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The digitalization of physical reality: Theoretical lenses to incorporate digitalization into management research

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Abstract

The management literature has recently witnessed a considerable escalation of research around the implications of digitalization for firms and their environment. Yet, the conceptualization of the construct of digitalization remains elusive at best. In this Chapter, we develop a taxonomy of the outcomes of the digitalization of physical reality, and of the interaction amongst digitalized units of physical reality. We maintain that these taxonomies may enhance the scope for combining extant research in integrative frameworks as well inform management research that links digitalization and its agency in a more systematic way.

1 Digitalization in business and management research

In the early 2000s, digitalization was a fairly obscure construct. As shown in Figure 1 below, in just a few years, digitalization has become a popular topic that fascinates both academics and practitioners in business and indeed all types of organizations. This growing popularity is not surprising. Digitalization is associated with several transformational outcomes for firms and their environments (World Economic Forum, 2020). A substantial body of research in several streams of the management literature has investigated the impact of digitalization on areas including management practice (Jarzabkowski and Kaplan, 2015; Sharker et al. 2019;

Majchrzak and Griffithet al. 2020; Mousavi et al. 2021), organization and organizing (Yoo et al. 2012; Bailey et al. 2019; Kretschmer and Khashabi, 2020), firm boundaries (Nambisan et al. 2017; Lyytinen et al. 2020), business models (Teece, 2010, Massa et al. 2017; Lanzolla and Markides, 2021), partnerships (Adner, 2017; Jacobides et al. 2018; Dattée et al. 2018; Wang, 2021), innovation (Afuah and Tucci, 2012; Villarroel et al. 2013; Nambisan et al. 2020; Lanzolla et al. 2021), strategy (Bharadwaj et al. 2013; Berente, 2020; Hanelt et al. 2021), and the macro environment (World Economic Forum, 2020). In these studies, the digital technologies leading to digitalization have been conceptualized as general-purpose technologies (e.g., Gambardella and McGahan, 2010); based on their capabilities such as monitoring, control, connectivity, optimization, autonomy (Porter and Heppelmann 2014, 2015); for the degree of their technical properties, e.g., interoperability, speed (Bresnahan and Trajtenberg, 1995); or treated as mere contextual background. Granted, the vast majority of these studies focus on the use of digital technologies and on the implications of digitalization (e.g., Tilson et al. 2010) rather than on the technology *per se*.

[Figure 1 about here]

We argue that the unsystematic conceptualization of the relationships between digital technology and digitalization has hampered the scope for comparing and contrasting extant research and developing integrative theoretical frameworks. In this Chapter, we aim to address this gap and provide a conceptualization of the different ways in which the digitalization of physical reality can take place. First, based on a systematic analysis[1] of the business literature,

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[1] We reviewed the literature published in Organization, Management, and Information Systems journals using *digitalization* as a keyword. For comprehensiveness purposes, we also developed a list of synonyms and related processes and concepts including digitization, connectivity, datafication, digital materiality, artificial intelligence, and digital artefacts. An initial Scopus search of 30 leading business and management journals covering several domains, such as general management, management science, information management, human resource management, innovation, marketing, organization studies, and strategy, with the identified keywords, returned 680 journal articles. We then read all the abstracts to identify the non-spurious articles, i.e., articles where our keywords were used with reference to the mechanisms studied in the paper and not just quoted as examples. This reduced

we propose a taxonomy that reveals that the digitalization of physical reality leverages several digital technologies and outcomes ranging from full digitization, i.e., substitution of physical reality, to partial digitalization, i.e., complementarity between the legacy unit of physical reality and the digital artefact. We then show that partial digitalization of physical reality can rest on very different logics, i.e., simulation, emulation, and / or "feeling of presence." For all these potential outcomes of digitalization, we highlight affordances as well as technical constraints to deliver on such affordances.

Second, the digitalization of the physical world does not happen one physical component at a time, nor one component independently from another. We maintain that the interactions among digitalized units of physical reality could be analyzed through the conceptual lens of complexity theory. Borrowing from complexity theory, we identify three types of interactions, which we label digital convergence, "phygital" convergence, and no convergence.

Overall, by providing a taxonomy of the outcomes of digitalization of single units of physical reality and of their interaction, this Chapter suggests that business and management researchers open the black box of digitalization and be systematic and explicit in describing the boundary conditions under which their research has been developed. We also propose a research agenda for deepening the study of digitalization in order to inform business and management research.

2 The digitalization of physical reality

The process of digitalization of physical reality is realized through different technical processes and technologies, hereafter called digitalization "technologies." The most common digitalization technologies include digitization, smartification, digital twins, augmented reality,

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the number of articles to 200.

virtual reality, and metaverse. In what follows, we briefly describe these digitalization technologies and their affordances, and we then provide an integrative taxonomic framework.

2.1 Digitization beyond gravity: The de-materialization of physical reality.

Digitization is the process of changing from analog to digital form (Yoo, 2010). Converting text, videos, and music into digital form are all examples of digitization. Fully digitized artefacts acquire new properties vis-à-vis their physical earlier versions. Here we summarize some of the most salient properties that fully digitized artefacts acquire (please see Appendix 1 for supporting evidence).

