Towards Architectural Coordination of Digital Twin Development in Urban Planning

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Abstract. Digital Twins (DTs) carry the promise of improved decision-making about, as well as monitoring and understanding of, the twinned entity. This makes them an attractive instrument to support the, often complex and multi-faceted, decision-making processes germane to urban planning. DTs require considerable technological investments, as they tend to be data-hungry and computing-intensive. Business-wise, such investments are only meaningful if they really add value to the intended decision-making processes. However, most current DT development approaches primarily focus on the technological potential of DTs within the limited scope of isolated business scenarios, and rarely address trade-offs between costs and benefits towards the business case, let alone the broader implications for IT/IS portfolio management. These broader considerations are crucial in urban planning contexts, which typically involve a broad ecosystem of parties, complex decision-making challenges, and pre-existing technological landscapes. Drawing on the discipline of Enterprise Architecture Management (EAM), this paper argues that *architectural coordination* of DT development initiatives would enable more effective valorisation of DTs potential, and more effective management of DT-related technology within a broader technological landscape. To this end, the paper discusses the vision for and an initial sketch of a specialisation of EAM for DT development.

Keywords: Enterprise Architecture · Architectural Coordination · Digital Twins for Urban Planning · Local Digital Twin

1 Introduction

The concept of Digital Twin (DT) was coined by the National Aeronautics and Space Administration (NASA) [2] in the context of digitally mirroring and predicting the behaviour of spacecraft during space missions[1]. The original definition of DT conceived it as providing a virtual model of a *physical entity*, designed

[1] More specifically, "*The idea of a "digital twin" was born at NASA in the 1960s as a "living model" of the Apollo mission*" [2].

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to collect, transmit, and analyse real-time data, facilitating a bi-directional relationship [18] between the virtual model and its counterpart, to offer real-time monitoring, simulation, and optimisation functions [11] regarding the twinned entity. These *DT functions* are generally enabled by collecting large amounts of data, which are combined with digital models, symbolic and sub-symbolic AI, as well as different optimisation, simulation, and visualisation techniques.

The emergence of industry 4.0 [17] resulted in the exploration of the DT concept in other areas[2], such as e.g. infrastructure, vehicles, environment, and buildings. This also resulted in broadening the scope of entities to be twinned well beyond *physical entities*, to include even complex socio-technical systems (STS) such as in urban planning [31], business processes, and enterprises [22]. In these domains, the capability of DT to analyse large amounts of data, draw insights and visualise them in 2D/3D space adapted to non-technical stakeholders, offers an interesting potential for DTs to *better inform decision-making* pertaining to a twinned entity, allowing to even *actuate* these decisions. In the context of urban planning, DTs are advocated as a particularly promising technology to assist urban planners and policy makers [9,38]. The urban environments in which we live and work involve an increasingly complex web of social, ethical, economic, and ecological needs. Planning these environments involves decision-making processes regarding design and development of land use, planning construction projects, mobility and transportation network management, energy use and production, water and waste management, etc. Nowadays, such decisions face the urgency of balancing the mentioned needs across different systems to leave sustainable and resilient urban environments for future generations. Therefore, making well-informed decisions with high confidence in estimated consequences becomes vital.

Although not specific to urban planning, the major challenge with DTs lies in demonstrating the business value of DTs, which justifies the required technological investments. Twinning requires investments for Internet of Things (IoT) equipment, as well as for serious computing power [46] to store, manipulate and visualise large quantities of data. The efforts of twinning in urban planning settings are typically realised in an ad-hoc manner, focusing on the technological potential of DTs within the scope of an isolated scenario [19]. Insufficient integration of domain knowledge and processes [26] limits the added value of thus developed DT services to the business. Furthermore, due to pre-existing organisational silos, it is not uncommon to observe parallel DT initiatives within the boundaries of a single organisation, which only exacerbates technological fragmentation and functional silos. To fully harness the potential of twinning, a significant change is needed in not only digital capability of organisations involved, but also at operational and strategic levels, governance of technology and data (eco)systems [19,31], as well as decision-making culture of urban planning. Within the information systems (IS) field, the discipline of Enterprise Architecture Management (EAM) is positioned [23,36] as enabling informed decision-making in managing and coordinating structural planning challenges

