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RESEARCH

Digital twins of organization: implications for organization design

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Abstract

The recent rise of using digital representations for products and processes has created a movement to use 'digital twins' for organization design. We provide an overview of the notion of digital twin as a synchronized, real-time two-way interacting digital representation of the real-world phenomenon it is expected to replicate as a twin. The claim of a two-way causal connection between the real-world and the digital representation makes the current rhetoric about Digital Twins especially problematic. To grasp the challenges involved in Digital Twins of Organizations (DTO), we start from Digital Twins of Things (DTT) and Digital Twins of Business Processes (DTBP). We analyze and compare different kinds of digital twins using Peircean theory of semiotic relationships, which differentiate between signals, icons, and symbols. We posit that in order to fully model organizations as digital twins, an organization designer needs to model features of organizations that are not present in DTTs and DTBPs, such as agency, conflict, and emergence. Given the inevitable presence of symbolic phenomena, we speculate to what extent it is possible to move towards full DTOs, what characteristics broader DTOs need to have, and what benefits more extensive use of DTOs will offer for organization designers. We finally offer pointers towards a research agenda for DTOs that have the potential to improve organization designs and contribute to theory on organization design.

Keywords Digital twins · Digital twins of organization · Organization design · Routine dynamics

JEL Classification M1 · M10 · M19

Digital paradise for organization design?

As a manager or an organization designer,[1] imagine that you have a tool that allows you to diagnose organizational problems, design, implement and test interventions in your organization, and then run "what-if" scenarios based on complete, up-to-date information. Let us call this new tool a *digital twin of your organization*, or DTO. Your DTO encompasses all salient details about your organization in a digital model; the model is synchronized with the current state of the organization, so that the interventions and designs you implement based on the model will have predictable consequences. In the strongest version of this story, changing the model will cause changes in the real-world organization, because there is a two-way causal connection between the model and reality. This sounds like science fiction, but "digital twins of organizations" currently attract a lot of attention from serious scholars in information systems and process management (Caporuscio et al. 2019; Park and van der Aalst 2021).

In this paper, we examine the possibilities and limits of such a provocative idea for the canons and practice of organization design. Because the technology is rapidly evolving, the idea of a "digital twin" is a moving target and to characterize the evolution and variation of the concept we begin

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[1] We assume that from time to time, most managers are designers (Boland et al. 2008). And since the concept of digital twin comes from engineering, we adopt an engineering/functionalist perspective on organization design.

by outlining several ways how digital representations relate to the real-world of organizations and interact with it and consequently identify alternative classes of digital twins and how they might relate to a DTO. To do so, we need to probe in what sense can a digital representation stand for another object (i.e., a thing, a process, or an organization)? How complete or faithful is such representation? How fully synchronized is the representation and how does this representation interact with the real-world setting it mirrors and then influence it? These attributes and functions define the space of possibilities for what a digital twin could be and how it can evolve. We show that digital twins of *things* are now commonplace, and digital twins of *business processes* are improving quickly. But depending on how they are defined, our analysis indicates that digital twins of *organizations* (DTOs) may not be feasible now, nor may they ever be. To clarify why this is so, we review how the current state of the art around digital twins will evolve and articulate some boundary conditions about what is realistic to expect from DTOs. As technology continues to change, organization designers need to understand the limits of these tools to determine whether they are fit for all purposes of designing and managing organizations, what their limitations are, but at the same time recognize that organization design will be different when these new tools become widely available.

How do digital models relate to the world?

To understand how DTOs operate as mechanisms of organization design, we need to first understand how any model such as a DTO generally relates to the world. Many in the current movement to build DTOs treat it as a simple correspondence between the model elements and the things and states in the real world. But at closer scrutiny—especially in the context of DTOs—the simple correspondence argument appears to be far more complicated and will unravel during such an exercise. To illustrate the complexity involved, we draw on the classic semiotic framework of Charles Sanders Peirce (Peirce 1991). Per Peirce, all designs, things, organizations and so on, are in some ways semiotic: a drawing of an engine, a model of a process, or an organizational chart of the whole organization being designed; are all semiotic signs. In this framework, a model serves as a sign (or Signifier); a thing, process or organization is the Object that is Signified. The relationship between the Signifier and the Object is, however, in most cases not given or fixed ex ante, i.e., there is no fixed correspondence. It needs to be fixed and interpreted for each sign–object relationship and its related use within a community of interpretants. In this sense, the designer is what Peirce would call the "Interpretant" and there can be multiple communities of interpretants for each digital twin which complicates the matter.[2]

The reason for using any model is that even during the most rudimentary, momentary forms of designing designers need to communicate, e.g., to talk. Through communication, they will build a "model" of organizing as to coordinate or collaborate on a task. Designers' communications signify the objects or actions they intend to produce. When designers start designing more formally, with a clear intention and using codified plans and related representations—such as using organizational charts, flowcharts, service blueprints, and so on—in order to have a force to shape the world these representations need to gain the capacity to *stand for the thing being designed*. The relationship then allows the designer to address specific questions about the properties of his or her design such as its content, completeness, and feasibility.

Building on Lyytinen (2021) and Bailey et al. (2022), we posit further that to become effective organization designers we need to engage more deeply with different kinds of semiotic representations mobilized during organization design. As designers, we need to ask in what capacity the signs we use stand for the objects we design. During this process, we need to become cognizant of the multitude of semiotic relationships a designer needs to understand and command when he/she engages in organization design. As designers, we need to understand more fully the capacities through which the Signifier (model) they use relates to the object being designed (thing, process, or organization). As designers, we need to also understand how the nature of this relationship affects what we as designers can do with the model and what value it offers. Different semiotic relationships we draw upon during organization design open up different possibilities and are subject to different constraints. All models we use are not the same, and their differences are important in knowing how they can be effectively used.

Three semiotic modes of representation

In principle, organization design and related representations covers the whole gamut of semiotic relationships that Peirce conceived: *signal*, *iconic*, and *symbolic*. Peirce posits that these three types of semiotic relationships form the principal modes of representation ('standing capacity') of the world. Each of them assumes a different relationship between the Signifier (the model) and the Object (the real world). With *signal* representation, the Signifier has a causal

[2] Peirce was not writing about models and organizational design and his original terminology can be somewhat obscure for modern readers. Here, we translate the concepts so they will be meaningful to an organizational design audience.

(cause–effect) relationship with the Object being represented. When the Object changes, it *causes* the Signifier to change. For example, when an Object catches fire, it emits smoke. Smoke is a Signifier—signal—that stands for fire. In digital devices, a light emitting diode (LED) lights up when it gets the right electrical input. In some situations, this can go also another way such as when a signal is sent to an actuator (thermostat) in a management system of temperatures it changes the state of a valve.

