles and enhance their empirical utility when studying or categorizing digital twin projects. From a conceptual perspective, these dimensions can be grouped and hierarchized as follows:

- Purposes provide the strategic and normative orientations that motivate digital twin projects. They shape how the other dimensions are configured and evaluated.
- Actors and the distribution of Responsibility among them constitute the structural and institutional core. These dimensions define who participates in twinnation, how power is negotiated, and how accountability is ensured.
- Maintenance and Scalability represent the dynamic and operational layer. They reflect the temporal and spatial evolution of projects, as well as their capacity to be sustained, adapted, or replicated across scales.

This tripartite structure (orientations, institutions, evolutions) enables a clearer understanding of how digital twin projects emerge, stabilize, and evolve within specific governance contexts. It also supports a more operational use of the framework, notably for comparative studies. Such a structure could be used in the future to analyse and categorize from a twinnation perspective UDTs initiatives around the world.

5. Conclusion

In this paper we have argued for developing an approach to the current spread of UDTs in terms of 'twinnation'. We have defined what this term encompasses and distinguished it from that of 'twinning'. We have shown that the notion of twinnation allows us both to move beyond definitional and typological debates and

to broaden the focus by situating the twinning process within the web of interactions it has with the wider environment in which it takes place. In other words, twinnation is a notion that allows us to capture the interactions between the development of digital twins and wider changes in the way a city is governed. Understanding these interactions, as we have shown, is crucial both for understanding the full picture of what the spread of UDTs means for governance, and for thinking upstream about the development of digital twins that are better adapted to the specific contexts in which they will be developed and used. Our argument has been based on an illustrative empirical case study. The next step is to compare the notion of twinnation with other case studies and undertake comparative analyses to determine its applicability to different situations. In a recent article (Knopf et al., forthcoming), Namur 3D was compared to two other cases (in Munich and Boston) in terms of the impact of urban twins projects on the ways cities are digitally represented, the epistemic promises associated with digital representations, and the ideas of desirable governance associated with urban digital twins. Future similar studies would allow to further develop the conceptual proposal of the present article. Similarly, the notion introduced in this article must still be shared with and critically examined by the diverse communities engaged with urban digital twins, including technical, sociological, and socio-technical perspectives. Its adoption depends on its dissemination and the degree to which it proves useful in advancing our understanding of the multifaceted implications of digital twin technologies in society. If, as we argue, it offers a more comprehensive grasp of these implications, it could significantly enhance how public administration's approach the challenges of implementing digital twins and inform the development of more context-sensitive recommendations for policymakers. For now, by drawing up a prospective list of key dimensions to be taken into account when considering a process of urban digital twinnation, we have opened up avenues for future research into contemporary changes in digitalised urban governance. In particular, and in line with our desire to go beyond typological efforts, we believe that these dimensions can be used to conduct comparative studies of different urban digital twin projects and lead to maps of twinnation varieties. These mappings would make it possible, for example, to identify patterns of similarities and divergences in the way different twinnation dynamics develop in different cities, and thus to broaden our understanding the articulation between ways of digitally representing and governing a city.

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