[2] https://awortmann.github.io/research/digital-twins/.

in enterprises and in their portfolio of ISs. EAM provides structured approaches for *architectural coordination* [36], in particular to (1) align technological, information, and organisational architectures towards strategic objectives [39], (2) specify and restrict the design space of solutions towards strategic business needs [10], (3) enable informed decision-making [23,24] regarding the impact of, and roadmaps for, transformation initiatives, (4) coordinate among relevant stakeholders and ensure the overall coherence and alignment of business initiatives [35,36], and (5) govern (digital) transformation programs and projects to ensure their delivery and overall coherence [23,36].

In this paper, we argue that challenges underlying the development and evolution of DTs need to be considered in a broader context, i.e. involving a structured approach of alignment and coordination, such as the ones established by EAM. In this context, and in line with [5], we argue that DTs should not be treated as a monolithic notion, but rather as a paradigm of functions/services provided to 'the business' based on a sophisticated combination of emerging and advanced technologies. As such, DTs can be seen as fundamentally a class of advanced (active) ISs, and treated as an integral part of larger IT/IS portfolio. This makes it more natural to see investments in DTs as being part of a broader portfolio of data collection and processing, embedded in the wider organisational strategy, from which to consider a more (economically and organisationally) sustainable development of DT services. In our view, existing EAM approaches could be (en)able(d) to manage and coordinate the development of (portfolios of) DTs. While we expect to be able to use existing EAM frameworks and associated modelling languages for the development of DTs as a starting point, we do expect a need for specialisations and even extensions to deal with the challenges of DT development in general and of urban planning in particular.

This vision paper provides a first sketch of the ingredients needed for the above-mentioned specialisation/extension. As such, we position this paper at the start of the design science research cycle [51], or in terms of van Aken and Nagel [1], at the *fuzzy front end* of design science, where we are still exploring the specific needs and requirements for a design artifact (i.c. an EAM framework to support the development of DTs in an urban planning context).

The remainder of this paper is structured as follows. Section 2 explores some of the key planning challenges regarding DTs for urban planning. Subsequently, Sect. 3 highlights the value of adopting a broader EAM perspective to effectively address these challenges in terms of *architectural coordination*. To have a better overall understanding of the design trade-offs and possible synergies in a broader IT-landscape context, Sect. 4 explores some of the key functions involved in a DT. This is followed in Sect. 5 by an initial sketch of an EAM framework for DT development in an urban planning context. Finally, Sect. 6 discusses our next steps and concludes the paper.

2 Urban Planning and the Role of Digital Twins

Urban planning (UP) is the process of directing the use and development of land, urban environment, and its infrastructure, the related ecosystem, and human services, to promote sustainable growth, high quality of life, efficient service delivery, and responsible use of natural resources [4]. This involves the coordinated planning of physical structures (e.g. buildings, streets, neighbourhoods), infrastructure systems (e.g. transport, water supply, communication), ecosystem services (e.g. energy, water, food, air quality), human services (e.g. education, healthcare, culture), and administrative functions (e.g. regulatory compliance, public service provision, policy development). The overarching goal of UP is to create resilient, inclusive, and sustainable urban environments that are both liveable and attractive [14]. Nowadays, these environments are made up of an ever more intricate combination of human, physical, and IT-based components. Those "*technological components and social arrangements are so intertwined that their design requires the joint optimisation of technological and social variables*" [3].

With the growing complexity and interconnectedness of systems within UP, comes a growing pressure to ensure planning decisions are well-informed, taking global impacts across different systems into account. This requires delicate tradeoffs across a range of relevant needs (sustainability, cost optimisation, safety, social needs, etc.) and stakeholders' concerns. In this context, DTs are seen as a promising technology because of their ability to process large amounts of data, combine the resulting insights with background knowledge, while also allowing for the simulation and visualisation of the effects of different scenarios [38][3]. However, the rate at which decision-makers adopt this technology is still relatively low, due to factors ranging from financial to human ones [33]. DTs still struggle to demonstrate their added value to decision-making: the efforts of twinning are typically realised in an ad-hoc manner, with overly techno-centric focus and a reduced scope and understanding of the requirements of decision-making processes [19]. At the same time, critical reflection on how DTs contribute to broader policy goals and integrated urban solutions remains limited [30]. Next to not enabling to fully materialise the potential of DT technology, this situation induces significant costs and long-term challenges to DTs' socio-economical sustainability [41]. Based on [41] and a selective literature search that does not claim to be complete, we discuss some of these challenges below.