Editability. Full digitization allows the elements by which a digital artefact is made to be rearranged, while leaving its logical structure unchanged by deleting existing elements or adding new ones, modifying some of the functions of individual elements, and updating the content, items, or data fields. This is the case for digital repositories, whose utility is closely associated with constant updating. In this vein, editability intentionally makes digital artefacts incomplete throughout their lifetime and perpetually "under construction" in some sense, rendering their boundaries unknowable.

Replicability. Full digitization allows the reproduction and distribution of each form of a digital artefact for (typically) an unlimited time and at virtually no cost. The classic example here might be the replicability of a song, perhaps via Spotify, at zero marginal cost. From the industrial perspective, another example is that of ERP systems, which allow business processes to be replicated by replacing independent applications—unique for each function—with interrelated and standardized programs in functional modules.

Modularity. Full digitization allows the elements by which digital artefacts are made to be decomposed—expanding the notion of modularity adopted from the physical world—and enabling the re-shuffling and the reorganization of these elements not only into new configurations, but also into unrelated use contexts. For example, software can be developed by different teams that work in parallel once the architecture has been defined.

Granularity. Distinct from modularity, granularity refers to the “ingredients” from which blocks are made and describes the minute size and resilience of the elementary units or items by which a digital object is constituted. The granular constitution of digital artefacts is conveyed by the difference between their physical counterparts, which are non-granular blocks or elements bundled together in such a way that they are not readily decomposable or traceable as elementary units. In this vein, although modularity concerns relationships between blocks, granularity entails tracing composite units back to the most minute elements and operations of which they are made.

Re-programmability. Full digitization allows a digital artefact to be released from its immediate use context by modifying its structure and repurposing it through a later binding of form and function. The re-programmability attribute builds on the von Neumann computing architecture in terms of enabling the separation of the semiotic functional logic of the digital artefact from the physical embodiment that executes it, thus allowing a digital artefact to perform a wide array of functions (such as calculation, communications, word processing, encryption, browsing, and so on). In contrast to manufacturing capability, the primary cost of digital development is limited to the hours of development thanks to the re-programmability characteristics of digital artefacts.

Homogeneity. Full digitization allows any analog signal to be mapped to a set of binary numbers (discrete representation of data in bits of 0 and 1), thereby allowing any digital artefact to be stored, transmitted, processed, and displayed using the same digital devices and networks, e.g., location streaming services can be mixed with other services and content. Thus, the homogenization of data and the emergence of new media essentially separate the content from the medium. The homogenization of digital data at the service layer allows the emergence of new products and services through mashups across different product architectural boundaries. Therefore, devices, networks, services, and contents created for specific purposes are now being re-mixed to repurpose their usage.

Traceability. Full digitization allows events and entities to be chronologically interrelated over time and space, thus leaving an unprecedented volume of digital traces as by-products which, in turn, can lead to new innovations that had not been anticipated by the original innovators or consumers, e.g., integrating and analyzing data from jogging exercises and using them to create personalized training plans. Such derivative innovations add new layers of affordances to the digital products and services. Indeed, the bulk of innovations in social and mobile media results from the generative use of their digital traces, now reflected in the popular idea of "Big Data."

Interoperability. Full digitization enables data to be shared amongst different digital artefact formats by enabling their manipulation and expanding their accessibility over devices and platforms, e.g., the Nest self-learning thermostat that was designed with an application-programming interface that allows it to exchange information with other products, such as a smart lock. Whenever a homeowner enters his/her house, the smart lock communicates this information to the Nest thermostat, which then adjusts the temperature according to the homeowner's preferences.

Speed**.** Full digitization enables the instant transmission of real-time data across a wide range of networks that generate, transform, and connect products and sensors by increasing speed and responsiveness and reducing latency. 5G is currently (2022) in the process of rollout with 6G under development, and they will enable a great improvement in bandwidth and latency that is predicted to lead to the emergence of new "Internet of Things" business models that will involve massive quantities of data and/or mission-critical processing. Self-driving cars and healthcare services will be amongst the beneficiaries, but wireless protocols will also pose a competitive challenge to fixed wireline services, which have historically been a cash cow for telecommunications companies.

Synchronization**.** Full digitization also enables synchronization, that is, synchronous communications between different data sources stored in different electronic memories at different "clock speeds." For instance, the "clock speed" of software development is generally much faster than that of traditional manufacturing; a software development team might create as many as ten iterations of an application in the time it takes to generate a single new version of the hardware on which it runs. Therefore, companies will need to synchronize these very different clock speeds of hardware and software development and will have to rethink many aspects of organizational structure, policies, and design principles.

Accessibility / Transferability**.** Full digitization enables homogeneous and heterogeneous digital artefacts to be found and accessed through standardized protocols (such as an IP address and metadata), thereby enabling them to be enrolled in the global information infrastructure, the Internet. In this vein, connectivity also allows transferability by conveying changes in one part of the system to other parts of the system, or by distributing them to other system processes or objects.