With *iconic* representation*,* the relationship between the Signifier and the Object is based on similarity. The Signifier resembles the Object in appearance, proportions, or other chosen dimensions. In graphical user interfaces, we normally think of icons as little buttons on the screen, but the concept is deeper and more general. A set of blueprints can be considered an icon for a manufactured part or a building, because they resemble the Object they represent. The relative size and position of the lines on the blueprint signify the proportional size and shape of a real-world object. Many icons do not have direct causal relationship to the object they signify—a sign of children on the road does not cause a driver to be more careful—it needs to be interpreted. Some icons such as full 3D models of some objects can now be causally related to their physical counterparts through 3D printing devices, i.e., the relationship is technology mediated. Generally, icons represent objects in such a way that physical relationship of the elements of the icon dominates the capacity to represent, rather than conventional interpretation of symbols discussed next.

With *symbolic* representation*,* the relationship between the Signifier and Object is completely untethered. Such relationship applies to all modes of conventional spoken languages[3] where anything can stand for anything (e.g., *bad* can mean *good*). There is no necessary or principled connection between words and objects like we have with signals and icons (Saussure 2011). In consequence, different languages have different words (Signifiers) for the same objects (*apple, Apfel, pomme, omena*, …). To the extent that there is a stable relationship between a symbolic Signifier and the object it signifies, that relationship is formed and sustained by a negotiated social convention within a community (interpretants) (Berger and Luckmann 1966).

Finally, it is worth re-stating the fundamental semiotic principle that all three modes of representation always rely on the presence of an Interpretant to assign meaning (decode or make sense) of the Signifier (e.g., to see that smoke is a sign of fire). Signifiers do not speak for themselves. In the sections that follow, we translate this classic semiotic terminology (Signifier, Signified and Interpretant) into design-relevant terminology that dominates the digital twins discourse which recognizes models, organizations, and managers/organization designers. We argue that the three modes of representation (signal, iconic, symbolic) can be thought of as separate representational layers that co-exist to varying degrees, rather than being mutually exclusive alternatives when building DTOs. This discussion sets the stage for the main argument concerning DTOs: how these three modes of representation apply to the idea of digital twins, where the model (the digital twin) stands for a thing, a process, or an organization.

An important addition to this tri-partite view of how signs and the real world relate to another was later made by Searle with his notion of a world ‘fit’ (Searle 1979; Searle and Vanderveken 1985). This notion clarifies the directionality of the ‘stand for relationship’. This idea is important in showing that the Signifier can either mirror a pre-existing Object (‘world-to-word fit’) or it can precede or trigger the creation of the Object (‘word-to-world’ fit). This distinction is important in organization design in that many times designers create models (signs) first whereby the organizational object is created afterwards. In the design of physical objects, the digital model often precedes the physical thing (Baskerville et al. 2020). As we discuss below, the strongest version of the digital twin concept implies that the causality flows in both directions: ‘world-to-word’ and ‘word-to-world’ but it will be conditioned by the type of sign.

The signal layer

In the world of digital technology, we currently face an endless variety of devices that send and receive signals. Doorbells, traffic lights, and satellites all have digital interfaces. Such devices inhabit what is called the cyber/physical layer of digital technologies often referred to as the Internet of Things (IoT) (Holler et al. 2014). The IoT encompasses cyber–physical devices (sensors) (world-to-word fit) and actuators (word-to-world fit) that can be programmed into functional systems using (digital) code (signals) to do some operations that are part of an organization’s task (such as manufacturing a car). Systems of such interconnected devices have been built since the 1960s for process and manufacturing automation, while over the last 30 years Internet technologies (e.g., by using the TCP/IP protocol and widespread connectivity) have dramatically expanded the variety and scope of such devices and the use of signals in supporting and carrying out organized work.

In semiotic terms, IoT devices emit signals that causally relate in both directions to the real world. For example, a temperature sensor sends a signal that changes when the nearby temperature goes up or down. When the sensor is working, the relationship between the digital representation (e.g., a bit-string that encodes temperature) and the reality

[3] There are some exceptions such as onomatopoetic words which resemble in sound the phenomenon they stand for.

(e.g., the real temperature) is based on physical, causal interaction of the sensor and its environment. This change in the temperature can then be used to trigger a heating process to keep the temperature in a specific range (thermostat). This is the defining quality of this mode of signal representation: changes in the world *cause* changes in the representation, and vice versa.

IoT devices and their controlling programs provide a cyber/physical layer of an organization. All contemporary organizations we know of rely more or less on a cyber/physical layer in their operations. Ironically, the more virtual they are the more they rely on such causal IoT-based capabilities. Even the most virtual organizations such as Google need swaths of artifacts with signals and causes to operate, such as computers, networks, and so on. Contemporary buildings have networked systems to monitor and control access, safety, climate, lighting, and these systems operate at the cyber–physical level. Under the heading of Industry 4.0 (Grieves 2011), the cyber–physical layer is currently being extended to automated manufacturing, warehousing processes, robots and cars.

As noted, at the cyber/physical level, the relationship between the model and organizational reality is causal. At their core, the devices at this level obey causal, physical laws (e.g., electromagnetism). The signals they emit have a causal relationship to the underlying state of the device and vice versa. Furthermore, because the devices can be connected causally to a network, where the state of each device is observable in more-or-less real time (with latency), they can be used to create an up-to-date representation of a cyber–physical system that many call a digital shadow (van der Aalst 2022).

The iconic layer

In the iconic mode of representation, the model "stands for" some aspects of a thing, process, or organization. Like a blueprint, the model *resembles* the object it represents. Unlike the cyber/physical layer, the icon lacks any causal connection to the real-world object: a blueprint does not automatically vanish when the building is torn down. The icon also lacks any capabilities for sensing, acting, or doing any operational work. But icons often are important precedents for creating real-world objects—some of them through 'causal mapping'—as the common practice of using blueprints and now full-scale 3D digital models of buildings and their components to construct buildings (Boland et al. 2007).

Still, icons come with much more than just offering 'a picture' of the real world. An iconic representation can offer a detailed model to simulate and/or trace the behavior of a real thing, process, or organization (e.g., a video stream is basically a set of icons strung together). To be useful, the iconic representation needs to capture the relevant aspects of the thing, process, or organization being modeled. To represent a thing (such as a building), the model should reflect correctly the structure, materials, and dimensions. To represent a process, the model should reflect the flow of control or execution between the process steps. To represent an organization, the model should represent appropriately how tasks are grouped into job roles and organization units.[4] As these examples suggest, iconic representations include most of the models we typically consider organization or process models.

Iconic representations can represent combinations of things, processes, and organizations. Consider, for example, car crash simulations used in automotive design (Leonardi 2012; Bailey et al. 2012). The digital car crash simulation can be used to replace a real-world crash. To serve as a faithful enactment of a real crash, the model must be able to convey relatively detailed account of different kinds of impacts during the crash (head on, rear end, etc.). In this application, an iconic model is based on complex mathematical foundations and engineering details, such as finite element models that help capture important properties of each part of a car and how they dynamically interact during a crash in order as to visualize such effects in 3-dimensional space (icon). The ability to use an iconic representation to test and validate effects of a change is a core component of any digital twin of an organization (Grieves 2011).