DTs as Isolated Monolithic Systems – DTs are often introduced within narrow case-specific problems without embedding them in a broader socio-technical and governance context [19]. This risks to induce or exacerbate architectural inconsistencies, redundancy, scalability, and maintenance issues [19]. In a UP context, another crucial factor to consider is how DTs constructed with this approach would evolve in light of continuously changing policy requirements.

From a technological perspective, DTs involve different IT components and functions, including sensors and actuators, external data sources, the integration and further processing of data, as well as advanced simulation and user interfacing. Such components and function, may not only be beneficial towards

[3] In this context, Local Digital Twin (LDT) as a notion is coined by [27] as being "*virtual city replicas that make it easier for anyone to visually understand the complex real-time interrelation between different urban factors such as traffic, noise, and environment*".

a specific DT, but also used by other DT initiatives within organisation [19,40], and even other ISs within the broader IT/IS landscape [41].

Furthermore, while a monolithic DT platform may appear technically compelling, the realistic integration of such a system into existing urban governance structures is far from guaranteed, as current institutional arrangements and decision-making processes are often not aligned with centralised, data-driven models. Additionally, a centralised 'single source of truth' DT platform also brings about the risk of (and resistance towards) power centralisation, reduced transparency, or dependency on proprietary technologies [31].

The Lack of User Engagement and Domain Expertise Integration – Applications of DTs in UP are still limited to basic functions such as static data visualisation and near real-time monitoring [37], with their marginal integration into actual decision-making processes. One key obstacle lies in the inherent technical complexity of DTs, which can alienate decision-makers who may lack the required technical background [33]. Without a clear understanding of DT functions and benefits, the perceived complexity of the technology can hinder user engagement and limit DTs' practical application in policy and planning processes. Furthermore, the opaque or 'black-box' nature of predictive algorithms and AI/ML components tends to raise concerns among domain professionals, thereby reducing their willingness to rely on outputs like simulation results for critical decisions [8].

Nonetheless, the involvement of domain experts and other stakeholders throughout the DT lifecycle is crucial, not only to align DT services with decision-making needs but also to embed domain expertise and help establish transparency and trust. As a consequence, DT development approaches cannot remain techno-centric, but need to use a more participatory approach.

Avoiding Fragmented Data Ecosystems – DTs are inherently data-intensive systems. While sensor networks and other data acquisition technologies enable the continuous collection and monitoring of system behaviour, the mere accumulation of data does not automatically translate into value. On the contrary, the integration of large volumes of data – often collected at varying temporal resolutions, in heterogeneous formats, and across multiple levels of abstraction – can significantly exacerbate existing issues of fragmentation within data landscapes [8,26]. This highlights the critical importance of robust data management strategies and the development of well-defined data semantics as foundational elements of effective DT implementation. Next, due to their reliance on high-quality and timely data, DTs require dependable and secure data access, an objective that presents a range of technical challenges, e.g. interoperability, data quality assurance, and cybersecurity. Beyond these technical dimensions, the socio-technical context of DTs in urban planning contexts [9] brings about the intricate questions of data governance. In such cases, the challenges of data access are often shaped less by technical limitations and more by institutional concerns such as data ownership, competitive sensitivities, and the willingness (or reluctance) of actors to share data across organisational boundaries [32,47].

Managing the Necessity and Costs of Organisational Maturation – A purely techno-centric perspective fails to account for the individual (e.g. upskilling) and organisational (e.g. inter-institutional collaboration) learning processes and their associated costs, which are essential for the effective adoption and integration of DTs into policy-making structures and workflows. Also important is the consideration of skills and capability gaps, as input for educational outcomes, to enable a more meaningful digitalization as part of smart urban development [19,31]. The resulting costs, both financial and social, of such *organisational maturation*, are often implicitly expected to be borne by the intended users, including local authorities, institutions, and urban residents. In contrast, we argue that these learning requirements should be systematically embedded into the design and implementation of DTs.

