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ORIGINAL PAPER

Towards a Citizen- and Citizenry-Centric Digitalization of the Urban Environment: Urban Digital Twinning as Commoning

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Abstract
In this paper, we make a case for (1) a sociotechnical understanding and (2) a commoning approach to the governance of digital twin technologies applied to the urban environment. The European Union has reinstated many times over the willingness to pursue a citizen-centric approach to digital transformation. However, recent studies show the limits of a human right-based *only* approach in that this overlooks consequences of data-driven technologies at societal level. The need to synthesize an individual-based and collective-based approach within an ecosystemic vision is key, especially when it comes to cities, which are complex systems affected by problems whose solutions require forms of self-organization. Tackling the limitations of current tech-centered and practice-first city digital twin (CDT) projects in Europe, in this article, we conceptualize the idea of urban digital twinning (UDT) as a process that is contextual, iterative, and participatory. Unpacking the normative understanding of data-as-resource, we claim that a commoning approach to data allows enacting a *fair* ecosystemic vision of the digitalization of the urban environment which is ultimately *both* citizen- and citizenry-centric.

Keywords Data commons · City digital twin · Ecosystem · Citizen-centric · Fairness · EU

1 Introduction

The European Union (European Parliament and Council, 2016, 2020a, b, 2022; European Commission, 2019) has taken various steps to pursue a citizen-centric approach to digital innovation, striving to keep fundamental human rights—enshrined in the European Charter of Fundamental Rights (European Parliament and Council,

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2012b)—and collective principles and values—such as social inclusion, democratic participation, and environmental sustainability (European Commission, 2022)—as its polar stars. However, de facto what is being enacted is a human right-based *only* approach that, while protecting individual freedoms, autonomy, and privacy, overlooks collective-level effects of digital innovation (Viljoen, 2021) and its potential societal harm, notably on the rule of law's functioning (Smuha, 2021). As we will argue, to strike a balance between individual and collective dimensions is key for developing a *systemically fair* approach to digital transformation.

This discussion finds pertinent contextualization in the city for two conjoint reasons: the city is a locus of technological innovation *par excellence* (Jacobs, 1969) and it is also the target of increasing tech-based digitalization, which entails an ongoing "translation" from the physical to the digital and vice versa. An example of such a translation occurs through digital twin technologies (Shahat et al., 2021), whose trading mark is that an existing physical object or process and its digital counterpart are integrated in *both* directions, thus mutually affecting each other in real time (Fuller et al., 2020). As such, a city digital twin (CDT) can provide the technology-driven and policy-oriented basis for tackling the city's complex problems (Bettencourt, 2015), from mobility to energy production and consumption to logistics. Pilot CDTs are being developed across Europe, such as in Helsinki (City of Helsinki, 2022), Rotterdam (Municipality of Rotterdam, 2022), and Dublin (Dublin City Council, 2022).

When digital twin technologies are implemented in the context of the city, intertwined issues of modelling design and governance emerge (Kitchin et al., 2021). On the one hand, far from being processable machines (Mattern, 2021), cities are complex systems showing emergent hard-to-predict behaviors (Grieves & Vickers, 2017; Portugali, 2011). This entails that the problems affecting cities elude tech-only solutions and require, rather, an orchestrated self-organization bringing together diverse actors and disciplines (Bettencourt, 2015). On the other hand, far from being a mirror of physical reality (Batty, 2018), a digital twin provides a modelling of such reality: this means that a CDT is not just a digital replica of the physical city, but a representation of it, which depends on both technical affordances—what a certain technology *can* represent and *how*—and non-technical factors, such as funding allocation, political support, legal frameworks, and local needs (i.e., the "*why*"). Currently, however, CDT projects tend to follow a tech-centered practice-first approach (Nochta et al., 2021) on the wave of smart city agendas. This means that CDTs (1) focus on technical concerns (e.g., data interoperability and data semantics), without exploring the societal context surrounding these technologies, and (2) lack robust governance for the implementation and use of these technologies, resulting in a fragmented scenario. To counter this, it is crucial to advance and design a sociotechnical approach and governance for CDTs, as preconditions for the fair development, implementation, and use of CDTs.

To tackle the tech-centered nature of current CDTs, we follow up on calls from various scholars (Boje et al., 2020; Nochta et al., 2021; Papyshev & Yarime, 2021) and propose a conceptual transition from CDT to urban digital twinning (UDT). This shift allows foregrounding the process of digitalization (digital twinning) rather than the technical model (digital twin), as well as a spatial dimension with no fixed

boundaries (urban environment) in contrast to the city as a reified entity. UDT, then, compels to think of the digitalization of the urban environment as a sociotechnical process of translation of the physical into the digital (and vice versa) which links digital twin technologies *with* urban development: the design of a model of the city is always entangled with its use.

