EXPLORING DIGITAL TWIN ADAPTATION TO THE URBAN ENVIRONMENT: COMPARISON WITH CIM TO AVOID SILO-BASED APPROACHES

A. Deprêtre[1,2*], F. Jacquinod[3], A. Mielniczek[3]

[1] Université Gustave Eiffel, Lab'urba, 77454 Marne la Vallée Cedex 2, France, adeline.depretre@univ-eiffel.fr
[2] UMONS, Faculté d'Architecture et d'Urbanisme, 7000 Mons, Belgique, Adeline.DEPRETRE@umons.ac.be
[3] LASTIG, Univ Gustave Eiffel, EIVP, F-75019 Paris, France, (jacquinod, alexandre.mielniczek)@gmail.com

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ABSTRACT:

The use of digital models and tools to support a more sober, sustainable and human-centred spatial planning is constantly expanding. Among those, digital models of buildings and territories are considered useful by scientists and practitioners and used for a wide range of purposes. Several labels are currently used to characterise those digital tools and models, partly reflecting on technological developments: 3D city models, Planning support systems, Smart Cities, urbanism 3.0., City Information Model (CIM), Digital Twins (DT), etc. First used in industry, the label DT is now both used by practitioners and researchers, in relation to the development of innovative city models. Nevertheless, this label remains fuzzily defined and designates heterogeneous models from a technical standpoint. In this paper, we propose an exploration of the definitions and technical contents of DT at the city scale and a comparison with CIM approaches, as CIM is also used to label similar city models. Our analysis is based on a literature review of both DT and CIM definitions and applications to the urban context, an exploratory survey conducted with 13 practitioners about their views on DT and its potential regarding urban planning and management and a comparison of a few real-world projects either labelled CIM or DT by practitioners. Our analysis leads us to pinpoint several of the remaining challenges for a DT approach to be developed at the city scale. We also shed light on potential shortcomings of future research, if based on too narrow DT definitions.

1. INTRODUCTION

Urban planning digitalisation has been evolving rapidly in recent years. Complex urban systems (Delaître et al., 2016; Dovey & Wood, 2015) and the drive for a more sustainable development of cities (Elmqvist et al., 2018; ICSU & ISSC, 2015; Klopp & Petretta, 2017; United Nations, 2015) lead stakeholders to resort to digital technologies, some being imported from other fields.

For many years, urban planners have used digital models such as Geographical Information systems (GIS) and data (Goodchild, 2010; Longley et al., 2005) and 3D city models (Biljecki et al., 2015; Jacquinod, 2014). Building information modelling (BIM) tools and processes as a method to assist and enhance planning, construction and management quality throughout the life cycle of a project are progressively being adopted (Gil, 2020; Ohori et al., 2018). In the last few years, many concepts considered useful for achieving a "planning revolution" (Grimwood, 2021) are also used in both scientific and operational fields (Centre for Digital Built Britain, 2020). Among those, the Digital Twin (DT) notion is more and more used by practitioners to label their city modelling approaches, although not always clearly defined (Dawkins et al., 2018; Kang et al., 2021; Ketzler et al., 2020; Shahat et al., 2021). Indeed, various definitions of DT coexist and their concrete technical realities are heterogeneous.

Given the growing use of the term DT both in scientific literature and professional practices, this notion needs to be taken seriously, even though some researchers (Ketzler et al., 2020), as well as some practitioners, consider DT more as a trendy label or a new way to label existing tools and methods than an innovative way of performing urban design and management. In this paper, our purpose is to explore the notion of DT and to put it into perspective with the City Information Model (CIM) one, since they sometimes encompass similar conceptual and technical realities. First, we examine definitions of each label (DT and CIM) in order to assess their uniformity and possible variations. Then we establish a list of criteria that should allow us to differentiate between DT, CIM and other types of city models. Afterwards, we confront those criteria with practitioners' definitions and practices through an exploratory survey and 4 case studies. We then discuss our results in order to pinpoint challenges for the use of the DT notion in urban planning and management and for researchers working on the subject.

2. METHOD

In order to gain insights both on conceptual and concrete technical aspects of CIM and DT, we combined three complementary approaches: a scientific literature review on CIM and DT definitions and uses for urban planning, an exploratory survey conducted with 13 practitioners and a comparison of 4 city models labelled either DT or CIM.