3 Architectural Coordination for DT Development

The previously discussed challenges provide a broad range of concerns towards socio-economically sustainable development and evolution of DTs. As mentioned in the introduction, within the IS field, the discipline of EAM is positioned to meet these challenges by providing a means for *architectural coordination* of DT development. In this section, we discuss what we see as being the key needs for such architectural coordination for DT development in an UP context.

The Need for a Modular Perspective on DTs – In line with the challenge to avoid *DTs as isolated monolithic systems*, and as argued by e.g. [5], to cost-effectively and sustainably realise the potential of DTs, they should be regarded not as a monolithic, stand-alone technology, but rather as a modular assembly of functions/services provided to 'the business', having potentially different levels of service and complementing traditional IS functions. In other words, DTs can be regarded as a special kind of (active) IS, and be managed as an integral part of the IT/IS landscape. The details and implications of such conception of DTs are further elaborated on in Sect. 4. Just as modern information system architectures are expected to be integrated, modular, and interoperable, DTs should also be conceived as components within the broader IT/IS landscape [25]. Furthermore, their development and evolution should be managed against this background and be subject to architectural coordination.

The Need for a Holistic Perspective – Next to the need for a more modular view on DTs, their planning, design, and evolution of DTs should be managed with a comprehensive understanding of the data, technological, business and institutional landscape of the twinned entity. This would not only be beneficial to anticipate integration challenges, but also to identify valuable additional data sources (including historical data from traditional ISs/databases), and certainly aid in managing the challenge of *fragmented data ecosystems*. It is evident that such a holistic perspective also allows for better coordination among parallel DT initiatives within the same technological landscape, avoiding further silo formation and preserving its coherence. This also counts for 'business-IT alignment' concerns in this context: the holistic perspective allows to better relate decision-making requirements to DT services, and establish their business value more clearly. In the UP context, it is important to also take into account diverse cross-functional and/or cross-cutting opportunities in case of complex decisions, where DT services can be particularly valuable. Taking a more holistic perspective on an enterprise within its ecosystem, is a natural part of most EAM approaches, and certainly requires architectural coordination among the relevant stakeholders involved to also ensure *coherence* within the IS/IT landscape in relation to the business activities [35].

The Need for Stakeholder Engagement – Next to taking a holistic approach, it is crucial to ensure the engagement of different stakeholders all along the DT lifecycle process to translate holistic models into a coherent approach [29,35], also ensuring the involvement of 'the right' stakeholders [50]. The challenge of ensuring *lack of user engagement and domain expertise integration* stresses this need even more.

The Need for a Strategic Outlook – The considerable investments in DT technology and the needed organisational maturation can only be justified from a strategic perspective. Required investment should be planned incrementally, in stages, and in line with the expected business value of DTs, to better manage the involved risks [19]. A long-term, i.e. strategic, vision on digital capability also facilitates the effective governance, through establishing roadmaps and translating them into DT developments which can be monitored accordingly. From this perspective, it becomes evident that sustainable development of DTs demands change which resides in the governance space rather than technological space alone. DTs are not about introducing IoT, AI/ML and using their insights for quick gains in isolated domain challenges, they are about creating significant shift in how data, technology and infrastructure are harnessed to anticipate/emerge the business need, and turn it into value [20] while ensuring strategic alignment.

As EAM approaches generally make a clear link to the enterprise's strategy level, architectural coordination can be used to ensure DT developments are embedded in a broader strategic outlook, thus also aiding towards the challenge to leverage synergies from *DTs as isolated monolithic systems*, avoid *fragmented data ecosystems*, and manage *necessity and costs of organisational maturation*.

4 Key Digital Twin Functions

This section elaborates on our conception of DT as a modular assembly of functions/services provided to 'the business' with differing service levels. This conception partially blurs the lines between traditional IS and DTs, suggesting to regard DTs as a class of highly advanced and possibly (re)active IS, whose functions complement the ones of traditional ISs.