The symbolic layer

The third mode of representation differs from the first two because the relationship between the model and the object it represents is based entirely on social convention. This is the layer where most business systems are primarily and ultimately enacted including corporate database systems, Enterprise Resource Planning (ERP) systems, and workflow systems. When compared to the "real-world" they are designated to represent, the data in these systems are always first abstracted and symbolically contextualized to a community of users, i.e., interpretants (Hirschheim et al. 1995).

In these systems, the symbolic layer conveys representations of symbolically conceived actions and dependencies shared through a common professional language (e.g., accounting systems represent symbolically conveyed economic transactions and contracts). Unlike the causal and iconic layers, where physical/causal or physical/proportional relationship dominates, the symbolic layer is founded

[4] There are some arguments whether organizational charts are true 'icons' in the sense that the organization cannot be perceived and sensed like a building or a scenery. The relationships of the organizational chart, however, resemble in some dimension the conventional facts of the relationships concerning organizational decision rights, etc.

on linguistic and social conventions, meaning, norms and values of the humans who create and interpret the symbols (Giddens 1984). Because of its versatility (based on convention), the symbolic layer also helps capture relationships that exist in the causal layer. For example, the current inventory of an item may be represented based on a signal received from an automated manufacturing/warehouse system. But they also represent an abstract idea like “customer satisfaction” or “brand value” generated from surveys or using algorithms that are only loosely connected to the real world through symbolic mediation.

The symbolic layer drives organizational decision-making by providing meaning and information about goals, values and norms. It also offers means to account for deviations or fulfillment of those goals, values and norms. For this reason, language at symbolic level is also *performative*, i.e., the symbols motivate actions that create the symbols, and the creation of these symbols make specific things meaningful to actors or create new states in the world (such as signing a contract). In other words, symbols serve to create both world-to-word fit and word-to-world-fit relationships. In this regard, contextual uses of the symbols constantly change and modify relationships between symbols and the world, including relationships in the social world such as commitments, promises, etc., among actors (Searle 1979).

What is a digital twin?

We next apply the three semiotic modes of representation to probe how different kinds of digital twins in organizational settings relate to the world. In particular, we examine the concept of *digital twin* more systematically in light of these three modes of representation. Gartner Group (2019) defines a digital twin as “a software design pattern that represents a physical object with the objective of understanding the asset’s state, responding to changes, improving business operations and adding value”. But the term *digital twin* has been used in many ways and the general idea has existed for decades (see e.g., Becker and Pentland 2022).

Models, shadows and twins

The current state-of-the art distinguishes between digital models, digital shadows, and digital twins. Van der Aalst (2021) essentially distinguishes the three levels of representation by the degree to which the relationship between the model and the “organizational reality” is digitized and the execution of the organization’s operations is consequently automated. In a digital model, the digital model is created by hand, and concrete actions are derived from insights generated by the simulation model (icon) implemented manually. In a digital shadow, the digital model is automatically extracted from “organizational reality” by using process traces generated by systems combining signal and/or symbolic representations which are then fed into process mining. With a digital shadow, “it is often possible and desirable to update the model continuously. If reality changes, also the model changes. However, insights and diagnostics still need to be translated into actions manually” (van der Aalst 2021: 3). In this case, the digital shadow is said to have ‘high fidelity’ world-to-word fit while the word-to-world fit is achieved through human translation, i.e., it is a symbolic process. Finally, with a digital twin, the connection between the organizational model and reality is two-way: changes in the model can be directly enacted in the real world without human intervention and vice versa, i.e., the interactions between the model and world (world-fit) are treated in both directions as cause–effect relationships (signals). Per our discussion above, however, different kinds of entities populating organizations (such as material things, organizational processes, and organizational states such as commitments) assume different kinds of models. To understand the unique challenges involved in creating increasingly advanced forms of digital twin of an organization, it is helpful to locate the issues potentially covered by each type of twin to a broader context.

Essential components of a digital twin

We begin by identifying three essential components that define the digital twin concept: a digital representation of an object in terms of a model, synchronization between reality and model, and interaction between model and reality. Based on current usage (e.g., van der Aalst 2022), these three elements are necessary and sufficient for a digital representation to be recognized as a digital twin.

Digital representation of object (model)

A digital twin must include a model that describes “some” real-world objects in terms of static structure (their properties, their operations, and their relationships) as well as their dynamic behavior. The structure of a model includes the objects involved and a description of all relevant properties that influence the prospective use of the model which in combination allow to capture the *state* of the organizational system. For example, imagine a food distribution system. To capture the state of the inventory system, we need to know the types and quantities of the inventory. Many additional properties are needed: How fresh are the items? What is the demand for these items at this time of year? Where are the items located? How are they packaged? And what is the value of the current inventory in each location? How quickly can the inventory be replenished? At what cost? And so on. This feature list is also expandable as new features enter the fold such as the origin of the item, its “accreditation” as climate friendly production, or its potential health effects. Most of these features are symbolic (such as cost or demand) though some can be reduced to signal-based representations (freshness). Moreover, the structure of the model will entail a family of operations that will take place in that system. For example, the inventory can be refilled through an order and delivery cycle (leading to a state change, i.e., a different number of products in stock). As the example suggests, any model of a reasonably realistic organizational system tends to be elaborate and to grow in complexity over time. Of course, different (sub)models of such a system can be used for different purposes. When making operational decisions, like purchasing, it is mainly useful to know that a certain item is usually in high demand at certain locations in the summer—location in the warehouse is secondary. When making strategic decisions, such as opening or closing new locations, or new categories of products, a different set of objects, properties and states should be included in the model such as future growth in locations, variation in demand, etc.

Synchronization (what makes a digital model a digital shadow)

To be useful, a model needs to be somehow synchronized with the real world (i.e., state changes in the real-world need to reflect with some delay in state changes in the digital representation). The assumption is that the current state describes (with some error tolerance) the current values of chosen objects and properties and generally there is some delay between the change in the world and change in the model. While it is nice to have a model of food distribution in general, it becomes increasingly useful when the model faithfully reflects nearly in real time not just the correct structure of the system, but additionally the current state of a specific organization and its inventory.

The time scale and the requirements for proper synchronization can vary widely for different applications. For digital twins of some signal-based processes (e.g., chemical plants), close real-time synchronization (microseconds) is essential. For processes that operate on longer time scales (such as value and variation in inventory), daily or even weekly synchronization is often adequate. In practice, close real-time synchronization can be supported mainly by signals sent/received at the causal (cyber–physical) layer for properties of world that directly connect to the cyber/physical layer. For example, digital devices that sense RFID tags or bar codes in food distribution can be used to track the location of inventory and its states such as temperature. However, some properties (such as the flavor of a shipment of fruit or the satisfaction of your customers or the price) may need to be synchronized in some other way using symbolic mediation.