To tackle CDT's lack of governance, we propose to look at the commons. This regime for managing resources can be regarded as enacting principles and values that maintain the collective at their core (Calzati, 2022). Self-organization is key to the commons; yet, to really accommodate a fair sociotechnical perspective, it is necessary to move away from an institutional take (Ostrom, 1990)—which remains anchored to an economic-legal perspective—and favor an understanding of the commons as a practice, or "commoning" (de Angelis, 2017). To do so, we revisit the normative understanding of data—as it also appears in institutional literature on "knowledge commons" (Hess & Ostrom, 2007)—allowing for an effective application of commoning to the digital realm. From here, we will characterize UDT as a contextual, iterative, and participatory process.

The article is organized as follows: in Section 2, we outline Europe's vision on digital transformation and unpack individual and collective rights and values, advancing the need for a fair ecosystemic vision able to accommodate both; Section 3 focuses on digitalization, digital twin technologies, and the city, showing the extent to which the digitalization of the urban environment is a matter as much of tech affordances as of (self-organized) urban development; in Section 4, we look at literature on the commons arguing in favor of a commoning approach to digital twins in/of the city, based on a sociotechnical understanding of data; in Section 5, we look at city digital twins through the lenses of "commoning" as a sociotechnical process, thus speaking of urban digital twinning; Section 6 points to research ahead.

2 The EU's Human Right-Based Approach: Prospects and Limits

In December 2012, the European Parliament, conjointly with the European Parliament and Council (2012a), released the Charter of Fundamental Rights (CFR). This document comprehensively details the human, political, social, and economic rights of European citizens, which were previously scattered across different documents. The CFR contains six chapters—"dignity," "freedoms," "equality," "solidarity," "citizens' rights," and "justice"—for a total of 50 rights. While the "solidarity" chapter includes rights such as "collective bargaining and action," "social assistance," and "environmental protection," which do maintain a collective-by-default outlook, most of the rights enlisted are individual rights, meaning that they relate to the single individual.

Today, the CFR constitutes the polar star of the human right-based approach (HRBA) pioneered by the EU when it comes to governing digital transformation. The rationale behind such an approach is to tackle adversary effects of data-driven technologies by protecting citizens from the potential infringement of their fundamental rights (Brown, 2019; Davis, 2020). For instance, human rights can be either used as a normative framework (Yeung et al., 2020) or inscribed by

design into the development of data-driven technologies (Aizenberg & Van Den Hoven, 2020). While such an approach is certainly pivotal for preserving individuals' integrity before digital transformation, recent studies have shown the limits of a right-based *only* approach to digital transformation. This is so because the underpinning individualistic vision of the HRBA risks overlooking population-level effects of digital transformation (Viljoen, 2021) and potential societal harm (Smuha, 2021) which cannot be reduced to the sum of individuals and their rights. Hence, to the extent to which HRBA does constitute the *fundamental* baseline to citizens' autonomy, it might not be *sufficient* to protect Europeans as a whole. For instance, Viljoen (2021) notes that the individualistic vision behind the HRBA does not account for the relational nature of data and the consequent trade-off effects that data re-use involving two subjects might have on unaware third parties. Similarly, to the extent to which data-driven technologies do impact on society as a whole, with systemic consequences that fall below the radar of HRBA, there is increasing need for frameworks able to capture and regulate the effects of digital transformation for the entire groups or communities (Lane et al., 2014; Taylor et al., 2017; Smuha, 2021). Smuha (2021) suggests taking inspiration from environmental law for tackling potential collective-level harms—such as the erosion of the legitimacy and functioning of the rule of law—caused by digital transformation, which can be neither accounted for nor mitigated by current individualistic approaches. Lane and colleagues (2014), instead, map the epistemological, ethical-legal, and practical boundaries to do public good with and through big data, while preserving privacy. Similarly, Taylor and colleagues (2017) discuss the idea of "group privacy" and the need to redesign current legal frameworks, starting from the acknowledgement that data-driven technologies address and impinge on groups-as-collectives to be tokenized besides and beyond individuals.

A partial response to these positions comes from the Declaration on Digital Rights and Principles (DDRP) released by the European Commission (2022). The document defends "a European way for the digital transition, putting people at the center." It is certainly not the first time that the EU claims such a goal. Indeed, for years now, the EU has taken steps in this direction as part of a digital strategy that aims to promote digital transformation and keep the EU abreast of geopolitical competitors, while preserving its core rights and values towards social inclusion, economic competitiveness, and environmental sustainability. Notably, what the DDRP does is to pin down six principles: (1) preserve people's rights; (2) support solidarity and inclusion; (3) ensure freedom of choice; (4) foster democratic participation; (5) increase safety, security, and empowerment of individuals; and (6) promote sustainability. Noteworthy is that these principles equally split between a half (1, 3, 5) focusing on the individual and the other half (2, 4, 6) pertaining to society as a whole. Hence, the DDRP does strive to strike a balance between subject-centric and collective-centric dimensions. This however signals the need—unmet so far—to

enact forms of "collectual" governance (individual + collective) of digital transformation (Calzati, 2022) that couple citizens *with* citizenry.[1]

2.1 A Fair Data Ecosystem

Moving beyond current contributions framed within democratic theory (e.g., de Gregorio, 2020), to enact a governance that is both citizen- and citizenry-centric means to acknowledge the copresence of an individual and collective dimension and to devise mechanism to negotiate and/or disentangle among the two on a case-by-case basis. Such governance needs to move away from either targeting certain actors over others—e.g., citizens, public actors, and private actors—or prioritizing one value over the others—oftentimes economic competitiveness over social equality and environmental sustainability—to go towards an ecosystemic approach.