At the very core of a DT, we identify two **overarching functions**, namely to (1) ***inform*** users to support them in e.g. decision-making, monitoring, and learning tasks in relation to the twinned entity, e.g. by way of simulation and visualization techniques, and possibly, (2) allow users to ***control***[4] the twinned

[4] Taken in a broad sense, including *influencing*, *changing*, *nudging*, etc.

entity by immediate **actuation**(s), or deferred ones in terms of e.g. trigger rules. The functions that sit 'behind' these are illustrated in Fig. 1, in terms of ***sensing***, ***acting***, ***triggering***, ***deriving*** and ***interacting*** (all marked with a cogwheel). In the remainder of this section, we will have a closer look at their differing service levels and involved cost/benefit trade-offs.

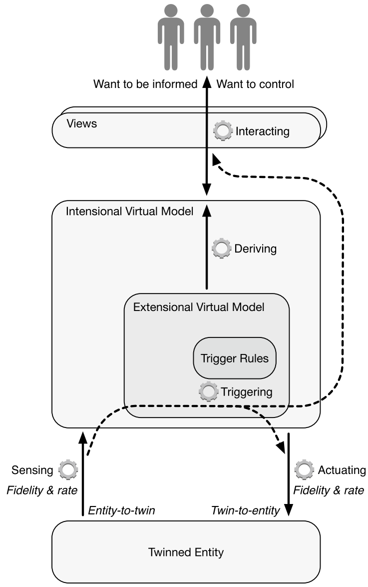

Fig. 1. Overview of key digital twin functions

These functions are enabled by what Jones et al. [18] refers to as the *virtual model* of the twinned entity. The relationship between the virtual model and the entity is bi-directional: by ***sensing***, changes in the twinned entity should result in an update of the virtual model, while changes in the virtual model should result in the ***actuating*** of changes in/of the twinned entity.

The ***sensing*** function should be seen in a broad sense, as ranging from capturing human based observations, inclusion of existing models pertaining to the twinned entity, via inputs of existing data sets, to real-time IoT-sensor based data collecting. Needless to say that behind the term ***sensing*** a world of data integration and harmonisation [42] is 'hidden'.

Both ***sensing*** and ***actuating*** functions may come with requirements regarding *twinning fidelity* and *twinning rate* [18], where *twinning fidelity* refers to the level of correspondence (at a given moment in time) between the virtual model and the twinned entity, while the *twinning rate* refers to the frequency at which the two are kept in sync.

DTs are often divided [21], into those that provide only a *digital model*, or a *digital shadow*, or actually a *'true' digital twin*. In terms of Fig. 1, the distinction is that a DT qua *digital model* has a very low twinning rate on the entity-to-twin side, and basically none on the twin-to-entity side. A DT qua *digital shadow* adds a stronger (IT-enabled) twinning rate on the entity-to-twin side, but has no ambitions regarding the twin-to-entity side. A *'true' digital twin* adds a stronger (again IT-enabled) twinning rate on the twin-to-entity side on top of the latter. Specific choices and requirements on the twinning fidelity and twinning rate will have a significant impact on the architecture of a DT, the insights it may offer to its users, as well as the associated potential costs involved, thus leading to an important cost/benefit trade-off.

The *virtual model* at the core of a DT does share fundamental similarities with the underlying database of (computerised) information system [16], as it essentially constitutes a model of the domain it represents, capturing its state and, often, its historical evolution. However, what distinguishes contemporary DTs from traditional ISs is the integration with IoT devices for ***sensing/actuating*** the twinned entity, as well as an AI-enabled a real-time ***derivation*** function (monitoring, simulation, optimisation) and potentially even combined with automated ***triggering*** of ***actuation***. By incorporating advanced data-fuelled, real-time, and AI-powered functions, DTs go beyond traditional ISs, which serve as a mere repository of the factual data. Another advanced function of DTs, setting them further apart from traditional ISs, is the ability to use the virtual model as a base for a wide range of (what-if) analyses regarding the twinned entity. Such analyses may pertain to the present 'state of affairs' of the twinned entity, as well as its expected/predicted 'states of affairs'.