2.1 Scientific and Grey Literature review

Our scientific review process is described in Figure 1. Firstly, we selected a large panel of documents from scientific databases such as Scopus, ScienceDirect, Clarivate (formerly WoS) and Semantic Scholar. We experimented with several keywords' combinations in order to target papers dealing with CIM and DT as digital models for urban planning at the district and/or city scale. We excluded literature from several unrelated fields (Medicine, Mathematics, Energy and Agriculture and Biological Sciences) and focused on the last 25 years. This first step enabled us to compile a collection of 91 documents. This corpus was studied by reading the abstracts, keywords, introductions and

* Corresponding author

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conclusions. We finally kept for our literature review a panel of 68 relevant scientific documents.

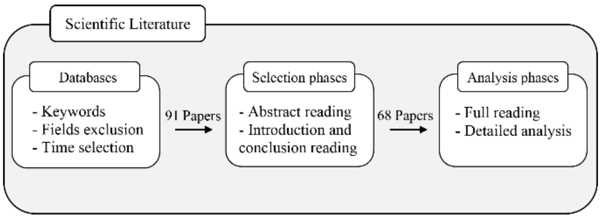

Figure 1. Scientific literature review method

We also looked at grey literature as we wanted to compare scientific definitions with urban planning practices. We searched for and reviewed different ongoing or completed projects labelled either “City Information Model” or “Digital Twin” by practitioners. In order to select existing models that could be compared more extensively, we used three models for which we had access to precise technical information (through partnerships or direct exchanges with practitioners) and one additional case study that is extensively described in a report available online (City of Helsinki, 2019).

2.2 Exploratory survey

We noticed some discrepancies between professional uses of the DT label and its scientific definitions, as well as many similarities between CIM and DT during our literature review. We thus decided to try to explore further practitioners’ views, although our time frame was limited. Exploratory interviews were conducted with 13 practitioners from 12 different entities between December 2021 and January 2022. Participants were selected either because they used the DT term or because we identified them as highly skilled specialists in their field of expertise, who would be aware of new trends. The entities they work for are specialised in facility management, architecture, airport design and operation, railway station design, city administration, general contracting and software development. 3 architects, 9 engineers and 1 marketing specialist were interviewed. Interviews were conducted by a building physics engineer, former BIM consultant now doing research.

Video conferencing tools were used for interviews, each lasting about an hour. Eight questions were asked to each participant concerning their definition of DT, its specificities regarding other labels such as CIM as well as current practices and their potential limits and difficulties. Answers were simply registered and not challenged. Our aim was to gather a first impression of the uniformity or variety of practitioners’ definitions and of practitioners’ overall sentiment towards DT. Our survey is not representative of the whole urban planning field, and is only used to explore practitioners’ definitions of DT and CIM and how they differentiate between DT and CIM in real life, in order to compare those few examples with scientific works. We do not plan any specific generalisation from those results, although we will use them to formulate hypotheses to be tested for a more extended survey. However, the fact that several practitioners had a vision which was different than most scientists on DT definition seemed already noteworthy, although we cannot yet quantify this phenomenon. This is why we included feedback from our interviews in this paper.

3. COMPARISONS BETWEEN DT AND CIM

3.1 DT scientific literature review

3.1.1 Origin and current definitions of DT:

One of the difficulties in the study of the DT concept is its evolution over several decades, with various uses and definitions, partly evolving over time and together with technological developments. Identified by Gartner in 2019 as one of the top ten strategic technology trends (Ezhilarasu et al., 2019), the term “digital twin” was reportedly introduced in 2003 by Grieves (2014) for product lifecycle management (PLM) in the Industrial sector. However, in the last sixty years, the term DT has been used in various settings. Some authors argue that models from the 1970s were actually DT, even if not so labelled, having the same characteristics as current models (for instance digital twins of the Apollo 13 shuttle by NASA (Ferguson, 2020). Older uses refer to digital models in various contexts without matching most current definitions (for instance to refer to a digital search interface that would be the “digital twin” of a person browsing through books in a library (Kent et al., 1968)). The notion also appears in research from the 1990s dealing with the 3D digital models’ applications for urban planning (Hernandez & Hernandez, 1997).