Interaction (what makes a digital shadow a digital twin)

Finally, a digital twin should involve and enable a two-way interaction with the real world. The model can be more or less automatically mapped from real-time data to model states, but the model can also directly influence reality, i.e., changes in the digital representation can and should lead to changes in the real-world objects. For example, when changes in the water pressure of a heating system update the digital model of the heating system (a signal), the digital model is expected to trigger a valve to let water flow into the heating system, increasing water pressure. Similarly, when the digital model of the stock level of the inventory item placed at the conveyor belt in an automotive manufacturing plant drops below a certain threshold, the digital model is expected to trigger a transport robot to replenish the stock at the conveyor belt so the assembly workers always have the required parts at hand.

Types of digital twins

As the aspirations for this model-based digital technology have grown, the types of organizational objects being modeled have become more complex. Above we started with digital twins of physical objects or things (DTT). We now also have digital twins of business processes (DTBP), and in some speculations, we are moving towards digital twins of organizations (DTO). Like all models each type of digital twin serves a different purpose: DTT is for product design and related operation control, DTBP is for process design and process optimization and variance control, while a DTO is claimed to serve fuller forms organization design (structure, direction, even strategy or business model). We next discuss each and how they relate to different types of semiotic relationships.

Digital twins of things (DTT)

The original idea of digital twins (DTT) emerged with the design and use of physical objects, such as machines and buildings (Boland et al 2007; Grieves 2011). Such a DTT is primarily formed using the iconic mode of representation. Iconic digital models in engineering, construction and design have grown rapidly since the 1980s—e.g., first in CAD “blueprints” and later in 3D models of buildings, cars, road, bridges and so on. These models visualize and represent in concrete ways the “real things to be designed” (Boland et al. 2008; Grieves 2011). We can observe outcomes of this trend in architecture and a host of other engineering areas where “Digital First” has become common (Baskerville et al. 2020). Starting from a common digital representation (‘digital first’) makes it easier to distribute and coordinate work among trades and vendors (Argyres 1999; Yoo et al. 2012; Gal et al. 2014). The principle also makes possible module re-use of specific components and their integration (Argyres 1999). Each vendor can faithfully produce a part or a sub-system from the overall design given the exact full-scale digital model of the product. This capability has changed the way whole design and manufacturing industries are now organized and coordinate their supply chains and product architectures and thus affected organization design. Finally, the availability of modeling/simulation technology enabled by underlying mathematics has had a huge impact on the ways how such iconic models can be used during design to anticipate expected features and behaviors of the manufactured physical objects (see e.g., Boland et al. 2008; Bailey et al. 2012).

Because designs of such artifacts change over time, the individual iconic models of artifacts also call for constant maintenance—typically realized through an Engineering Change Notice (ECN) process in a Product Lifecycle Management environment. Every change in the real world is expected to be diligently translated to a change in the (iconic) digital twin, so it is accurate and up to date—"virtually perfect" (Grieves 2011). For manufactured products, a rigorous process of engineering change orders is needed to keep the digital model up to date. For buildings, maintenance and other changes need to be recorded (e.g., when replacing equipment in an HVAC system). These kinds of changes need to be carried out through some kind of organizational process as the icons are not causally connected to their counterparts. Some parts of the current *state* of a DTT can be also *synchronized using signals* from the cyber–physical layer (such as the status of a machine, Jonsson et al. 2010), while the *structure* of a DTT needs to be *updated with human input*. Based on past experiences with creation of DTTs, these models require extensive involvement and collaboration of teams of high-skilled human specialists that maintain and organize these models in the same manner how construction teams organize and coordinate their updates and use of construction documents (Yoo et al. 2006; Gal et al. 2014) or how mechanical engineers update their designs (Leonardi 2012).

Digital twins of business processes (DTBP)

The next step beyond DTT is the Digital Twin of a Business Process (DTBP). We distinguish DTT from DTBP by two additional conditions. First, the models are about *business processes* composed of a collection of events, activities and decision points related by control flow that involve a number of actors and objects (Dumas et al. 2018, 3–4). These models are not iconic, though they use commonly iconic forms or representation in what counts as events, activities or decision points. Such forms are determined by ways in which process modelers seek to symbolically represent organizationally typified actions as activities, or how they symbolically define collections of actors and their roles and decision-rights. The control flow—connections between events, activities and actors—defines the logical structure of the business process, i.e., what types of activities will take place next given the past events and decisions. Second, while the initial structure of a process model may be stable,[5] the current state of a business process changes constantly as organizational actors perform the actions and make the decisions included in the process model (vom Brocke et al. 2021). These states can even change rapidly while the process is performed. As a result, DTBP requires different types of models—twins—than DTT. Where models for DTT use icons and integrate related geometric or dynamic analysis in the represented system using finite element analysis, models for DTBP are essentially discrete and temporal and demand other types of mathematic tools like Petri nets (van der Aalst 1998) or dynamic systems (Sterman 2000).

The technology for creating DTBP has been rapidly advancing. Unlike DTT which are generally "digital first", DTBP requires discovering the operations of an existing business process through process mining (van der Aalst et al. 2004). Once created, these models offer several possible use cases for designers: identifying the actual process, spotting inefficiencies, process standardization, compliance and risk management, resource optimization, change management, employee training, and more. There is vigorous competition in this market and continual refinements and extensions to product offerings. All models derived from process mining depend on the availability of accurate, detailed digital trace data that describe the running process (vom Brocke et al. 2021). In Table 1, we summarize three broad and widely used approaches to the creation of DTBP using process mining: imperative, declarative and object-centric.

While there continues to be rapid innovation in this area, each comes with inherent limitations. First, across all three approaches, the level of analysis concerns the details of process execution. The models are useful for the design of specific processes or groups of related processes, but it is not clear how they scale up to whole organizations, which include many interdependent processes across many locations, operating under different economic and cultural conditions. Second, with the current state of the art, the models created by process mining are best described as shadows, not twins. There is one-way causality (from the world to the

[5] This structure is also negotiated social order and not a physical system obeying laws of nature and thus can be reorganized by symbolic effort (often called process engineering) and related negotiation who does what and under what conditions.

Table 1 Three approaches to process mining

Approach	Description	Potential application to organization design
Imperative (van der Aalst et al. 2004)	Imperative process mining technologies focus on the sequences and flow of activities. The models resulting from imperative approaches, like Petri nets or BPMN (Business Process Model Notation), define a specific path or paths that processes should follow The approach provides a clear visual representation of process flows, showing the exact sequence in which tasks or activities are performed	Because of its sequence-oriented nature, imperative process mining is particularly useful when one wants to understand the exact flow of activities and identify any deviations from the standard flow. This helps establishing standard operating procedures, pinpointing bottlenecks, and identifying inefficiencies
Declarative (Pesic et al. 2007)	Declarative process mining technologies focus on rules and constraints. Instead of defining specific paths, they specify conditions or rules about what can or cannot happen in processes. Models like Declare or DCR (Dynamic Condition Response) graphs are examples of declarative approaches Declarative models tend to be more abstract, showcasing the rules and relationships between activities without enforcing a strict sequence	Declarative process mining is beneficial when processes are flexible, complex, or when they are not strictly linear. By focusing on rules and constraints, it can help identify where there might be compliance issues or where specific rules may be causing inefficiencies
Object-centric (van der Aalst 2019)	Object-centric process mining focuses on multiple objects or entities and their interactions in a process. Instead of focusing on a sequence of activities, it analyzes how different objects relate to each other during the process. The objects can include orders, invoices, customers, products, etc.	Object-centric process mining can provide a bigger picture of how different entities interact, influence, and depend on each other across multiple processes Since this technology is new, there is little evidence of its use or efficacy in organization design

model), not the other way around. Changing the model does not change the running process.