An ecosystem is characterized by homeostasis, that is, the balanced interaction between biotic and non-biotic elements within an environment. This implies that the ecosystem's behavior cannot be studied by isolating either elements or interactions; rather, it must be studied in its entirety. While largely related to the natural world, the notion of ecosystem has also been applied to other settings, such as the digital landscape (Jarke et al., 2019; van Loenen et al., 2021). To endorse an ecosystemic vision towards the governing of digital transformation means to seek a *fair* governance in which all actors' interests are accounted for and negotiated. In other words, fairness underscores here the *systemic* trading off among different interests in view of an overall equilibrium, moving beyond reductionist (Wong, 2020) and essentialist (Lee et al., 2021) understandings of fairness, which fall short of producing a comprehensive tackling of digital transformation.

A fair data ecosystem, then, is based upon the recognition, synthesis, and, if needed, adjudication among different interests in play, on a flexible and rolling basis. Such ecosystem shall be regarded not much as an arena where different players are connected, but as a process that constantly reshapes its own power relations. As Pagallo (2022) notes, at stake is the "role that mechanisms of coordination and methods of cooperation play in EU law." A governance framework that aims to regulate a digital ecosystem fairly identifies roles and rules to represent the data interests of all actors, as well as mechanisms to adjudicate situations where conflicts among actors and/or values might arise.

Such a form of governance becomes particularly relevant in the context of the city not only because this is where the individual and collective dimensions of citizen and citizenry are best expressed but also because the city is at once a unique locus of tech innovation (Jacobs, 1969) and a major target of this same innovation. At the same time, however, the city as a physical dimension is a complex system (Portugali, 2011; Bettencourt, 2015; Mattern, 2021) that eludes a straightforward technologization. This poses great opportunities *and* challenges

[1] In this context, citizens and citizenry formally identify the two sides of being subjects in/of the city: while "citizen" refers to physical people—although always already socialized—"citizenry" inevitably entangles both physical and juridical subjects.

to the governing of the digital transformation in/of the cities, especially through emerging digital twin technologies.

3 Digital Twins and Cities: a Techno-urban Entanglement

3.1 Unpacking Digitalization

Digitalization and digital transformation refer to tech-based procedures that aim to "translate" the physical into the digital. As scholars (Bolter & Grusin, 1998; Eco, 2003) in linguistics and media studies know well, there is no such process of translation that is "neutral," that is, that can fully and faithfully render the original message into a new format: the medium *is* the message (McLuhan, 1996).

When a text is "translated" into a digital format, the term used is "digitization." This is a procedure that has an identifiable beginning and end. When it comes to "digitalization," the issue at stake is richer because this process refers to the translation of ongoing phenomena, such as complex scenarios. Yet, the fundamental idea remains: through digitalization, we witness the translation of physical reality into a set of 0 s and 1 s, which inevitably leads to foreground some aspects over others. To put it simply, modelling does not equal to reality itself, but to a *certain* formalization of it. The effects of digitalization, then, open a Pandora box: which aspects of physical reality fall beyond digitalization? Which others are radically transformed? And how? When historian Kranzberg (1986) contends that "although technology might be a prime element in many public issues, nontechnical factors take precedence in technology-policy decisions," he is pointing exactly in this direction. Digitalization is not a computing affair, but a complex and ongoing process of translation that needs to be inscribed into a broader (societal) framework to be properly understood and fairly implemented.

3.2 City Digital Twins: Challenges and Prospects

Differently from traditional 2D-3D modelling, the trading mark of a digital twin is that an existing physical object or process and its digital counterpart are integrated in *both* directions, thus mutually affecting each other in real time (Fuller et al., 2020). This means that, as a model, a digital twin gets repeatedly updated through real-time data coming from and about the object or process it represents; in turn, the digital version can, at any time, affect or steer the behavior of its physical counterpart. Originally industry-born technologies to simulate, for instance, the performances of turbines or engineering systems (Grieves, 2002), digital twins are now being increasingly applied to complex settings such as cities (Shahat et al., 2021). Pilot projects of city digital twin (CDT) are being developed across Europe, such as in Helsinki (City of Helsinki, 2022), Rotterdam (Municipality of Rotterdam, 2022), Dublin (Dublin City Council, 2022). However, the CDT's scenario in Europe remains fragmented and at an early stage of development.