The distinction between earlier and current uses of the term are often focused on the use of sensors and Internet of Things (IoT) to connect a DT to its “physical twin”. This is why it is often considered that some technological developments are key for DT. Tao et. al (2019) argue that limited literature on DT between 2003 and 2011 demonstrates that technologies were insufficient to develop proper DT and Grieves (2014) links this to the lack of methods and tools to automate data collection. Thereafter, the concept has been widely developed in several fields, such as aircraft structures life cycle sustainability (Tuegel et al., 2011) or production optimization in various industries (Boschert & Rosen, 2016). The concept is now being increasingly discussed within the urban design and planning field (Mohammadi & Taylor, 2017) and within the built environment sector (ARUP, 2019), where it is considered as substantially valuable to all associated parties (Brilakis et al., 2019). A large potential of development is identified by some authors as well as industrial actors, who consider that building and city management are still insufficiently “digitised” compared to other fields (Bughin et al., 2016).

Current definitions of DT in the scientific field are relatively consistent but differ somewhat between authors and domains. DT is often seen as an iterative process involved in a loop connecting the physical to the virtual (Grieves, 2014). El Saddik (2018) defines the DT as a digital replication of a living or non-living physical entity linking the physical and the virtual to provide a way to monitor, optimise and predict processes so as to improve human well-being and quality of life. Wagg et al. (2020) also argue that beyond the supervision and exploitation of physical assets, DT must be predictive and quantify the reliability of the latter. Boschert and Rosen (2016) state that a DT describes performance but also provides solutions for the optimisation of the real twin. In the urban planning field, DT is supposed to improve creativity, allowing for urban design to be more human-centred and responsive (ARUP, 2019). Nevertheless, the use of DT in planning is not necessarily straightforward. For Batty (2018), a DT mirrors a physical process exactly corresponding to its real-time operation, so he believes that a DT is an idealistic and unachievable vision as it could only represent a limited set of variables, rarely including social and economic processes. From this perspective, some authors propose to use instead the notion of cyber-physical integration (Haag & Anderl, 2018; Tao et al., 2019; Tomko & Winter, 2019).

From a technical standpoint, there is not a single format or type of tool that is meant to be used for every DT of cities or territories.

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Boje et al. (2020) argue that many concepts and applications already discussed in the past are reused and renamed as building blocks of a DT, in order to foster interoperability, automation and intelligence of systems. In the built environment, some authors promote the use of BIM or CIM as inputs for the DT digital model allowing, among other things, the visualisation, exchange, sharing and management of the physical twin data (Boje et al., 2020; Deng et al., 2021; Ding et al., 2018; Petrova-Antonova & Ilieva, 2019). Sensing capability, characterising the flow of data "in real time" (Haag & Anderl, 2018; Tao et al., 2019), is often attributed to the IoT as a means of linking the physical and the virtual. However, this step is still unclearly defined as far as its technical implementation is concerned. For instance, Martinez et al. (2018) consider the use of a virtual environment as a virtual sensor to predict the facilities' behaviour. Howell et al. (2017) also stress the importance of the semantic web for resolving interoperability issues between different practitioners exchanging information. Finally, Boje et al. (2020) argue that artificial intelligence algorithms and associated tools/processes allow for various analyses, simulations but also predictions to be performed in a DT. Eventually, since DT cannot be limited to specific formats, tools or technologies, we propose to focus on DT characteristics which are widely accepted among studied authors. We use them as key defining criteria for DT, so as to be able to distinguish a DT from other types of city models.

3.1.2 Key criteria to characterise a DT according to scientific literature:

- A DT requires the creation (or re-use) of a digital model which represents all the constituents of its physical twin and contains information related to its entire life cycle (Boje et al., 2020; Grieves, 2014; Qi & Tao, 2018);
- Different forms of data gravitate bidirectionally between physical and virtual entities. These data are delivered "in real time" by sensors to the virtual twin to be processed in order to establish knowledge bases, providing one of the added values associated with DT (Batty, 2018; Grieves, 2014; Haag & Anderl, 2018; Howell et al., 2017; Mohammadi & Taylor, 2017; Qi & Tao, 2018; Tomko & Winter, 2019; Tuegel et al., 2011);
- A DT must be able to perform various analyses, simulations and predictions to achieve some decision making and optimisation (Batty, 2018; Tomko & Winter, 2019; Tuegel et al., 2011).