Digital twins of organizations (DTO)

As DTBPs have grown in popularity and importance in organizational practices and related design of micro-level process structures, several practitioners and scholars have expanded their ambitions and started to treat digital twins of *business processes* (DTBP) as digital twins of *organizations* (DTO) (see e.g., https://www.my-invenio.com; Caporuscio et al. 2019; Park and van der Aalst 2021). While operational business processes and their organization and dynamics form an important element of any contemporary organization and their design, they are only one part of the whole. Any functioning organization always includes operational processes such as hiring, paying salaries, purchasing, logistics, sales, yet amenable to be treated with DTBPs. These are often associated with key functions of organizations that directly add value and/or support such activities within the organization (Porter 1980; Nelson and Winter 1982). But such processes are commonly viewed by organization scholars to be a lower level operational part ('zero-level' capabilities) of a larger and open, dynamic, adaptive organizational system ('first' and 'second' order capabilities) entangled in and interacting with a broader organizational, social, economic, and institutional context. Typically, these processes require multiple and highly varied inputs such as human resources, tools, symbolic resources such as language and various artifacts such as sites and buildings. Even if we adopt a relatively naïve and simplistic view of an organization,[6] a fuller "digital twin" of a broader *organization* as a system needs to be augmented with models that embody basic organizational properties of how organizations are held together, operate within and interact with such contexts (Becker and Pentland 2021). These include:

- *Agency*. The capacity of organization's members to reflect on the past and anticipate the future (Emirbayer and Mische 1998). Agents can also behave strategically in their own interest creating uncertainty what they will do next (Axelrod 1984). Agents can improvise (Moorman and Miner 1998) and deceive (Milgrom and Roberts 1992).

[6] Over the past decades, several debates among organization scholars have been focused on the questions what an organization is, how it can be represented semiotically, and what it amounts to. These date back to such classics as Burrell and Morgan's (1979) 'Sociological Paradigms and Organization Theory' or Morgan's book on "Images of Organizations" and Van de Ven and Joyce (1981) "Perspectives on Organization Design and Behavior".

- *Conflict.* Differences in agents' interests are common inside organizations (Jensen and Meckling 1976). They are commonly suppressed by "truces", which remain hidden until they are broken (Garfinkel 1967).
- *Learning and forgetting.* Organizations are open systems that change through experience (Huber 1991; Casey and Olivera 2011).
- *Hidden interdependencies.* Many processes in organizations share complex interdependencies with other units, other organizations, specific economic actors and actors within broader institutional environment (Thompson 1967; Raveendran et al. 2020). Such interdependencies behave like air; they surround everything but are difficult to see.
- *Multiple realities.* The definition of *digital twin* puts forth an image of an isomorphic, identical, mirroring entity of an actual physical entity. While evocative, the image is misleading because in general, the relationships to things in most cases are defined by symbols and conventions and related ongoing negotiation of meaning and how to make sense of the world and environment. There is no *single* organizational reality to mirror as it assumes a signal-based relationship between organizational entities and their representations (Berger and Luckman 1967). A multiplicity of sub-cultures, realities, temporalities and logics will inevitably co-exist within any single organization, because of the symbolic means through which organization's members obtain access to those organizational realities (Hirschheim et al. 1995).
- *Emergence.* Behaviors in organizations depend "upon entities at a lower level, but the behavior is neither reducible to, nor predictable from, properties of entities found at the lower level." (Hodgson 2007: 103). Further, organizations are constantly adapting and "becoming" (Tsoukas and Chia 2002). This suggests that any account of organization will have emergent and complex features.

Generally speaking, none of above properties are needed to create useful models of deterministic physical things or business processes treated as deterministic, discrete state machines. The absence of agency, conflict, and the other properties simplifies the task of creating DTT and DTBP and makes them useful for the specific purposes they are expected to serve (such as detecting deadlocks or optimizing process execution). But the inevitable presence of such properties complicates any task of creating a "faithful" DTO in several ways as will be discussed next.

Challenges of creating DTOs

Given the preceding discussion, it is clear that organizations present significant challenges in creating full 'digital twin' like models that faithfully represents reality in its structure, where the states of variables in the model and in reality are synchronized, and that establish an interactive connection between model and reality.

Challenges in modeling DTO

Through their ongoing operation, properties like learning, forgetting and emergence will change the structural relationships within the model. That means their main impact is that they will change the *structure* of the model, not just the current state of the variables in the model. Because organizations are open systems, subject to learning and emergence, organizations will be subject to continuous endogenous change, however (Tsoukas and Chia 2002; Feldman and Pentland 2003). In current organization theory, the process is referred to as ongoing patterning or self-organizing (Feldman 2016; Goh and Pentland 2019), where the ongoing performance of a process or routine results in endogenous (recursive) change to the process or routine itself (Feldman and Pentland 2003). This makes observability and synchronization conditions hard to sustain as the structure along which things are observed and mirrored (synchronization) can no longer be maintained. In any given organization, the magnitude of such structural effects is an empirical question and varies over time. But they form an established view of organizational reality as the model and related reality through which the reality is being constructed is under constant drift. Overall, we can posit that endogenous processes constantly changing the structure of the model are unique to DTO, because it has essentially symbolic character. In contrast, in DTT and DTBP, processes that change the structure of the model (e.g., engineering change orders) are considered exogenous. If we conceptualize organizations just as machines (Morgan 1986), we are likely to overlook these underlying and hidden organizing processes in organizational and institutional context, as well as agency, conflict and the other properties that flow from them.

The organizational properties listed above pose also challenges for capturing the *state* of an organization because many such elements are difficult to observe directly. This affects observability of the DTO. Individual agency is inherently manifest in many situations where there are incentives to hide what is really going on. Such tweaking happens in small ways all the time in organizations. Agency also enables goal displacement (Warner and Havens 1968), where local, departmental, or personal goals begin to substitute for organizational goals. Employees may be working hard to serve their self-interest or some other interests, but they often pursue goals not aligned with the organization as a whole. In extreme situations, actors will inevitably collude to commit fraud (Darby and Karni 1973) which purposefully renders the model incorrect, so the state deviates from the model. Such possibilities are omnipresent in real organizations and create the need for control systems and auditing (Ouchi 1979). Conflict, though inevitable, can also be difficult to observe. When there is a truce, conflict will remain hidden (Zbaracki and Bergen 2010) and surfaces only when the truce is broken either due to change in environment, actors' positions, and so on. The same is true for interdependence and multiple organizational realities.