The concept of CDT did not emerge in a vacuum. In fact, it couples the concept of digital twin (Grieves, 2002) with that of smart city, which characterizes ICT-backed and data-powered urban spaces (Ziosi et al., 2022). Hence, the concept of CDT moves a step further in the smartening of cities. As such, while bringing increased (cost–benefit) efficiency and customization of the services provided, CDT is subjected to the same criticism affecting smart city projects, notably in terms of commodification of the individual, risk of reinforced and new forms of discrimination, and possible emergence of surveillance regimes (Eubanks, 2018; Milan & van der Velden, 2016). In this respect, Madison (2023) notes that we shall "abandon the interest in creation and hold to evolution," when it comes to study new technologies in urban contexts. The issue, indeed, is as much technical as political.

A CDT can help synthesize data from various sources (e.g., GIS, IoT, archival data, and social media) to create an integrated real-time knowledge of the city, as well as scenario simulations, both in the short term and long term. As such, a CDT bears high expectations from tech experts, city officials, and policymakers (Shahat, et al., 2021) as a tech-driven solution to tackle the complex problems affecting cities (Bettencourt, 2015). Tech-driven, however, shall not mean tech-only. Critical data studies have extensively unveiled the sociotechnical imbrication of data-driven technologies. Kitchin and Lauriault (2014) seminally talk of "data assemblages" as "complex socio-technical system[s], composed of many apparatuses and elements that are thoroughly entwined." Most importantly, such entwinement configures not only an interconnection among its parts but also a co-dependency: this means that the decisions taken *by* and *through* data-driven technologies are the result of entangled bio-techno-social performances which cannot be neatly distinguished. When such understanding is transposed on to CDTs, it follows that technology alone is insufficient or even deleterious for producing an ecosystemic modelling in/of the urban environment.

Far from constituting a mirror of the city, a CDT delivers a model of it whose heuristics depends on tech affordances—*what* the digital twin as a tech-based model *can* grasp and *how*—and non-technical aspects that have to do with the design (by whom) and use (why) of such a real-time model. It is therefore necessary to conceive of CDTs as part of a sociotechnical dimension by which they are informed and which, in turn, they contribute to inform. If a CDT is meant to serve citizens (as well as citizenry) in solving their problems, then its conception, development, implementation, and use cannot do without a sociotechnical approach (Nochta et al., 2021). As Nochta et al. (2021) point out, "the usefulness of CDTs in decision-making depends on the success of reframing high-level policy goals into practical policy problems to which the model can suggest solution options. This reframing exercise must be informed by in-depth local knowledge and preferences and thus requires a participatory approach." Currently, however, CDT projects tend to adopt a tech-centered practice-first approach (Nochta et al., 2021). This means that they (1) focus on how to overcome technical limitations (e.g., data interoperability, data semantics, and data fusion), without exploring the societal dimension of digital twin technologies, and (2) largely lack a governance framework to orient and systematize the use of digital twin technologies in/for the city.

A tech-centered approach applied to most CDT projects promotes market-ready tech solutions (Kummitha, 2020), which overlook a cognizant understanding of the socio-economic tensions within the city (Sanfilippo & Frischmann, 2023). This translates into an enduring gap between the technical and the social (Kalpokas, 2022) so that, while a CDT might prove effective for reaching informed decisions on how to tackle complex urban problems, in fact, "the challenges of utilizing CDTs in the process of policymaking from a less engineering-oriented perspective are rarely discussed" (Papyshev & Yarime, 2021).

A practice-first approach often lacks a long-term vision concerning the implementation and effects of digital transformation, running the risk, especially in the context of CDTs which require coordinated long-lasting efforts, to "overlook the necessity and costs of individual (upskilling) and organizational (collaboration) learning" (Nochta et al., 2021, p. 268). In fact, practice-first approaches miss to conceive and, in turn, inform the city as a complex ecosystem, whereby urban policymakers, tech innovators, the public sector, private actors, academia, and citizens define orchestrated strategies of action (Cazacu et al., 2020).

For instance, Dublin, Helsinki, and Rotterdam are three robust CDT initiatives in Europe, but each of them shows some of the limitations discussed. Dublin's CDT revolves around a multistakeholder regime supported by a city dashboard (Dawkins et al., 2021) that supplies different layers (e.g., underground and overground infrastructures, buildings, and air quality) of real-time data about the city. The initiative, while being public led by Dublin's city council, is largely implemented by private actors through diverse pilot projects, and it still has limited policy-oriented function. This leaves open the questions of interoperability across projects, as well as how to improve the CDT as a decision-leading tool. Moreover, while citizens have been encouraged to interact with the dashboard through virtual reality scenarios (White et al., 2021), the levels and results of such involvement remain scarce.

Helsinki is currently one of the longest CDT initiatives in Europe, having originated in the early 2000s (Hämäläinen, 2020). Helsinki's CDT is a top-down municipality-centered initiative (with private actors as tech suppliers) aimed at providing a real-time 3D modelling of the entire city for decision-making in matters of energy consumption and distribution and mobility. Currently, the digital twin's different themes lack mutual integration, while civic involvement is still tokenized as the project remains institutionally locked-in.