3.2 CIM

3.2.1 Origin and actual definitions:

The acronym CIM was reportedly first used by Khemlani (2005). It is increasingly used in relation to the possibilities offered by BIM functionalities in terms of urban project management at all phases and is considered to offer high potential for professions such as architects or urban planners (Dall'O' et al., 2020). The term "CIM" has been introduced to extend BIM cooperative processes at the city scale. CIM is often described by authors as a way to understand cities, to collaboratively involve stakeholders in their improvement so as to move them towards sustainability and quality put forward by the smart city vision (Amorim, 2016; Billen et al., 2015; Dantas et al., 2019; Petrova-Antonova & Ilieva, 2019; Sielker & Sichel, 2019; Thompson et al., 2016). Khemlani (2016) discusses it as a way to support and facilitate urban planners' and designers' work by addressing various issues (traffic congestion, accessibility, connectivity, impact of natural disasters). Mityagin et al (2020) therefore propose to visualise CIM as a meta-model of the city to host data describing the urban environment, population and its activities. Hägglöf and Salminen (2015) suggest that CIM can provide cities with more efficient planning processes by bringing together tools and numerous data sets in a common environment. Thompson et al. (2016) echo the words of different authors (Duarte et al., 2012; Gil et al., 2009; Hamilton et al., 2005) in synthesising the CIM vision as a global and transversal philosophy generating spatial data models. Furthermore, CIM could be used to model changes over time, to observe the different impacts on the urban system (Sielker & Sichel, 2019).

From a technical standpoint, various tools and formats are considered by scientists to produce and exploit a CIM. Some consider CIM as semantically enriched visual representations that go beyond the visualisation function to offer a range of information, resulting in a decision-making, design and planning support platform (Billen et al., 2015; Lancelle & Fellner, 2010; Petrova-Antonova & Ilieva, 2019; Stavric et al., 2012). On the one hand, some authors refer to CIM as an extension of BIM (Chen et al., 2018; Correa, 2015; Dall'O' et al., 2020; Müller et al., 2016), adding together, in one environment, several models of buildings, infrastructure and public spaces modelled according to BIM processes. Gil (2020) uses "BIM+" to name this particular type of CIM. On the other hand, other researchers consider CIM to be an extension of GIS approaches (Gil et al., 2011; Schiefelbein et al., 2015). This approach implements city models with GIS data and couples them with tools for various analyses and simulations. Overall, BIM and GIS integration and their use in a common framework is widely discussed and CIM is more often described at their confluence. Concretely, this approach puts CIM into perspective as a mean of integrating IFC (open format for BIM) and CityGML (open format for 3D GIS cities) formats (Dall'O' et al., 2020; Müller et al., 2016; Xu et al., 2014). In the same dynamic, another approach describes CIM as a CAD parametric data with GIS data integration (Beirão et al., 2012; Gil et al., 2011; Stojanovski, 2019).
Eventually, just as for the DT concept, there is no consensus on CIM concrete technical design. Thus, CIM, as DT, is used to label heterogeneous digital models and tools aimed at better and more efficient urban planning. Again, we propose to focus on characteristics which are widely accepted among studied authors and to use them as key defining criteria for CIM.

3.2.2 Key criteria to characterise a CIM according to scientific literature:

- A CIM represents the aerial and underground space at the urban scale, which involves the three-dimensional modelling of public infrastructure and buildings as well as various related amenities (Bi et al., 2021);
- A range of semantic information is linked to the geometric model to allow for data filtering as well as simulations and analyses (Billen et al., 2015; Dall'O' et al., 2020; Petrova-Antonova & Ilieva, 2019);
- It promotes collaborative work and interoperability and facilitates exchanges between all actors in an urban project (Berman, 2018; Gil, 2020; Sielker & Sichel, 2019).