Ubiquity. Finally, with its relatively inexpensive and ubiquitous connectivity, full digitization allows the types of information and knowledge that were not readily available in the past to be stored, mobilized, and interpreted anywhere, e.g., from a robot to a mechanical press, the performance of an industrial machine can be remotely monitored and adjusted by the end-users during operation. This offers users the unprecedented ability to customize the function, performance, and interface of products, and to operate them in hard-to-reach environments.

In isolation, and when combined with each other, these properties of digital artefacts make digital artefacts less subject to the constraints of the physical world, i.e., less subject to the constraints of "gravity."[2]

2.2 Smartification and Digital Twins: The emulation at scale of physical reality

According to Porter and Heppelmann (2014), smartification requires three core elements: (1) physical components comprising the product's mechanical and electrical parts; (2) sensors, microprocessors, data storage, controls, software, and, typically, an embedded operating system and enhanced user interface that amplify the capabilities and value of the physical components; and (3) connectivity components that amplify the capabilities and value of the smart components and enable some of them to exist outside the physical product itself.

Digital twins take smartification to the next level. They are adaptive models that emulate the behavior of a physical system in a virtual system exploiting real-time data to update itself along its lifecycle (Semeraro et al. 2021; Tao et al. 2018). In the commercial world, different variations of the term have emerged to highlight some specific aspects of this emulation (see below), and these include: "digital model," "product avatar," and "digital shadow." These different digital twins differ mostly in the level of data integration between the physical and digital counterpart (Krtzinger et al. 2018).

Smartification and Digital Twins are two examples of digitalization technologies that build on *emulation* of physical reality to create digital copies of it. Emulation seeks to duplicate an object exactly as it exists in physical reality. For instance, Alemdar and Ersoy (2010) and Porter and Heppelmann (2014, 2015) define emulation as the (complete) imitation of a physical object through sensors, computing, and networking technologies that allow the physical object to provide information about its environment, context, and behavior, thus enabling it to operate

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[2] Obviously, this is a metaphor and we are not referring to gravity in the sense of physics (exertion of force based on the mass of an object).

not only in the real world but also in a digital environment.

The performance of digital emulation depends not only on the accuracy of the emulation logics but also on the level of data synchronization. Tao et al. (2018) identified three key technical properties that might have an impact on data synchronization:

1) Real-time reflection: Two spaces exist in digital twins, physical space and virtual space. The virtual space is the real reflection of the physical space, and it can keep ultra-high synchronization and fidelity with the physical space.
2) Interaction and convergence in physical space, between historical data and real-time data, and between physical space and virtual space.
3) Self-evolution: Digital twins can update data in real time, so that virtual models can undergo continuous improvement through comparing virtual space with physical space in parallel.

The most recent advances in emulation have been based on the use of artificial intelligence. Smartification, Digital Twins and, more broadly, digital emulation overcome some of the constraints of the physical world by complementing the physical object with digital copies that acquire the properties of digitized artefacts. As such, emulation has the potential to decrease optimization costs in numerous ways, many of which were not previously possible (Porter and Heppelmann, 2014). For example, through emulation, algorithms and analysis can be applied to in-use or historical data to improve production, utilization, and efficiency. In wind turbines, for example, a sensor can adjust each blade at each revolution to capture maximum wind energy. And each turbine can be adjusted not only to improve its performance, but also to minimize its impact on the efficiency of neighboring ones.

2.3 Virtual reality: Creating virtual worlds

Virtual reality occurs when digital representations stand for, and in some cases completely substitute for, the physical objects, processes, or people they represent. For instance, Lyytinen

(2021) defines “virtual embedding” as the agreed virtual representations of real-world phenomena such as an organization’s assets, actors, entities in physical environments, and immaterial “objects” (e.g., money, equity). Virtualization enables spatial separation and independence between people and objects (or other people) through three core elements (Bailey et al. 2012): operating with or on representations; operating through representations; and operating within representations. According to Baskerville et al. (2020), virtualization results from pre-formatted, automated, and contingent, “live actions” performed by software. Virtual reality is often associated with *simulation*. Simulation is the use of a mathematical or computer-based representation of a physical system for the purpose of studying constrained effects or how physical systems work. Crucially, it seeks to simulate some aspects of the physical systems but does not necessarily represent all the aspects or follow all the rules of the real environment. According to Bailey et al. (2012), simulation is important because it is through simulation that virtuality comes closest to replacing reality.

Referring to virtual reality, Baskerville et al. (2020) introduce the concept of “ontological reversal,” in which the digital version is created first, and the physical version second (if needed)—e.g., 3-D printing. With ontological reversal, non-physical digital objects are not only as real as physical objects; they are more “real.” It used to be that the sale of a ticket (plane, train, concert, event) produced a physical ticket and a digital record of the transaction was stored in the company's information system as proof of the transaction. Today, physical tickets are no longer produced. Real tickets exist in the cloud. When a user needs physical proof of the real (non-physical) ticket, they can reproduce a physical copy of the non-physical item. The ontology of physical and digital has been reversed. With the ontological inversion, there is a temporal inversion in the way products are produced. The digital version is produced first, the physical version is produced when and where it makes sense (cf. Nambisan et al. 2020; Baskerville, 2020;).