From a more fundamental perspective, it is relevant to draw a parallel between what Ullman [48] defined as the so-called *extensional database*, being the data that is stored as tuples in a database, and the *intensional database*, involving the extensional data, as well as all data that can be derived from the former data using derivation rules. In the context of DT's virtual model, we argue that, architecturally, one should make a distinction between (1) the *extensional virtual model* corresponding to what is known about the twinned entity (in relation to the chosen level of fidelity) that cannot be derived from other elements in the model, and (2) the *intensional virtual model* pertaining to all things that can (potentially!) be *derived* from the extensional model using any form of analytics (including the use of symbolic and sub-symbolic AI, and/or simulations). The ***deriving*** function in Fig. 1, therefore, refers to the function (e.g. involving symbolic or sub-symbolic AI, optimization techniques, etc.) needed to actually derive relevant parts of the intensional model. Needless to say, that this function potentially requires significant computational power, likely to induce significant costs, resulting in another important cost/benefit trade-off consideration.

A *'true' digital twin* is likely to include a function to, based on sub-symbolic or symbolic *action rules*, pro-actively *trigger* actions when data stream from the twinned entity (and its environment) give rise to do so. The resulting action may involve the ***triggering*** of actuations towards the twinned entity, or notifications towards users (the dashed flow in Fig. 1). Again, a function with its own cost/benefit trade-off.

To enable users of a DT to be ***informed*** about the twinned entity and/or to ***control*** the twinned entity (via DT), they need to ***interact*** with the virtual model. This interaction is typically centred on the use of (focussed) *views* on the virtual model, while making use of advanced user interfaces, involving e.g. 3D rendering, animations, as well as augmented, or virtual, reality based interaction. Needless to say, that such advanced interfacing comes with its own costs-benefit trade-offs.

While each of the DT functions comes with cost-benefit ratios, each of them also comes with opportunities for synergy. Some examples include:

– *Sensing & actuating* – Existing, to be collected, or externally purchased, data collections/streams may be used to feed multiple ISs. The data communication, integration, cleaning, and harmonisation infrastructures needed for both sensing and actuating can potentially be shared among multiple ISs. Additional sources of domain knowledge (e.g. enterprise models, information models, domain ontologies, etc.) can also be utilized as inputs for the virtual model, and/or used to better contextualize other 'raw' data sources [26] from e.g. IoT sensors.
– *Deriving & triggering* – Rulesets, trained neural networks, etc., are likely to be specific to a single DT. However, the 'engines' (rule engines, simulation engines, etc.) these run on, and associated computing infrastructures, can be used as shared infrastructures among ISs – in general, not just DTs – within, and beyond, an enterprise.
– *Interacting* – Again, the views used for the interaction are likely to be DT specific. However, the underlying rendering engines, can be used across different DTs and possibly even ISs in general.

Having a more component-based view on DTs is also supported by recent efforts such as [25], which explore the embedding of DTs into comprehensive digital infrastructures. Aligning with the approach proposed by [40], such a component-based view also enables a progressive development path for DTs: starting from conventional decision-support systems and incrementally enriching them with additional data sources, more sophisticated virtual models, and advanced simulation and optimisation capabilities, thus ultimately evolving toward comprehensive DT-enabled decision-making environments tailored to specific domains and policy challenges. The suggested progressive development path for DTs has to, in our view, be motivated by clear business requirements and priorities, derived from a clear strategic outlook on the digital transformation of the UP (eco)system as a whole.

5 Towards an EAM Framework for DT Development

In Sect. 3, we discussed the need for architectural coordination of DT development for STS in general, and UP in particular. While for this purpose, existing EAM related frameworks and modelling languages could be a starting point, we expect there to be a need for specialisations, and even extensions, specific to the challenges outlined in Sect. 2. In this section, we explore key ingredients for such a specialised EAM framework. Based on e.g. [23,44], the framework should cover at least the following key ingredients:

- a description of the *processes* needed to do architectural coordination, as well as the *roles* (e.g. stakeholders, architects, developers) to be involved,
- an integrated *content framework*, and associated *modelling language(s)*, defining the topics, aspects and concerns, to be addressed,
- *reference models* of the application context (i.c. urban planning), as well as DT related function,
- *architectural roadmaps* for (de-)growing DT function, and
- situation-specific *guidelines and heuristics* for the application of the framework.