3.3 Exploratory interviews with practitioners about DT

From the criteria we extracted from scientific works in order to try to be able to characterise DT and CIM respectively, we do notice different focus for CIM and DT. DT is now often associated with real life sensor feedback and actions taken in the physical world derived from analysis and simulations performed in the DT. On the other hand, CIM is more often associated with the notion of multi thematic and collaborative (multi actor) approaches of cities. Nevertheless, it still seemed unclear to us how to distinguish between CIM and DT, since technologies and tools cited as well as enunciated goals are very similar. Thus, we explored practitioners' definitions of DT and its potential differences with CIM through an exploratory survey.

As previously stated, 13 practitioners working in 12 different organisations have been interviewed for our exploratory study. As far as the definition of DT is concerned, 7 of the participants defined it as a digital model being a replication of a real-world asset integrating real time data coming from sensors, cameras, i.e., IoT, although confirming the IoT support needed might be hard to achieve in an urban setting. On the other hand, 4 interviewees stated that they would not consider real time data as mandatory for a DT to exist. Lastly, one respondent was more sceptical and stated that if a comprehensive DT really was in place, it would be outdated as soon as it is finished. Overall, if we had added all key features cited by practitioners, we would get a similar DT description as in the scientific literature. Nevertheless, several respondents claimed to have a less literal application of the concept to the built environment than many researchers, without rejecting the label altogether. Rather, they adapted the label to current professional practices, taking into account digital simulations and analysis allowed by a DT without numerous and “real time” feedbacks from sensors.

From a technical standpoint, practitioners' descriptions of DT mainly involved already existing data and tools related to BIM, CIM, GIS and CDE (Common Data Environments). Interviewed public actors emphasised the need for open tools to share progress and facilitate national deployment. This confirms the trend observed in our scientific literature review regarding the use of some similar tools and data for CIM and DT. Moreover, half of the respondents underlined the need for interoperability, collaboration and the fact that DT were built (or to be built) thanks to tools they were already using (rather than envisioning a whole new process to build a city DT). Even if they saw the DT as related to concrete technical realities, one fourth of the respondents described it as a “buzzword”, more useful for marketing purposes than for technical innovation.

3.4 Case studies and labelling practises: can your DT be my CIM, and vice versa?

Variabilities in DT and CIM definitions have been identified in the scientific literature on both concepts as well as in DT-focused practitioner interviews. Proximity between the two notions was also confirmed in scientific literature and by practitioners. Therefore, we propose to put those definitions in perspective by comparing a few existing models. We selected two instances of district models named City Information Models (in Bordeaux and Châtenay-Malabry, in France), and two models labelled DT by their producers (Kalasatama in Finland and Rennes in France) and compared them with the key features extracted from our literature review.

3.4.1 La Vallée and Le Belvédère, two CIM of French districts:

From a technical standpoint, the CIM of La Vallée (Arcadis, 2021; Eiffage Aménagement, 2018) is strictly a BIM+ model, composed of BIM entities describing both buildings and public spaces (including underground utilities). This BIM-only process is due to the lack of available GIS data. On the other hand, Le Belvédère CIM (Duloup & Fredon, 2019) is derived from both BIM and GIS data and represents the same elements as La Vallée. Both models correspond to the criteria describing CIM listed from the scientific review: they encompass a digital 3D model of the territory with semantic data and are used for simulation and analysis. At least one version of both CIM is in an Open standard (IFC) and both CIM have been produced in order to be used by several actors in collaborative settings. According to the criteria from scientific literature, neither should be labelled as DT, since they do not rely on feedback from the physical world through sensor data.

3.4.2 Kalasatama and Rennes, two multipurpose DT used for urban planning:

From a technical standpoint, both DT have been produced from geographical data acquisition. In the case of Rennes (IGN, 2021; Le Breton et al., 2021), a metropolitan 3D city model based on GIS tools data was already available. For the Kalasatama project (City of Helsinki, 2019), specific acquisitions were made. Building and public spaces are modelled, except underground utilities.
Both models correspond to some but not all of the criteria extracted from our DT literature review: they are both used for simulation, analysis and decision making. Nevertheless, they do not have a bidirectional link between the physical territory and the digital model through sensors and “real-time” feedback. According to our scientific literature review, they both should not be considered as DT. On the other hand, again according to the criteria from scientific literature, both could be labelled as CIM.