2.4 Augmented reality and metaverse: Toward digitalizing the biological and sensory spheres

Porter and Heppelmann (2017) define Augmented Reality (AR) as the process of transforming volumes of data and analytics into images or animations that are superimposed on the real world. The real-time use of information in the form of text, graphics, audio, and other virtual enhancements integrated with real-world objects is the element that differentiates AR from virtual reality. AR integrates and adds value to the user's interaction with the real world and does not simulate an interaction with the physical world as in virtual reality. The author Neal Stephenson succinctly summarizes such differences: "the purpose of VR is to take [people] to a completely made-up place, and the purpose of AR is to change your experience of the place that you're in" (Robinson, 2017). By overlaying digital information directly on real objects or environments, AR allows people to process the physical and digital simultaneously, eliminating the need to mentally bridge the two. That improves people's ability to rapidly and accurately absorb information, make decisions, and execute required tasks quickly and efficiently. AR also improves how users visualize and therefore access new monitoring data, how they receive and follow instructions and guidance on product operations, and even how they interact with and control the products themselves. According to Rasool et al. (2021), two key properties of AR are vividness and interactivity. Factors of vividness are sensory breadth and sensory depth. Sensory breadth is the number of sensory dimensions, and sensory depth is the resolution of each channel. How these sensory inputs come together, i.e., how they are mediated, creates the sense of vividness. Interactivity has to do with how the user can map and make their actions into the mediated environment persistent.

Metaverse takes Augmented and Virtual Reality to the next level. Metaverse is a term created by Neal Stephenson in the 1992 novel *Snow Crash*. In the book, the protagonist Hiro enters a virtual reality called the metaverse as an escape from his physical reality living in a run-down container. Perhaps one of the first iterations of the metaverse was Second Life (2003). However, the concept of the metaverse began to take hold in 2020, when several platforms (including Facebook, which changed its name to Meta in 2021) imagined their own versions of the metaverse. The metaverse represents an evolution of social connection, an “embodied Internet,” where the user is no longer a spectator but becomes an integral part of the experience of connection, communication, and transaction (Balis, 2022). According to Meta, the 3D spaces of the metaverse will allow users to socialize, learn, collaborate, work, play, shop, create, find communities, and grow their business through avatars that actually inhabit the virtual space having a real “feeling of presence” (Meta Connect Conference, 2021). Balis (2022) points out that the immersive environment of the metaverse is an opportunity for consumer companies as well as industrial ones. For example, Nvidia is investing in forms of metaverse related to manufacturing and logistics to reduce waste and accelerate better business solutions. Microsoft is positioning its cloud services to engage forms of the metaverse where avatars and immersive spaces can infiltrate collaboration environments such as Teams. Nike and Louis Vuitton are investing in the most assertive part of the metaverse by investing in both building virtual retail environments for selling their physical products and creating virtual products and collectibles (e.g., virtual sneakers in NFTs) for the metaverse.

Some technologies underpinning the metaverse, such as ubiquitous and mobile supercomputing, neurotechnological brain enhancements, and genetic editing, seek to extend beyond physical reality by integrating the biological sphere and undoing the gravity that currently distinguishes the physical from the digital world. The digitalization of the “feeling of presence” promises to bring the digitalization of the physical world to the next stage in terms of affordances.

2.5 A taxonomy of outcomes of the digitalization of the physical world

Beyond the proliferation of technologies and commercial jargon, the review above allows us to highlight that the digitalization of the physical world, overall, has multiple potential outcomes. On one hand, in limited cases, digitalization can lead to full substitution of physical reality. On the other hand, digitalization can lead to outcomes where there is a degree of complementarity between the digital artefact and physical reality. Such degree of complementarity is mediated by the logics underpinning the digital artefacts: emulation; simulation; or “feeling presence”—and by the level of digital / physical (data) synchronization. In Figure 2, we show a taxonomy of potential outcomes of the digitalization of the physical world.

[Figure 2 about here]

3 Interactions among units of digitalized physical reality

As shown in Figure 2, the digitalization of physical objects may span full digitization to partial digitization, in other words, a physical “unit” (or “component” or “object”) can be fully replaced by a digital one at one extreme, or the physical unit could be partially replaced by a digital artefact that complements the physical one. We call this *substituting* for physical reality or *complementing* physical reality and can take the form, as mentioned above, of *emulation*, where one attempts to mimic the behavior and properties of a physical system; *simulation*, where one creates a digital reality independent of physical reality; or *feeling of presence*, where simulation is connected to some elements of physical reality.

However, the digitalization of the physical world does not happen one physical component at a time nor is any one component typically fully independent of other ones. Thus, what happens when the different elements represented in our taxonomy interact with one another? What are the outcomes of these interactions? While our taxonomy in Figure 2 provides guidelines as to what should be considered when exploring the outcomes of digitalization in isolation, we claim that we also need a framework to explore their complex interactions. Complexity theory provides a suitable way to help think through interactions or interdependencies.