Challenges with DTO–world interaction

Properties like agency, conflict and multiplicity emerge and operate at the symbolic layer. Bureaucratic turf wars are commonly fought over matters of perceived autonomy, authority, responsibility, and prestige and related ways of making arguments and meaning. These matters are inherently social and organizational (e.g., who has authority over whom) and symbolic (who gets the best parking space). These kinds of phenomena are difficult to model in ways that have clear and direct effects to the world. Even if they can be modeled, insights from the model need to be communicated back to the real world in symbolic means. Limits on observability for DTOs limit the possibility of synchronization affecting DTO and world interactions. Managers may learn that there is a correlation between employee satisfaction and turnover, but the current state of employee satisfaction may be difficult to observe. In addition, it is difficult to tell what interventions will increase or reduce satisfaction, i.e., to build a structure within the DTO that connects satisfaction to other states in the model in a causal manner.

'Faux' DTOs

Recently, there have been some efforts to expand both DTTs and DTBPs to encompass also DTOs in ways which we call here 'faux' DTOs (apparent but not real). Some have labeled collections of interconnected process models DTBPs as DTOs (e.g., Park and Aalst 2021). Such equating of the term "organization" with interconnected processes tends to conflate the idea of organizational processes with that of an organization. While such extended process models will certainly prove useful in modeling and intervening on processes and managing their interdependencies, they are not DTOs per our definition above.

Another subtle and important conceptual problem involves the assumption of the two-way causal connection between the model and reality defined for digital twins and whether they apply to DTOs. In recent definitions (see e.g., van der Aalst 2022), a digital twin is characterized by an automated, real-time connection between reality and the model in both directions: the model is automatically mapped from real-time data and directly influences organizational reality, e.g., by automating process improvement. In our view, a two-way connection is plausible for some class of DTTs and DTBPs, but even here it applies only for a restricted class of cyber/physical systems and organizational process systems emulating such behaviors where the model entity and the object are one-in-the-same (such as automated inventories or production lines). These are not "twins" in a conventional sense as twins, though same, are different entities. In terms of smoke/fire, smoke is a useful indicator of fire, because of their causal relationship. Fire causes smoke, but smoke does not cause fire.

In practical terms, the two-way causal relation would severely limit the scope of digital twins to those parts of organizations that are fully automated. For example, removing an RFID-tagged item from a shelf in a warehouse could causally change the digital shadow of the warehouse in real time while using IoT technology. However, changing the inventory level in the model would not automatically return the item to the shelf unless there is a robotic system in place to perform the action. van der Aalst (2022) introduces such vision of autonomous process execution management and differentiates here between six levels (from fully manual to fully autonomous). With humans-in-the-loop, the causal chain from the model back to reality would by necessity need to include a symbolic representation subject to interpretation by the people involved and break down at some point the causal two-way interaction.

Comparing three kinds of digital twins

The preceding discussion provides a useful foundation for comparing how digital twins are applicable to model things (DTT), business processes (DTBP) and organizations (DTO). In this section, we review and contrast the properties of different kinds of digital twins proposed so far (summarized in Table 2). Throughout the discussion, we noted that different kinds of digital twins serve different purposes. A model is always a model to address a specific set of questions. DTT is primarily for product design, DTBP is primarily for operational process design, and DTO is for overall organization design. The contrast is important and instructive, because the success of DTT and DTBP can indicate, by analogy, what might be needed for creating a useful DTO.

The progression from DTT to DTBP to DTO involves representing more and more of the organizational world by relying on different modes of semiotic representation. Whereas the DTT is focused on things and causal relationships, and DTBP is focused on discrete activities viewed as

Table 2 Comparison of digital twins for different kinds of objects

	DTT	DTBP	DTO
Focal use	Product design	Process design	Organization design
Focal objects	Things	Activities Things	Systems of people and their relationships People Activities Things
Observability	High	Medium	Low
Interaction accuracy and impact between the model and world	High	Medium	Low
Outcomes of interest	Functional and non-functional requirements Failure modes DFMA	Cycle time Bottlenecks Other process metrics	Social/psychological Organizational Economic Strategic/competitive ESG KPIs
Disciplinary base for digital model	Physical science Engineering	Computer science Industrial Engineering	Organizational behavior Operations management Accounting Organization theory Strategy/industrial economics of organizing
Core models	Functional geometry Finite element	Network and event models (e.g., Petri Nets) (discrete event) System dynamics (continuous)	Generalized linear models QCA models System dynamic models Agent-based models
Proportional modes of representation			
Causal	+ +	+ +	
Iconic	+ +	+ +	+ +
Symbolic		+	+ + +

states and their properties in the organizational system, DTO will come to include things (such as inventory and equipment), activities (business processes), and people and their relationships (workers, customers, managers) and increasingly latent and ephemeral properties. Properties are treated as exogenous (not part of the model) in DTT and DTBP, but become inherently treated as endogenous (part of the model) in DTO. As a result, the models often become what defines what reality is and how it behaves—in organization theory this is called 'performativity' of organizational and economic models and theories (MacKenzie 2006; Marti and Gond 2018).[7]

Observability is another dimension on which the three types of digital twins differ. We expect that the properties of a DTT will be the primarily observable, because of the causal representation at the cyber/physical layer and resulting causal signal-based connection. If more sensors are needed, more and varied types can be added. In contrast, the properties of a DTO will be the least observable and the observability can never be exhausted and remains a subject to various arguments. At the same time observability is crucial for digital twins because it keeps model structure and model state synchronized with the real world.

Users of different kinds of digital twins are interested in different kinds of outcomes. Users of DTTs are mostly interested in determining desired behaviors (expressed in requirements) and detecting failure modes of alternative product designs, i.e., does the model allow us to predict how the real product will behave (as in the crash test) and based on that maximize behavior of desired behaviors and minimize the variance of unwanted the product behaviors. Users of DTBP are interested in process change and improvements expressed in various process metrics, such as average cycle time and its variance and related improvements. Organization designers are commonly interested in a broader range of outcomes organizational outcomes including strategic/competitive outcomes, organizational viability, or boundary conditions for its existence. Because each user group of digital twins is expected to model different kinds of outcomes, each type of digital twin comes with a different type of disciplinary base and employs different kinds of models.

[7] As performativity, the impact and ways of addressing the word-to-world effect of organizational models is a rich and growing topic in organizational theory and analysis.

For example, DTTs largely draw on physical science and derivative engineering disciplines, while DTOs need to draw on a wide range of disciplines and explanations that speak to the main outcomes of interest, such as organizational behavior (employee satisfaction), operations management (supply chain viability and behavior) and accounting (cost ratios), organization theory (coordination and task variability), or strategy (business model components and change).