4. DISCUSSION

In the urban planning field, DT definitions are broader and sometimes less IoT-oriented in professional practices as they are in scientific literature. On the contrary, CIM definitions in scientific literature have a broader range. Consequently, CIM could easily be used to label all case studies, although some are labelled DT by their producers and users. In this perspective, DT could theoretically be considered as a specific type of CIM. Nevertheless, some practitioners and researchers envision DT as a global framework that would encompass all sorts of digital models, including CIM as base models for DT. As those notions are rarely studied together, it is not easy to differentiate between them with certainty. Taking into account the variety of definitions and practices, we propose to analyse those discrepancies so as to shed light on challenges to be tackled in order to adapt DT approaches to urban settings.

4.1 Loosening the “bidirectional link between model and reality” constraint

The ideally bidirectional link between the physical and digital model is the one key feature that shows the most variations in its application to cities and territories. As said, derived from works in the industrial field, DT are supposed to offer a digital model of a physical territory with bidirectional links between these two, notably through sensors and real time data analysis leading to actions on the physical territory. However, many practitioners using and promoting DT approaches foster their own definition of DT which differs from the scientific literature, although they are also working together with researchers. They state that a DT is a virtual model of a physical entity and underline the collaborative aspect of the DT, in order to support public policies (Centre for Digital Built Britain, 2020; City of Helsinki, 2019; IGN, 2021).

The scale factor, the complexity and variety of processes involved in cities’ evolution as well as the wide range of political and societal objectives for city DT framework play a key role in the difficulty to precisely define sensors and “real-time” feedbacks deemed necessary in a DT approach of a territory. For instance, in Great Britain, there is a national DT approach that has been developed for several years by scientists and practitioners. At the local scale, some existing DT of territories do gather data from sensors to use them for urban planning and management (see Vilo (Dawkins et al., 2018) or Newcastle

(White, 2018)). Practitioners label them as DT, although they do not allow for the adaptation of the urban environment through automatic processes, hence still lacking the ideal bidirectional link between the physical twin and DT. However, the national definition established for the DT is less "sensors/IoT-driven" and, therefore, broader: "*In the context of Digital Built Britain a digital twin is "a realistic digital representation of assets, processes or systems in the built or natural environment*" (Centre for Digital Built Britain, 2020). This definition is similar to other practitioners' definition (City of Helsinki, 2019; IGN, 2021) and allows to encompass various models and experiments at various scales, some relying on sensor and/or real-time data and others being used for other types of analysis, simulations or visualisations. Therefore, it seems to us that what is at stake for urban designers is the integration of all useful digital models into a common digital city framework, regardless of the chosen label (CIM, DT, etc.) or the use of sensors.

4.2 Specificity of urban settings and derived challenges for DT approaches:

Several challenges appear with the application of the industrial DT approach to cities and territories. Thus, it seems unrealistic, at this point, or even ever for some authors (Batty, 2018), to develop an exhaustive DT of a large territory being able to monitor and simulate its every aspect. In this section, we try to list some challenges to be tackled in future research so as to be able to produce more accurate DT of cities and territories.

4.2.1 Data Availability about the built environment:

In their work, Jones et al. (2020) point out that issues related to data availability, ownership, security and privacy pose major challenges. Indeed, Notcha et al. (2021) state, many data are not easily available and processes involving all actors (public and private organisations and citizens) need to be developed in order to be able to gather those data and manage them in a secure and sustainable way.

4.2.2 Knowledge of human (and other living beings) behaviour and social interactions:

Tomko and Winter (2019) underline that this knowledge is yet insufficient, so that accurate modelling cannot be done and that those aspects are not sufficiently taken into account in DT approaches. Further interdisciplinary research must be conducted in order to better understand human aspects and their consequences on urban spaces.