There are many ways of thinking about complexity, but most if not all of them refer directly or indirectly to whatever phenomenon under consideration as a *system* (cf. Forrester, 1961), where the units or components have greater or lesser degrees of interdependencies between them. In other words, when something changes in one component of a system, to what degree does that change the other parts of the system? This varies considerably with the kind of system under consideration, from mechanical systems to biological systems to social systems (Massa et al. 2018). Of course, there is variance within these different kinds of systems (one single cell is much less complex than a human being, but both are more complex than, say, a table). In general, the more we move from a simpler system to a more complex one, the less the mere representation of the elements (components) of the system is sufficient to provide a complete picture to understand the whole system.

NK modelling (cf. Kauffman, 1993) has often been employed to describe different levels of complexity. Originally developed to understand the "fitness" of biological systems, *N* refers to the number of attributes or components, and *K* the interdependencies between components. If we start with mechanical systems, these can be broken down, from least complex to most complex (see Massa et al. 2018 for more detail), into static mechanical systems with no retroactivity; mechanical systems with predetermined dynamics; and mechanical systems with control mechanisms. It is at this last level of complexity where interdependencies are more pronounced and *feedback loops* develop (for example, different devices on an airplane that regulate the behavior of the aircraft). At a higher level of complexity, we move to biological systems with self-maintaining dynamics such as autopoiesis and many more interacting feedback loops. And finally, when we arrive at social systems, the number of feedback loops and interdependencies between the components, themselves biological systems, becomes even more pronounced and difficult to predict (Anderson, 1999; Massa et al. 2018).

Thus, a focus on the number and type of interdependencies is the key tenet of complexity theory and some related management streams (e.g., Siggelkow and Terwiesch, 2019; Adner, Puranam and Zhu 2019; Massa et al. 2018; Anderson, 1999). We claim that the concepts developed in complexity theory offers suitable lens to study the interdependencies between the different outcomes of digitalization. For instance, complexity theory highlights the need to consider the role of *different types of feedback loops* and *to what degree the system is constrained by physical* components. In Figure 3, building on these concepts we show how different interactions may lead to different types of convergence (Yoffie, 1996) between physical and digital reality.

[Figure 3 about here]

Figure 3 shows how a fully digital artefact interacts with a system in which some or all of the other units or components are fully-, partially-, or un-digitized. In the first column (I), when the component is fully digital and the rest of the system is, too, we would characterize the situation as being subject to a continuous, synchronous, and autonomous feedback loop, since there would not be human intervention or the necessity of waiting for a mechanical system to complete a task. We would say that the physical world does not exert “gravity” toward the digital world in this situation. Examples of this situation could be a “smart contract” that is executed automatically in the future when certain conditions are met, or autonomous drone inspection leading to automatic insurance payouts. In terms of outcomes, we might call this column “autonomous realities” (imagine virtual reality not mediated through humans) in which new fully digital logics emerge and the feedback loops are self-reinforcing or self-correcting. Of course, one challenge in this column is the self-reinforced amplification of unintended consequences.

Column II shows the situation in which the focal artefact has been fully digitalized, but the rest of the system is only partially digitalized. Depending on the degree of human or mechanical intervention and the degree to which the digital components act as a complement to the physical ones, we would say that the physical elements of this system exert gravity on the digital ones. The feedback loops could still be continuous, but would not be fully synchronous, since automation would be more difficult, especially if people or batch-processing machines bottleneck decision-making and reactions. Examples of this particular situation might be digital twins, where outputs of sensors on a real piece of equipment is fed into a simulation to track the current state and predict future states. In the case of future predicted problems, an intervention (e.g., replacing a physical component) is then done in real life. In this case, we are concerned with the "dual clock" speeds of the digital vs the physical, for example if problems were identified using a digital twin but the intervention was not done for some time. Thus, we speak of the asynchronous nature of the different processes.

Finally, Column III demonstrates the case of a fully digitalized component in a system where the rest of the components are entirely physical. Here we would say that "gravity" would constrain the digital element to a greater degree and feedback loops would be non-existent or very slow. An example would be a digital music player, e.g., the Apple iPod, that offers a one-way flow of information for storage of digitalized data. Fans can listen to their preferred music, but they cannot interact with it. This applies equally to Web 1.0 applications. In this case, we would argue that there would be no convergence between the digital and physical world, or at least it would be extremely slow, thus our characterizing the clock speed as "divergent at scale" with a “decoupling” of the digital element from the physical one(s).

4 Incorporating digitalization into management research

In this Chapter, we have argued that management research exploring the implications of digitalization should incorporate a more nuanced and systematic definition of digitalization. Digitalization is a multi-dimensional construct. For instance, the digitalization of physical reality may be based on logics ranging from emulation to simulation and may lead to very different outcomes, e.g., the digitalization of physical reality might result in full substitution of physical reality and / or in the complementarity between units of physical reality and related digital artefacts. Furthermore, interactions among digitalized units of physical reality generate feedback loops that lead to new—or even new and autonomous—forms of physical / digital convergence. Building on a systematic literature review, we have developed a taxonomy to classify the different forms of digitalization of units of physical reality (Figure 2), highlighted the affordances of such digitalized units, and developed a further taxonomy to classify outcomes when these units interact with one another (Figure 3).