In shaping such a framework, we intend to apply the following **key principles**:

- ***Digital twin(ing) as a collection of functional components*** - This principle is a direct consequence of the challenge to avoid *DTs as isolated monolithic systems* (Sect. 2) and the *need for a modular perspective on DTs* (Sect. 3 and Sect. 4). Doing so also requires the *need for a holistic perspective*, in particular a comprehensive understanding of the data, technological, and institutional landscape of the twinned entity. It also requires a *need for a strategic outlook*, when e.g. taking decisions regarding infrastructural investments, to ensure *no regret* decisions.
- ***Embedded in a broader socio-technical ecosystem*** - This principle primarily addresses the challenges of avoiding *fragmented data ecosystems* and ensuring *necessity and costs of organisational maturation*, while answering the *need for a holistic perspective* as well as the *need for stakeholder engagement*. The core of the principles lies in a correct understanding the fabric of (data) ecosystems surrounding a (planned/existing) DT, and goals, interests and concerns of the involved stakeholders [32,47].
- ***Thriving information & control market*** - This principle primarily targets the challenge to manage the *necessity and costs of organisational maturation* as well as the information economical considerations behind the challenge to avoid a *fragmented data ecosystems*. Ultimately, the business case for any DT needs to be based on the added value it provides towards its users. Key in this is to consider a DT from the perspective of an *information & control market*, where demand for information and control (the top of Fig. 1) meets the available services from DTs[5]. Just as an actual marketplace may involve some pro-active marketing, the *information and control* market of DTs can also involve some marketing. For instance, in an UP context, one could imagine to provide insight (to the users) not only of the presently available information (and controls), but also create awareness of the *potential*

[5] This is actually a generalisation of the *information market* [6,7] in an information retrieval sense, as well as (since the heart of a DT is formed by its *virtual model*) an operationalisation of the RoME (Return on Modelling Effort) concept [12,34].

for access to more relevant information and control options. Even more, this could lead to pro-active investments in DT related infrastructures, based on expected needs.

- ***Integrated in a broader dynamic capability*** - This principle addresses the general need to anchor the management of DT development within the broader context of organisational development and change, and more specifically digital transformation [49]. EAM is proven as a valuable instrument to govern such changes, offering its long-term holistic view of the organising logics of processes, systems, and technology [39], enabling decision-making on organisation's projects such that it actually builds capabilities[6] and is not only impacted by immediate needs. For DT projects in UP, this embeddedness in the broader context through architectural coordination will grow in importance as this novel technology gets increasingly explored in UP. Ultimately, it will become crucial to have DTs firmly embedded in the broader *dynamic capability* [43].
- ***Customer engagement*** - The previous principle positions the users of DTs as essentially being 'customers'. This principle makes it explicit that these 'customers' should be deeply engaged in the decision-making and development (priorities) of the DTs. This primarily addresses the challenge to avoid a *lack of user engagement and domain expertise integration* towards the development of the (future) DT. This also entails enabling them to learn about the opportunities (and limitations) of DTs and their development.

The (key) consequences of the above principles towards the design and development of (components of) an envisaged specialised EAM are discussed below.

Processes and Roles – The *embedded in a broader socio-technical ecosystem* and *customer engagement* principles will lead to a stronger focus on the identification of the relevant stakeholders, as well as a need to actually engage them in the architectural decision making process. Starting points for an elaboration of existing EAM approaches can be found in e.g. [29,35].

Furthermore, as a result of the *necessity and costs of organisational maturation*, it will also be necessary to increase the general awareness of the involved stakeholders regarding the use, threats, and opportunities of DTs. In line with the *thriving & control market* principle, the latter will also need to involve the creation of awareness of the (potential) users of DTs of the information, and control, they may potentially have access to, by way of the DTs.