Rotterdam's CDT follows an integrated approach bringing together the physical, digital, and societal dimensions (Municipality of Rotterdam, 2022). The municipality team in charge of CDT hosts one working group dedicated to enabling data interoperability, and one aimed at exploring non-technical issues. Currently, the CDT platform, which is expected to connect different projects and catalyze public–private synergies, has entered the implementation phase, leaving on hold a cognizant assessment of its use, as well as the envisioned formation of a cognizant digital urban community able to participate to the CDT.

While an exhaustive analysis of these examples and their comparison is beyond the scope of this article, they manifest at varying degrees the struggle to overcome tech-centered approaches and advance a robust coupling between top-down and bottom-up stances. As we will see in the next section, such coupling, given the

complexity of cities, must prescind from state- or market-only solutions to promote orchestrated strategies and forms of self-organization.

3.3 Cities as Complex (Eco)systems

Cities are agglomerations that cannot be approached as a machine (Mattern, 2021), that is, as something to be mapped, broken into smaller parts, and then processed and recombined. Rather, they are "hybrid complex systems" (Portugali, 2011) composed of biotic and artificial elements, whose mingling creates a whole new sociotechnical ecosystem. As such, cities cannot be studied by isolating either elements or their interactions but require to be studied in their entirety, insofar as they manifest emergent behaviors that are very difficult to predict (Grieves & Vickers, 2017). As Sanfilippo and Frischmann (2023) write "intelligent governance of smart infrastructural systems in cities requires more attention be given to the complexities." On this point, Bettencourt (2015) contends that "the challenge for a modern science of cities is to define urban issues in their own right and to seek integrated solutions that play to the natural dynamics of cites." The idea of resorting to *integrated* solutions characterizes de facto an ecosystemic approach whereby urban interventions are explored and implemented according to a comprehensive view on/of the city, as well as of its citizens and the whole citizenry.

Further on, Bettencourt (2015) specifies that self-organizing practices—that is, practices able to give agency to the needs of all actors involved—represent the best response to tackle city's complexity, "placi[ing] emphasis on creativity and on effective social organizations, capable of coordinating their knowledge and action." It is social self-organization that is key to enable an integrated approach to the city, and this applies to both city's physical "messiness" (Jacobs, 1969) and to the design, implementation, and use of its digital model. Hence, a governance of CDTs shall be able to manage the sociotechnical entwinement between the physical and the digital and to do so by putting the complexity of the city—its people and data—at the center, moving towards "more extensive public consultation, collaboration and coproduction" (Cardullo & Kitchin, 2019). This is what can really enact an ecosystemic—both citizen- and citizenry-centric—digital transformation in/of the city.

From here, in the last section of the article, we will define the main features of a process of/for CDT: urban digital twinning (UDT). To this end, however, in the next section, we first look at the literature on the commons as a sustainable regime for managing resources, highlighting strengths and weaknesses when it is applied to the digital realm.

4 From (Natural) Commons to Data Commoning

A similar conclusion to Bettencourt's idea of self-organization was reached by Ostrom's (1990) extensive study concerning the community-led managing of common-pool resources (CPRs). Ostrom showed, contrary to supposed tragedies (Hardin, 1968; 2009), that the self-management of CPRs by communities can be more

effective than market-driven or state-led approaches, provided that principles and roles are designed and abided to. A commons approach to the managing of resources can be said to enact an ecosystemic approach by default, negotiating between individual and collective stances (Calzati, 2022). Scholars (Zygmuntowski et al., 2021) have hinted at the promise of designing an EU comprehensive commons-based data governance. Bloom and colleagues (2021) went further suggesting how Ostrom's design principles might be transposed in the context of data initiatives. However, these authors remain anchored to a normative understanding of data as a resource which does not do justice to their unique nature and, to an extent, prevents an effective tackling of data through the lens of the commons (Sanfilippo & Frischmann, 2023). To overcome this hurdle, some preliminary steps away from the institutional approach to the commons are needed.

4.1 Common-Pool Resources

Originally, the work by Ostrom (1990) referred to common-pool resources (CPRs) characterized by non-excludability (i.e., difficulty or impossibility of forbidding access and use of CPRs to any potential beneficiary) and rivalry (i.e., the use of CPRs depletes them and reduces further use by others).

Moving towards what has been labelled the "second wave" (Hess, 2008), by now, the commons has been applied to non-natural resources, such as data (Dulong de Rosnay & Stalder, 2020) and cities (Iaione, 2016). When it comes to data, the spillover has been favored by the consolidation of the Internet—an open infrastructure—which supplied the basis for the proliferation of new forms of co-innovation, via freely accessible knowledge, design, and software (Kostakis et al., 2015). Today, data commons (DC) characterizes a regime in which actors join forces in the collection, pooling, and use of data (and digital infrastructures) subservient to the delivery of services for the whole community. DC initiatives (Bangratz & Förster, 2021; de Lange & de Waal, 2019; Morozov & Bria, 2018) aim to counteract and/or repurpose the centralized ownership and use of data—either by tech companies or states—by giving these back to citizens, with the goal to foster sustainable collective data practices. For instance, Wolff and colleagues (2019) explored ways of creating more awareness in citizenry about what can be done with and through data. Their research shows that digital platforms can help urban communities gather around shared concerns and proactively advance solutions. However, data literacy is still limited in the population, requiring initiatives to tackle such scarcity through the institution of facilitating roles for connecting governing bodies with communities. Mulder and Kun (2019), instead, showed that data commons-inspired initiatives are largely effective to boost collaboration at local level and on a temporary basis, but they fail to put forth a systemic change. Overall, these experiences, however effective they are, fall short to consolidate by achieving replicability (de Lange & de Waal, 2019) and scalability (Calzada & Almirall, 2020).