Extant (strategic) management research has mostly focused on the strategic and organizational implications of “using” digitalization (e.g., Adner et al. 2019; Berente, 2020; Nambisan et al. 2020; Hanelt et al. 2021). We have argued here that a more nuanced characterization of digitalization will help to reveal what goes on below the surface and that, as such, should lead to more precise boundary conditions as well as to more clearly surfacing the mechanisms through which digitalization enacts its “affordances” and contributes to the co-creation of new organizational realities. For instance, our taxonomy might inform research seeking to reveal the seemingly unlimited generativity of digitalization (Yoo, et al. 2010; Zittrain, 2008; Yoo, 2012; Dattée et al. 2018; Cennamo and Santaló, 2019; Perreira et al. 2022) and provide indications on evolutionary trajectories; provide more nuance to the understanding of how social and technical elements jointly evolve in socio-technical systems (Tilson et al. 2010); inform strategy research on the capabilities, organizations, and management needed to leverage digitalization (e.g., Cennamo and Santaló, 2019; Lanzolla, et al. 2021); and help the logics that could lead to business model innovation (cf. Massa and Tucci, 2004; Bohnsack et al. 2021) be more specific. To put it in more general terms, our taxonomies might help to more systematically understand how new forms of business realities are emerging and provide a framework to compare and contrast the rich digitalization research that is emerging. Crucially—and by implication—our taxonomies might also prove useful to provide input in designing digitalization technologies and digitalization governance systems that keep “humans in control” (United Nations, 2020) over digitalized reality, which we strongly believe is a core, and unnegotiable, ethical imperative.

References

Adner, R. 2017. Ecosystem as structure: An actionable construct for strategy. Journal of Management, 43, 39–58.

Adner, R., P. Puranam, & F. Zhu. 2019. What is different about digital strategy? From quantitative to qualitative change. Strategy Science, 4(4): 253–61.

Afuah, A., & C.L. Tucci. 2012. Crowdsourcing as a solution to distant search. Academy of Management Review, 37(3): 355–75.

Alemdar, H., & Ersoy, C. 2010. Wireless sensor networks for healthcare: A survey. Computer Networks, 54(15), 2688–2710.

Andersen, P.H. 2006. Regional clusters in a global world: Production relocation, innovation, and industrial decline. California Management Review, 49(1): 101–22.

Anderson, P. 1999. Complexity Theory and Organization Science. Organization Science, 10(3), 216–232.

Angwin, D., & Vaara, E. 2005. Introduction to the special issue. "Connectivity" in merging organizations: Beyond traditional cultural perspectives. Organization Studies, 26(10): 1445–53.

Bahrami, H., & Evans, S. 2011. Super-flexibility for real-time adaptation: Perspectives from Silicon Valley. California Management Review, 53(3): 21–39.

Bailey, D.E., Leonardi, P.M., & Barley S.R. 2012. The lure of the virtual. Organization Science, 23(5): 1485–504.

Bailey, D.E., Leonardi, P.M., & Chong, J. 2010. Minding the gaps: Understanding technology interdependence and coordination in knowledge work. Organization Science, 21(3): 713–30.

Bailey, D.E., Faraj, S., Hinds, P., von Krogh, G. & Leonardi, P.M. 2019. Special Issue of Organization Science: Emerging Technologies and Organizing. Organization Science, 30(3), 642-646.

Baldwin, C.Y. 2007. Where do transactions come from? Modularity, transactions, and the boundaries of firms. Industrial and Corporate Change, 17(1): 155–95.

Baldwin, C.Y., & Woodard, C.J.J. 2009. The architecture of platforms: A unified view. In Platforms, markets and innovation, ed. A. Gawer, 19–44. Cheltenham, UK and Northampton, MA: Edward Elgar.

Baldwin, C.Y., & Clark, K.B. 2000. Design rules, Vol.1: The power of modularity. Cambridge, MA: MIT Press.

Balis, J. 2022. How Brands Can Enter the Metaverse. Harvard Business Review. Accessed December 15, 2021, https://hbr.org/2022/01/how-brands-can-enter-the-metaverse

Bardhi, F., & Eckhardt, G.M. 2017. Liquid consumption. Journal of Consumer Research, 44(3): 582–97.

Barrett, M., Davidson, E. & Vargo, S.L. 2015. Service innovation in the digital age: key contributions and future directions. MIS Quarterly, 39(1): 135–54.

Baskerville R.L., Myers M.D., Yoo Y. 2020. Digital First: The Ontological Reversal and New Challenges for Information Systems Research. MIS Quarterly, 44(2): 509-523.

Benkler, Y. 2006. The wealth of networks: How social production transforms markets and freedom. The Wealth of Networks: How Social Production Transforms Markets and Freedom. Yale University Press.

Berente, N., 2020. Agile development as the root metaphor for strategy in digital innovation. In: Nambisan, S., Lyytinen, K., Yoo, Y. (Eds.), Handbook of Digital Innovation. Edward Elgar Publishing, Cheltenham, UK, Northampton, MA, 83–96.