An equally profound difference between the three types of models concerns the relative importance and proportional role of different semiotic representation modes. A classic DTT relies primarily on iconic representations (such as 3D models) to represent the physical thing being modeled. Typically, the models are created or increasingly adapted from existing model libraries manually by skilled designers and the model crafting follows rules, conventions and standards related to specific engineering profession.[8] If so desired, a causal representation (signal) at the cyber/physical layer can be used to keep the state of the model up to date (e.g., for predictive maintenance). This combination of representational modes is proving to be very useful in product design. The models may have some aspects of organizational/symbolic models such as cost, delivery conditions, etc.

In the case of DTBP, the mode of representation is quite similar. However, instead of laboriously creating the model by hand every time, process mining can now be used to create an iconic model of the sequential relationship between activities of a process. These relationships can then be analyzed using mathematical models, such as Petri Nets, based on an event log of a running process. The same basic method can be used to update the current state of the system, as well. As long as the event log contains enough information, DTBP can be of high quality in terms of fidelity. Unlike DTTs, the created models are empirical generalizations of socially constructed activities such as paying a bill or ordering an item. They are not causally related to the actual reality, but record changes in that social reality (standing level of orders). They represent only the range of process behavior that appear in an event log, and do not model the underlying context and mechanisms that generated that behavior (e.g., why an order was made).

In the case of DTO, some representations are iconic, such as organization charts and flowcharts, but even here the relationship to reality is symbolically mediated (see footnote 4). Hierarchies and job titles on organization charts are symbolic entities. Therefore, most of the representations of the DTOs will be at the full symbolic level. This includes accounting systems, HR systems, etc., because the outcomes of interest for organization design at this level are primarily symbolic. Organization design inter alia is thus concerned with structuring social relations, e.g., designing positions, allocating people to positions, grouping positions into organization units, designing reporting relationships between positions, and allocating decision-rights to positions (Puranam 2018)—all efforts ultimately mediated and made possible by language and sense-making (Berger and Luckmann 1966). In this regard, organization design has always operated at the symbolic level, where linguistic conventions, meaning, norms and values of the humans who create and interpret the symbols play a decisive role (e.g., what being an "accountant" entails in organization XYZ).

DTO development from an organization design perspective

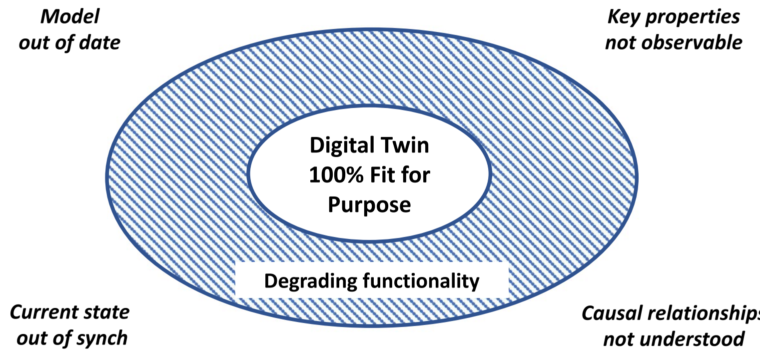
Broadly understood, organization design refers to the ongoing search for a set of solutions to the two universal problems of organizing, i.e., how to divide labor and integrate it again in ways that meets a specific set of constraints and specific goals including economic, social and short- vs. long-term goals (Puranam 2018). Division of labor refers to breaking down the organization's goals into tasks and sub-subtasks and eventually singular tasks (task division) and allocating the tasks to members or aggregates of members of the organization or some external actors (task allocation). The means for integrating the efforts of individuals (integration of effort) are commonly the distribution of rewards (reward distribution, e.g., by providing incentives) that help align the goals of the individuals, and the provision of information (information provision, e.g., by design of communication channels) as to coordinate and align their actions (Puranam 2018). There are also other mechanisms such as task and product modularization which help concentrate knowledge about specific tasks into specific "locations" of an organization and allows them to proceed without the interference of the rest of the work (see e.g., Baldwin and Clark 2000). From an organization design perspective, the challenge of DTOs is to find appropriate abstractions that will offer relevant answers to the organizational design problems stated in terms of goals and constraints relating to how to address both task division, integration and resulting incentive and coordination problems. We will discuss below to what extent this issue has been addressed, and what steps might be useful in addressing it.

Developing DTOs fit for organization *design*

Based on the above analysis, it is clear that organization designers have yet to arrive in DTO paradise. The

[8] Given the emergence of large-scale language models, the DTT models can be also produced based on a machine-based learning model which draws statistical probabilities of key features of the model (like curvature, composition, etc.).

Fig. 1 When is a digital twin fit for purpose?



organizational systems we design remain less understood and less observable than the physical product or deterministic business process designs enabled by DTTs and DTBPs. This obviously calls for further research to improve understanding of organizations and to collect data on how they work, undertaken in fields such as organization science, organization theory, organizational behavior, and organization design. Leveraging relevant insights on organizations from those bodies of research when modeling organizations in DTOs can contribute to developing DTOs that are useful for organization designers. Given the vast research on organizations that has been accumulated, and considerable untapped potential in this regard, this task appears to be of priority in developing DTOs that are useful for organization designers. Linking the digital twin- and the organization design-communities and building institutional bridges between them would provide powerful levers for tackling this task.

The benefit of moving to richer DTOs is that we will have increasingly varied models, more diverse design searches and more flexibility (as digital pervades many of the actions and activities) in designing and implementing the organizational designs we arrive at. Shortly, a wider range of DTOs will offer more diverse ways to learn from experience of how to carry out and execute organization design. DTOs will in a sense afford more degrees of freedom of how to do it. In this regard, it is worth striving to develop fuller models of DTOs to improve the state of the art in organization design.

Yet, those increased possibilities from better tools make more salient the question precisely how organization design researchers would like to use these tools. To have DTOs contribute to organization design practice and theory, it appears central to develop a better understanding of what DTOs as tools can do, and which of those capabilities are particularly useful for organization designers; what searches for organization designs we would like to carry out, given those capabilities of the DTO tool; and how to use the new potentials and affordances from availability of data and DTOs. These questions suggest points for the research agenda in organization science and organization design research. They also point to specific interfaces between the IT- and digital twin- and organization design communities, and concrete focal points on which dialogue between these communities appears particularly promising and productive.

As we make progress on DTOs, the central question will be whether the chosen DTO is fit for its intended purpose of organization design. For example, a digital twin that consists of a collection of business processes, no matter how accurate, cannot address questions of centralization or decentralization of strategic decision-making structures. The relevant mechanisms and outcomes (long-range competitiveness) are not captured in such process models. To put it differently, we need to always ask about the assumptions (or boundary conditions) under which we expect a chosen digital twin to be "fit-for-purpose".

This points to yet another fruitful interaction between the organization science and design communities and the IT- and digital twin-communities: a discourse providing a structured link between the desiderata on the organization design research agenda and what it would mean in terms of specifications of a model fit for those purposes.