In this context, the new concept of urban data commons (UDC) may be regarded as a third wave of the commons, synthetizing features of DC with a specific focus on urban settings. UDC initiatives are still scarce in the EU. One noteworthy

example comes from the city of Barcelona (Ajuntament de Barcelona, 2016). In 2016, the Catalan municipality launched a "new social pact on data": various initiatives informed the new digital agenda, among which platforms based on data commons regimes, allowing citizens regain control over their data. In the words of Morozov and Bria (2018), the goal is to make good and fair use of the power of data through "an ethical and responsible innovation strategy, preserving citizens' fundamental rights and information self-determination. This will help ensure that public resources and assets are publicly owned and managed for the collective good." Currently, Barcelona's case still presents barriers, as some of its proponents have witnessed (Monge et al., 2022), especially in terms of limited funding, swinging political support, and limited data literacy (in citizenry) and tech-legal capability building (in institutions). In this respect, this case teaches that the commons can be applied to data and digital infrastructures only to the extent to which they are inscribed into a broader ecosystem.

To do so, it is necessary to move beyond the conception of the commons as a resource—a thing—to accommodate the idea of "commoning" (de Angelis, 2017) as a sociotechnical process. As de Angelis (2017, p. 11) notes "commons are not just resources held in common, or commonwealth, but social systems [of] ongoing interactions, phases of decision-making and communal labor process." Further on, de Angelis (2017, p. 24) also specifies that "the origin of commons rights is in commoning, we are in the presence of a social system generated by its own operations, codes and values," thus subverting the normative relation between commons and commoning and reestablishing the right order: it is commoning that precedes and foregrounds the commons, not the other way around. Hence, through commoning, the commons comes to identify, more properly, a system consisting of a resource, its users, the institutions binding them, and the associated mechanism processes (Feinberg et al., 2021). The shift from the commons as a *thing* to commoning as a *process* is crucial when applied to the role of technology. Indeed, technology is pivotal in creating resources: as Hess and Ostrom (2007) explain, "[t]his ability [of technology] to capture the previously uncapturable creates a fundamental change in the nature of the resource, with the resource being converted from a non-rivalrous, nonexclusive public good into a common-pool resource that needs to be managed, monitored, and protected, to ensure sustainability and preservation." This means that as soon as a (new) technology creates or seizes a resource, this can effectively be managed as a commons. Yet, such (economical-legal) conceptualization is not enough: it does not explain *how* technology creates a resource and *how* to commoning it. To unpack these aspects with regard to data, it is necessary to reconsider the (normative) understanding of data.

4.2 Beyond Data as a Resource: Data as Entangled Sociotechnical Processes

Prainsack (2019) notes that the nature of data is different from traditional CPRs: "although digital data clearly have material components, their materiality is of a very different kind than the physical resources." Along this line, it does not surprise to find both advocates of data's global (virtual) nature (Shkabatur, 2019),

as well as defendants of data's local (material) roots (Loukissas, 2019). These positions are symptomatic of the difficulty to consider data as a resource in the traditional sense of the term, that is, as something to be found "out there," to which also the (abused) metaphor of data as the "new oil" aligns.

Differently from natural resources, data do not pre-exist in nature. Instead, data are a fully artificial (human and/or tech-created) construct that exists in the very moment in which a *certain* (sociotechnical) process is enacted to collect *certain* information. This leads also to suggest that data-as-resource are unique in that they manifest an entangled nature: if one stresses the *informational* constituency of data, then data are a virtual entity and are potentially distributable globally; if one stresses the *technical* constituency of data (from collection to storing and use), then data are material entities whose allocation and circulation can be favored or hindered in many ways. Therefore, to an extent, it is beyond the point to ask whether data-as-resource are non/excludable and/or non/rivalrous. On the one hand, being informational, data can be accessed (in principle) by anyone, thus being non-excludable; being technical, their access can be prevented, thus making them an excludable resource; on the other hand, being virtual, data are in principle non-rivalrous, while as a technical artifact, they are rivalrous. The hybrid nature of data is also responsible for tensions at legal level: someone can claim ownership over data even without control (and vice versa), stressing either the informational (e.g., European legal doctrine) or technical constituency (e.g., US legal doctrine) of data. When, for instance, the EU's General Data Protection Regulation is interpreted as the "law of everything" (Purtova, 2018), this attests to the friction between data as a technical construct and the application of the law to an informational realm that can hardly be parceled.