4.2.3 Complexity and variability of a city lifecycle:

Tao et al. (2019) shed light on the fact that a city life cycle includes many phases with various optimisation goals that still require work in order to be straightforwardly defined. In addition, given the numerous gains from the use of a unified framework and the importance of interoperability and collaboration expressed by practitioners, it seems mandatory not to ignore certain phases when designing a DT. Indeed, at least some of the data produced in the design phase are likely to be used in later phases. If a physical counterpart to the DT is required for a "true" DT, then no DT can theoretically be used during design phases before construction. This is why it does not seem relevant to ignore the design phase when trying to determine the best suited digital model for urban planning.

4.2.4 Definition of relevant temporal intervals for city monitoring:

Wright and Davidson (2020) insist on the various evolutionary paces of urban processes. Depending on the process, which is observed and analysed, data from analog or digital sensors might be needed, but the "real time" notion might cover a wide range of relevant time intervals for data gathering. Diverse data origins (surveys, citizen feedback, etc.), involving heterogeneous pre-processing methods, imply a large research effort to propose a more precise temporal framework for useful and efficient city models.

4.3 Where do we go from here? Labels and knowledge accumulation:

Eventually, the correct use of the DT label is less relevant to research efficiency than to the accumulation of knowledge from as many experiments and scientific works as possible (whether labelled 3D city models, smart cities, CIM, DT, etc). Indeed, new labels and notions will continue to emerge in the future to describe digital models at the city scale used in urban planning.

This is why it seems to us that silo-based approaches of digital models at the city scale which would lead to separately investigating models based solely on labels are to be avoided. Although DT and CIM are relatively close, they are still mainly studied separately. Jones et al. (2020) highlight the importance of gathering common knowledge from multiple fields. Thus, it seems more relevant to base future research on more stable characteristics, categories and types of models, so as to allow for knowledge accumulation. Use-based or task-oriented typology would probably be fruitful in this effort.

Indeed, dividing research efforts according to labels can lead to ignorance of previous experiments, preventing us from learning from their success and/or failure. In the case of the transposition of DT approaches to the urban setting, earlier works on smart cities and various attempts to mobilise digital tools for urban planning should be considered. Transversality between disciplines is also required. As Townsend (2014) demonstrates, several smart city projects were unsuccessful due to several shortcomings, mostly induced by a technology-driven approach that was not adapted to urban complexity and/or ignoring some of the involved actors, whether citizens or practitioners (Flood, 2010; Picon, 2013). Although technology involved were not exactly the same, lessons learned in terms of governance in earlier "smart city" experiments can still be useful. A recent French report (DGE, 2021) draws conclusions from interviews and collective discussions with 150 practitioners from public authorities, professional and citizen associations, elected representatives and private companies. It underlines the importance of governance and inclusion of all concerned parties in smart city, CIM or DT projects. It also states that such projects are never limited to technical innovation and that they must be included in a democratic, political, economical and local dynamics. These concerns can account for practitioners' necessity to focus on collaborative design and shared governance, so as to produce efficient models of cities, but also to achieve a more "human-centred" city planning and management. As such, those aspects should be taken into account in future research about application of DT to urban planning.

5. CONCLUSION

Our investigation confirms that, given the variability of CIM and DT definitions, these concepts remain fuzzy. It also shows that many aspects of both CIM and DT are similar to each other as they both are used to describe digital models of physical territories, coupled with data sets which allow to perform simulation and analysis for decision-making purposes. Overall, the main difference between the two concepts is the emphasis on the ideally bidirectional link between the physical twin and its

DT through "real-time" data. Nevertheless, it remains difficult to differentiate between various city models in real life, in order to decide whether they should be considered and studied as CIM or DT. Indeed, most city models of this kind are used for several purposes, some potentially including sensor data, others relying on other types of analysis. Moreover, as an urban setting is less controlled than a man-built factory, automatic adaptation of the urban environment following data analysis is not as easy in the case of intervention on a public space as it is to adapt temperature or light inside a building.

For future research work, we think silo-based approaches based solely on labels must be avoided. Scientific works would benefit from focusing both on technological opportunities and governance issues in interdisciplinary frameworks. The need expressed by practitioners for a DT city framework encompassing all phases of a city lifecycle could also guide some research efforts. Further studies on human and social interactions are also greatly needed in order to be able to model additional aspects of cities. Finally, the complexity of urban settings as well as the need to take into account local actors and specificities are reasons to foster research on agile and adaptable processes.

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