Berente, N., Srinivasan, N., Yoo, Y., Boland, R.J., & Lyytinen, K. 2007. Binate diversity and the rolling edge of design networks. In 28th International Conference on Information Systems. Atlanta.

Bharadwaj, A., El Sawy, O.A., Pavlou, P.A., & Venkatraman, N.V. 2013. Digital business strategy: toward a next generation of insights. MIS Quarterly, 37(2): 471–82.

Bohnsack, R., Kurtz, H., & Hanelt, A. 2021. Re-examining path dependence in the digital age: The evolution of connected car business models. Research Policy, 50(9), 104328.

Boland, R.J., Lyytinen, K., & Yoo, Y. 2007. Wakes of innovation in project networks: The case of digital 3-d representations in architecture, engineering, and construction. Organization Science, 18(4): 631–47.

Bose, R., & Luo, X. 2011. Integrative framework for assessing firms’ potential to undertake Green IT initiatives via virtualization - A theoretical perspective. Journal of Strategic Information Systems, 20(1): 38–54.

Breschi, S., & Catalini, C. 2010. Tracing the links between science and technology: An exploratory analysis of scientists’ and inventors’ networks. Research Policy, 39(1): 14–26.

Bresnahan, T.F., & Trajtenberg, M. 1995. General purpose technologies ‘Engines of growth’?. Journal of Econometrics, 65(1), 83-108.

Brynjolfsson, E., Hu, Y. & Rahman, M. 2013. Competing in the age of omnichannel retailing. MIT Sloan Management Review, 54, 23–9.

Cano-Kollmann, M., Cantwell, J., Hannigan, T.J., Mudambi, R. & Song, J. 2016. Knowledge connectivity: An agenda for innovation research in international business. Journal of International Business Studies, 47(3): 255–62.

Caridi-Zahavi, O., Carmeli, A., & Arazy, O. 2016. The Influence of CEOs’ visionary innovation leadership on the performance of high-technology ventures: The mediating roles of connectivity and knowledge integration. Journal of Product Innovation Management, 33(3): 356–76.

Cennamo, C., & Santaló, J. 2019. Generativity Tension and Value Creation in Platform Ecosystems. Organization Science, 30(3), 617–641.

Chatterjee, D.D., Segars, A.H., & Watson, R.T. 2006. Realizing the promise of E-business: Developing and leveraging electronic partnering options. California Management Review, 48(4): 60–83.

Chester Goduscheit, R., & Faullant, R. 2018. Paths toward radical service innovation in manufacturing companies - a service-dominant logic perspective. Journal of Product Innovation Management, 35(5): 701–19.

Cross, R., Laseter, T., Parker, A., & Velasquez, G. 2006. Using social network analysis to improve communities of practice. California Management Review, 49(1): 32–60.

Dattée, B., Alexy, O., & Autio, E. 2018. Maneuvering in poor visibility: How firms play the ecosystem game when uncertainty is high. Academy of Management Journal, 61(2), 466-498.

Dhar, V., & Sundararajan,A. 2007. Information technologies in business: A blueprint for education and research. Information Systems Research, 18(2): 125–41.

Elberse, A. 2008. Should you invest in the Long Tail? Harvard Business Review, 86(7–8).

Fang, E. 2008. Customer participation and the trade-off between new product innovativeness and speed to market. Journal of Marketing, 72(4): 90–104.

Faulkner, P., & Runde, J. 2009. On the identity of technological objects and users innovation in functions. Academy of Management Review, 34(3): 442–62.

Faulkner, P., & Runde, J. 2011. The social, the material, and the ontology of non-material technological objects. In 27th European Group for Organizational Studies Colloquium. Gothenburg.

Fichman, R. G., Dos Santos, B.L., & Zheng, Z. (Eric). 2014. Digital Innovation as a Fundamental and Powerful Concept in the Information Systems Curriculum. MIS Quarterly, 38(2): 329–43.

Fleming, L., & Sorenson, O. 2004. Science as a Map in Technological Search. Strategic Management Journal, 25(8-9): 909–28.

Forman, C., & van Zeebroeck, N. 2019. Digital technology adoption and knowledge flows within firms: Can the Internet overcome geographic and technological distance? Research Policy, 48(8): 103697.

Forrester, J.W. 1961. Industrial Dynamics. MIT Press.

Gambardella, A., & McGahan, A.M. 2010. Business-model innovation: General purpose technologies and their implications for industry structure. Long Range Planning, 43: 262–271.

Garud, R., Jain, S. & Tuertscher, P. 2008. Incomplete by Design and Designing for Incompleteness. Organization Studies, 29(3): 351–71.

Gosain, S., Malhotra, A. & El Sawy, O.A. 2004. Coordinating for flexibility in e-business supply chains. Journal of Management Information Systems, 21(3): 7–45.

Grover, V., & Kohli, R. 2013. Revealing your hand: Caveats in implementing digital business strategy. MIS Quarterly, 37(2): 655–62.

Hanelt, A., Bohnsack, R., Marz, D., & Antunes Marante, C. 2021. A systematic review of the literature on digital transformation: Insights and implications for strategy and organizational change. Journal of Management Studies, 58(5), 1159-1197.