This is why commoning can prove useful in the digital realm, by shifting the way to think about data and passing from data as a "thing" to data as *entangled processes*: data are always created under certain (sociotechnical) conditions, used for certain purposes, in certain contexts, and with certain results. Governance mechanisms must be designed to either negotiate between the two constituencies of data or disentangle and give priority to either one of the two. As Hummels et al. (2021) note, it is necessary to account for and mitigate the effects of inclusion *and* exclusion connected with the managing of data. At stake is a matter of regulation and control, not ownership.

When this discussion is operationalized in the context of CDT, it follows the necessity to reconsider what digital technologies can do *to*, *with*, and *through* the urban environment. Discussing the idea of smart city as a commons, Frischmann et al. (2013, p. 21) are right when they argue that "there is no clean way to separate a particular knowledge commons from its 'natural' cultural background"; however, these authors remain confined to an institutional position on the commons, missing to fully draw the consequences of their argument. If we are to commonize technologized urban environments, it is necessary to adopt a procedural standpoint. This is why we suggest reframing CDT as urban digital twinning (UDT).

5 Urban Digital Twinning as Sociotechnical Commoning

Dembski et al. (2020) warn against "the rationalization and technologization of the city [as] a neoliberal product," to which they oppose a digitalization in/of the urban environment that "link[s] and combin[es] various urban data from models, analysis, and simulation and (…) enables collaboration between stakeholders." Far from being a mere terminological issue, to reconceptualize CDT as UDT mirrors the transition from the commons to commoning and entails to acknowledge and design the in-the-making (i.e., never completed) and always-partial (i.e., digital twin as *one* possible modelling of the city) nature of any digitalization. A procedural understanding allows also to move beyond a static representation of the situation under exam and explore the entanglement of users and resources, thus advancing a truly ecosystemic vision. It is, then, UDT as a process that can and shall be commonized.

More to the point, we claim that UDT as a commoning should be (1) context-based, (2) iterative, and (3) participatory. Firstly, UDT requires the cognizant study of the urban environment to be digitalized, including current and past socio-economic-environmental dynamics that make such an environment unique. Suartika and Cuthbert (2020) argue—somewhat radically—that "the only dimension that is useful in any future development perspective is the manner in which any urban area has evolved into its present condition." As a digital process that is expected to attune to physical reality and people's needs, UDT cannot prescind from mapping the contingent dynamics that have led to (and still traverse) the present condition. This contextuality can also be projected on the commons, insofar as "resources, community, and goals often depend significantly on narratives of creation and operation and on history" (Frischmann et al., 2014, p. 27). This links, more broadly, to an issue of value: which values does a certain community prioritize? How has it arrived to do so? Only a contextualized analysis can provide pertinent answers, helping to design a fair integration between data and people.

Secondly, UDT must be able to perform iteratively, adapting to changing circumstances. This means that the process of digital twinning needs to be designed in such a way as to mitigate potential adverse events, as well as to accommodate unforeseen inputs. As a complex ecosystem, the urban environment configures an inter-acting—with both biological and non-biological elements—and intra-acting—within itself—dimension. Furthermore, such a dimension demands to be kept in balance. Hence, for the digitalization of an ecosystem to be a proper twinning process, it must continuously account for (in and out) relevant elements, while also striving for an overall equilibrium. When de Angelis (2017, p. 17) writes that "the subjects of this movement, the commons, are not here understood as individual subjects, but as already systemic subjects," he points exactly to the co-dependency between individual and collective stances and to commoning as a practice that negotiates between these two. At the same time, there must be a moment of "fixation" (for analytical purposes) of the commoning "dance" de Angelis (2017) envisions; this is why the whole process needs to be designed as an iterative one.

Thirdly, UDT must be participatory. Participation can be disentangled according to three axes: *who* participates? What *kind* of participation is at stake? *How* is

participation designed? Concerning the first question, by now, the quadruple helix approach—involving private actors, the public sector, academia, and citizens—has become the standard to achieve an inclusive digital transformation. Yet, from an ecosystemic perspective, the quadruple helix is not enough; it should be better regarded as the baseline, rather than the optimum. In fact, a whole galaxy of (non)institutional actors does contribute to inform the digital transformation of the city: NGOs, non-profit organizations, data intermediaries, data stewards, data cooperatives, as well as organizations pursing data altruism, etc. (*including* free riders). This heterogeneous galaxy is increasingly acknowledged—yet, not operationalized—by the EU. For instance, portraying many of the features that define data stewards, the Data Governance Act (European Parliament and Council, 2020b) specifies the need to "designate one or more competent bodies to support the public sector bodies which grant access to the re-use of the categories of data. The competent body or bodies shall have adequate legal and technical capacities and expertise to be able to comply with relevant Union or national law." Similarly, the same document identifies strategic areas of policy intervention, among which (1) a certification or labelling framework for data intermediaries and (2) measures facilitating data altruism. Data intermediaries and data altruism organizations are particularly relevant for the present discussion in that their acknowledgement by the EU attests to the multifarious nature of the emerging EU data ecosystem. How to manage such an ecosystem fairly remains an open issue, especially because it is up to member states to interpret these guidelines.