Figure 1 portrays three regions how digital twins can be applied in organization design. At the center, we have the region where the model is 100% fit for purpose. Within that region, it provides a useful tool in creating reliable what-if scenarios and designing alternative interventions within some range of outcomes that have likelihood of being correct. For this to happen, most effective operational causal relationships need to be identified and well understood, key properties of the design (parameters) need to be observable, and the model structure and the current state need to be up-to-date.

Outside of this region, the model's accuracy begins to degrade. The degradation may not be easy to recognize at first because it will appear to be working. Eventually, the degradation becomes so severe that the digital twin is completely unreliable (not a twin at all and not even a decent shadow). As discussed above, the digital twin capability to create a 'fit-for-purpose' condition depends on addressing three essential ingredients.

Model quality for causal explanation

Model quality depends on our depth of understanding of the focal organizational phenomenon. This can range from identifying essential causal mechanisms (necessary and sufficient conditions) to empirical generalization ("typically, this is what we see"). Depending on its purpose, a DTO might capture causal processes that characterize elements of conflict, learning and emergence observed in organizations. At the same time, these are not fully deterministic in that the DTOs should always allow for the agency to act otherwise or interpret the model in different way resulting making the model out of sync.

Observability of the real world

Observability is critical to keep the digital twin synchronized with the real world. Observability affects both the structure of the current model and the current state.

Internal to the organization

A lot of things in organizations and humans are becoming increasingly visible (Leonardi and Treem 2020), but some stuff will always be hidden either because agents benefit from them (e.g., fraud, conflict covered by truces, etc.) or observability is not socially acceptable or against ethical norms (e.g., privacy, health conditions, etc.).

External to the organization

Organizations are open systems. They are constantly influenced by various economic conditions (prices, interest rates, supply, demand, and competition), supply chain disruptions, natural phenomena (weather, fire, etc.), public health, etc. (the PESTEL factors from strategic management). Technological innovations may also be important. These limit what can be included or not included in the DTOs and to what extent the model of those things is adequately synchronized what is actually happening.

Synchronization of model and data

For DTT and DTBP, the cyber/physical layer can provide representations synchronized in real time. Unfortunately, that layer of representation is much less relevant for organizational outcomes, which largely involve phenomena that can only be accessed at the symbolic layer. However, this is not always a problem. Real-time data are less valuable and less necessary, if the organizational decision processes required to interpret and act on the data are slower, have high ambiguity and involve long time spans. Therefore, the rate at which models are synchronized needs to be adjusted to the temporal perspective and conditions that affect those decisions. For example, if decisions require approval at weekly or monthly periods, then having up-to-the-minute data is less important than the choice of the structural model and whether the model adequately reflects important abstractions concerning the decision.

These challenges in building DTOs that can advance organization design suggest further points on which dialogue between the digital twin- and the organization design-communities would be fruitful. It would be useful for organization scholars to understand for which variables observability is likely to increase with progress in technology, e.g., sensor technology, and for which variables this will be unlikely. This would enable an assessment of how increased observability (as signals of physical reality) can be integrated in ways that make sense for advancing understanding of organizations as symbolic systems and how to design them to attain certain objectives better. Likewise, it would help deprioritize objectives that seem difficult and less realistic to implement in the short-run, from a technical point of view. More broadly, these considerations invite a dialogue that systematically relates desiderata of organization design and organization science to the (emerging) possibilities and challenges of DTO technology.

Implications for scholars of digital twins and of organization design

Above, we identified several specific points on which a dialogue between the technical community developing DTOs as tools and the community of organization designers as users of those tools seems to be fruitful. DTOs can not only be used to improve organization designs, however; they might also be used to contribute to developing, elaborating, or falsifying theory on organization design and other aspects of organizations. A dialogue between the technical community and organization design researchers therefore also seems to hold potential for contributing to advancing research on organizations.

More broadly, such a dialogue could potentially impact the technological trajectory (Dosi 1982) of DTOs in important ways. This might, in turn, have consequences for the trajectory of organization design research and theory. The trajectories along which technologies develop are influenced by many factors and interdependencies and feedbacks between them, including technology-push and demand-pull factors. When it comes to DTOs, it appears that firms—and questions of practical relevance—currently dominate the 'demand-pull'. The community of organization design scholars goes beyond such concerns, however. It is also concerned with developing, elaborating, and falsifying theory underlying how to design organizations that can efficiently achieve their objectives. Because this community has different demands than users such as managers who want to solve practical problems, it is possible that a dialogue with this community could shape the trajectory of technology development slightly differently.

From an organization design researcher perspective, formulating ‘research demands’ for DTOs—rather than only practical demands—and mobilizing support for those thus appears useful. The sooner, the better: emerging paths are often quite malleable early on but much less so later in the process (David 1985; Arthur 1989; Stinchcombe 1965). The community of organization design scholars is one of the most immediately concerned, making it a potentially central dialogue partner of developers of DTOs. A dialogue between the digital twin-community and organization design scholars does not just appear a good idea for organization design scholars. Many arguments in this paper suggest that DTOs have at least some aspects of a discontinuous rather than incremental innovation, compared to digital twins of things or business processes (DTTs and DTBPs). As becomes clear from a Peirceian perspective (Sect. "How do digital models relate to the world?"), for instance, they involve not just more, but also substantially different mechanisms than digital twins of things or business processes (DTTs and DTBPs). This makes an engagement with the organization research community more attractive in order to develop DTOs that will be 100% fit for their purposes, both for solving practical tasks of organization design and for contributing to theory of organizations and organization design.

Conclusion

Organization designers are a long way from digital paradise. Without question, progress is being made in creating and deploying increasingly sophisticated models of business processes and operational product systems. However, in the current state of the art, those models are based on empirical generalization of observed behaviors (e.g., process traces), not underlying causal models. In the event of a labor shortage, or a supply chain disruption, or some other violation of an unstated (untested, unmodeled) assumption, the so-called “twins” will quickly lose their resemblance to their real-world counterparts.

Still, digitalization is fast expanding and changing how we represent and design organizations. Simply speaking, representations improve and change on manifold dimensions when they are born digital. For instance, they can, and typically do, become more fine-grained, more multi-dimensional, more real-time, or operate with more fine-grained time stamps, the operations can be more easily aggregated, and offered in higher resolution. The models allow zooming in and out and observing outliers. They can be visualized and also simulated for alternative outcomes. Organizations can also be made more flexible, more loosely coupled and more emergent by using digital representation.

As noted above, organization design has always been about representation and innovations with organizing have been connected with related innovations in representations, whether the design representation is an organizational chart, a workflow, a blueprint or a drawing of the thing to be produced. The improved quality, scale and computability of digital representations and their constant meshing and the possibility to integrate multiple representations into evolving DTOs brings new possibilities for what is being designed, by whom and why when we talk about organization design. The design of such designs has just started. At this point, dialogue between the digital twin-community and the organization design community seems particularly promising for the development of DTOs that are useful not just for improving organization designs, but also for contributing to theory on organization design.

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