Content Framework and Modelling Languages – Typically, EAM (content) modelling frameworks [44,45,52] cover the essential requirements for design of the enterprise in terms of multiple layers. Typically, involving *business* (ideally both in terms of strategic (e.g. objectives, capabilities, resources) and operational perspectives (e.g. services, processes, functions, roles)), *information* (e.g. information objects, services) [52], *IS/applications* (e.g. application services, functions, components, data) and *physical/infrastructure* layers (e.g. servers, network

[6] For managing and developing DTs in a technology agnostic way, Digital Twin Consortium's *Capabilities Periodic Table* offers some guideline.

connections, operating systems), as well as their mutual dependencies. To cover the specifics of DTs development and management, it is expected that a typical EA modelling framework would need to be expanded at least at the level of:

- *Ecosystem perspective* – The *embedded in a broader socio-technical ecosystem* principle will require models that capture the ecosystem of the planned DTs, in terms of the involved socio-cyber-physical actors and their potential role (e.g. user, supplier of data, etc.).
  Especially for the potential users, it will be important to also quantify (or at least qualify) the added value of the DT towards their tasks. Starting points could, e.g. be existing work on the economics of DTs [46], as well as work on dimensions to define the value of data [13] (data *in use* actually), or more fundamentally, the economics of/behind decision-making [28].
- *Information perspective* – At this level, as with other information services [52] in the IS landscape, it will be important to characterise the added information value DT provides towards decision-making. However, for DTs, there is the additional concerns to be covered, namely the data and model harmonisation concerns, both in terms of technical aspects (towards specific systems/platforms [42]), as well as in terms of link toward decision-making contexts, i.e. clear business case of DT. In line with the *thriving & control market* principle, it will be necessary to explicitly capture the decision-making and monitoring processes, and the potential added value which the DTs may provide to this. We hypothesise also that this information 'world' will have the crucial role in the extended framework, also as a strategy to avoid fragmentation of data.
- *Physical/infrastructure perspective* – For the purpose of architectural coordination between different DTs/ISs, we anticipate that characterisation of IoT sensors/actuators, their locations and objects, gathered 'raw' data, frequencies of their collection would at least be relevant to capture.

Reference Models – We foresee the development of a reference models for urban planning covering topics such as: (1) what urban planning 'is about', i.e. the 'subject of planning', (2) the typical roles/actors related to urban planning, (3) the associated decision-making processes and topics, (4) the potential added value of a DT towards the these decision-making processes, as well as (5) the skills needed regarding the use and development of DTs.

Architectural Roadmaps – In line with work as, e.g. reported in [40] regarding an agile way to 'grow' digital twins, architectural roadmaps can be defined. Such roadmaps would capture possible strategies to gradually grow (and de-grow) DT functions, based on the needs of their users (in relation to the added value to them), and embedded in the larger data ecosystem. Such roadmaps also need to cater for the optimisation of synergies in the IS/IT landscape, as well as *no regret* investments in infrastructure.

Guidelines and Heuristics – Depending on the specific UP context (large city, country, etc.), the more specific social and geographic setting, the maturity level of the organisations involved, etc., one may expect the need for situation [15] specific adjustments and priorities to the generic parts of the framework.

6 Conclusion

In this *vision* paper, we have argued that the development, deployment, and evolution of DTs should be subject of *architectural coordination* within the broader frame of EAM. This proposition comes hand in hand with the elaborated proposition to consider DTs not as monolithic systems, but as a modular assembly of components/services that can be combined and integrated with existing information (systems) architectures. As such, DTs can be considered as fundamentally special kinds of ISs, integrated into a broader (inter-organisational) IT/IS landscape, and their development and evolution managed against this background. The paper discussed different elements and dimensions regarding how such a broader perspective lays ground for a more socio-economically sustainable twinning, in particular in the urban planning context.

The reported results are positioned (in terms of van Aken and Nagel [1]) at the fuzzy front end of the design science research cycle [51]: the specific requirements for a design artifact, namely an EAM framework for DT development in an urban planning context are explored, as discussed in Sect. 5. The next steps of this research include: (1) further refinement of requirements for the framework, through combining the results of our ongoing structured literature review and observations from existing DT projects in UP setting (e.g. the Interreg project Twin4Resilience[7], and (2) the development and validation of the framework. The use cases will support the research process throughout different stages: in terms of refining requirements, or validating the framework or its components. Notwithstanding the generality ambition, the applicability of the targeted framework is, at this point of our research, consciously limited to UP, as the existing and planned use cases originate in this domain.

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