This leads to the second question, i.e., the kind of participation at stake. Arnstein (1969) developed a ladder for evaluating the level of citizens participation in the public sector, identifying eight steps over three degrees of participation: "non-participation," "tokenism," and "citizen power." According to Arnstein, it is only in the last three steps at the top of the ladder that citizens are really empowered, having effective and direct accountability and deliberative powers over the decisions to be taken. Literature (Toots, 2019) on citizen participation to e-government initiatives further confirms that among the factors that lead to low levels of participation is a discrepancy between the expectations tied to the outcomes of contributing and the perceived effort to do so. To have a successful participation in UDT, then, it is crucial to "manage the system as a process of continuous innovation, learning and adaptation" (Toots, 2019, p. 557).

This addresses the last question on how to design participation to/for the commoning of UDT. In this respect, participation needs to be regarded as *open-ended*, that is, designed in such a way that it repeatedly fine-tunes to the ever-evolving galaxy of city actors, both those who want to be involved and those who do not. Participation, then, demands as much contextual iteration as synthesis among different views; at the same time, participation is inclusive in the sense of plural and yet always incomplete, possibly irreconcilable. Similarly, commoning is entangled with participation to the extent to which participation sets the boundaries of systemic autonomy (de Angelis, 2017): commoning, in other words, establishes its own existence, defining lines of inclusion and exclusion on a rolling basis and based on contextual needs, in view of the whole ecosystem's blossoming. Given the complexity of the urban environment and the evolution of

the heuristics and tech affordances of digital twins, UDT can only accommodate participation as an open horizon: a horizon that requires constant monitoring by and through commoners.

6 Conclusion

In this article, we made a case for a sociotechnical commoning approach for governing the digitalization of the urban environment through digital twin technologies. Such an approach, we claimed, is the best way to strike an equilibrium between individual and collective dimensions impacted by the digital transformation. Indeed, research in the context of the EU digital strategy showed that while a human right-based approach to digital transformation is *necessary* to protect the individual's autonomy, it might not be *sufficient* to protect people as a whole. It is therefore crucial to develop an ecosystemic (balanced) understanding of digital transformation and its effects, intended as the ongoing translation of phenomena from the physical to the digital (and vice versa). This ecosystemic understanding is key especially in the context of cities, which are incubators and targets of digital innovation, as well as complex systems requiring orchestrated forms of organization to tackle their problems.

Currently, the development of city digital twins remains largely focused on overcoming technical limitations—e.g., data fusion, data semantics, and data interoperability—while lacking a full analysis of the societal impact of these technologies—e.g., who is impacted and how, who is left out, and why—as well as a robust governance to guide their implementation and use. At present, not only is there scant literature advancing the need for a sociotechnical standpoint towards city digital twins but also no scholarly work proposes to look at the commons as a governance approach to the implementation and use of these models. These two aspects have been discussed hand in hand here to overcome the tech-centered and practice-first results often derived from smart cities agendas. We therefore advocated the necessity to adopt a sociotechnical standpoint towards digital twin technologies in/of the city. This led us to advance the shift from "city digital twin" as a product to "urban digital twinning" as a process. More specifically, we argued that such process shall be designed as context-sensitive, iterative, and participatory. To operationalize this idea, we explored a commoning approach, which, while being inspired by literature on the commons, departs from an institutional take on common-pool resources to foreground the unique nature of data as entangled (informational and technical) processes.

Today, examples of city digital twins in Europe—e.g., Helsinki, Dublin, and Rotterdam—remain limited and at an early stage of development. While a comparative study among these (and other) examples is the focus of further research, the digital twin projects in these cities manifest similar trends concerning the tokenized involvement of citizens. Limited are also the studies, both within and outside academia, attempting to inscribe city digital twins into a broader picture of governance and urban development. In this sense, the present article represents a first operational

step coupling these directions, starting from the evidence that current tech-centered, practice-first solutions do not work in fixing the city's complex problems.

At the same time, we are aware that what we proposed here remains at a high level of abstraction, and it requires testing in real-life urban settings. At its core, the article has a conceptual rationale—even though it is based on a cognizant mapping of current trends and limits related to city digital twins—because the notion itself of digital twin is still emergent, especially beyond the industry sector. Testing of the tenets outlined here can be ideally done through forms of co-design and action research that give citizenry an informed understanding as well as knowledge transfer about the potentialities and uses of digital twins within an urban setting. Most importantly, literature shows the importance to bestow deliberative power to citizens if we are to make digitalization in/of the urban environment inclusive and participatory.

On the table is also the necessity to explore ways to institutionalize data commoning as a governance approach. Indeed, examples of commons-inspired data initiatives at urban level manifest enduring barriers, especially in terms of data literacies, tech-legal capacities, and political support. Valuable, in this regard, might be either studies that explore successful data commons initiatives across different contexts in order to identify replicable best practices that can be turned into a commoning process, or studies that compare data commons with similar initiatives such as land commons or voluntary initiatives for the preservation of natural and cultural assets, in order to identify value-laden practices that can maintain data commoning over time.

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