Henfridsson, O., Mathiassen, L., & Svahn, F. 2014. Managing technological change in the digital age: the role of architectural frames. Journal of Information Technology, 29(1): 27–43.

Iansiti, M., & Lakhani, K.R. 2014. Digital ubiquity: How connections, sensors, and data are revolutionizing business. Harvard Business Review, 92(11): 90–9.

Jacobides, M.G., Cennamo, C. & Gawer, A. 2018. ‘Towards a theory of ecosystems’. Strategic Management Journal, 39, 2255–76.

Jarzabkowski, P. & Kaplan, S., 2015. Strategy tools-in-use: A framework for understanding "technologies of rationality" in practice. Strategic Management Journal, 36(4), 537-558.

Kallinikos, J. 2009. On the computational rendition of reality: Artefacts and human agency. Organization, 16(2): 183–202.

Kallinikos, J., Aaltonen, A., & Marton, A. 2010. A theory of digital objects. First Monday, 15(6): 1-22.

Kallinikos, J., Aaltonen, A., & Marton, A. 2013. The ambivalent ontology of digital artefacts. MIS Quarterly, 37(2): 357–70.

Kallinikos, J., & Mariátegui, J.C. 2011. Video as digital object: Production and distribution of video content in the internet media ecosystem. Information Society, 27(5): 281–94.

Kambil, A., & Van Heck, E. 1998. Reengineering the Dutch Flower Auctions: A Framework for Analyzing Exchange Organizations. Information Systems Research, 9(1): 1–19.

Kane, G.C., & Alavi, M. 2007. Information Technology and Organizational Learning: An Investigation of Exploration and Exploitation Processes. Organization Science, 18(5): 796–812.

Kaschig, A., Maier, R. & Sandow, A. 2016. The effects of collecting and connecting activities on knowledge creation in organizations. Journal of Strategic Information Systems, 25(4): 243–58.

Kauffman, S.A., 1993. The origins of order: Self-organization and selection in evolution. Oxford University Press, USA.

Kim, S., & Anand, J. 2018. Knowledge complexity and the performance of inter-unit knowledge replication structures. Strategic Management Journal, 39(7): 1959–89.

Kolb, D.G. 2008. Exploring the metaphor of connectivity: Attributes, dimensions and duality. Organization Studies, 29(1): 127–44.

Kolb, D.G., Caza, A., & Collins, P.D. 2012. States of Connectivity: New Questions and New Directions. Organization Studies, 33(2): 267–73.

Kretschmer, T. & Khashabi, P., 2020. Digital transformation and organization design: An integrated approach. California Management Review, 62(4): 86-104

Kritzinger, W., Karner, M., Traar, G., Henjes, J., & Sihn, W. 2018. Digital Twin in manufacturing: A categorical literature review and classification. IFAC-PapersOnLine, 51(11), 1016-1022.

Krogh, G. von, Haefliger, S., Spaeth, S., & Wallin, M.W. 2012. Carrots and rainbows: Motivation and social practice in open source software development. MIS Quarterly, 36(2): 649–676.

Langlois, R.N. 2002. Modularity in technology and organization. Journal of Economic Behavior & Organization, 49(1): 19–37.

Lanzolla, G., & Markides, C. 2021. A business model view of strategy. Journal of Management Studies, 58(2): 540-553.

Lanzolla, G., Pesce, D., & Tucci, C. L. 2021. The digital transformation of search and recombination in the innovation function: Tensions and an integrative framework. Journal of Product Innovation Management, 38(1), 90-113.

Lazer, D., & Friedman, A. 2007. The network structure of exploration and exploitation. Administrative Science Quarterly, 52(4): 667–94.

Lee, J., & Berente, N. 2012. Digital Innovation and the Division of Innovative Labor: Digital Controls in the Automotive Industry. Organization Science, 23(5): 1428–47.

Leonardi, P.M., & Bailey, D.E. 2008. Transformational technologies and the creation of new work practices: Making implicit knowledge explicit in task-based offshoring. MIS Quarterly, 32(2): 411–36.

Leone, M.I., & Reichstein, T. 2012. Licensing-in fosters rapid invention! The effect of the grant-back clause and technological unfamiliarity. Strategic Management Journal, 33(8): 965–85.

Lycett, M. 2013. "Datafication": Making sense of (big) data in a complex world. European Journal of Information Systems, 22(4): 381–6.

Lyytinen, K. 2021. Innovation logics in the digital era: A systemic review of the emerging digital innovation regime. Innovation, 1-22.

Lyytinen, K., & Yoo, Y. 2002. Research commentary: the next wave of nomadic computing. Information Systems Research, 13(4): 377–88.

Lyytinen, K., Nambisan, S., Yoo, Y., 2020. A Transdisciplinary Research Agenda for Digital Innovation: Key Themes and Directions for Future Research. In: Nambisan, S., Lyytinen, K., Yoo, Y. (Eds.), Handbook of Digital Innovation. Edward Elgar Publishing, Cheltenham, UK, Northampton, MA, 279–286.

Lyytinen, K., Sørensen, C., & Tilson, D. 2018. Generativity in digital infrastructures: A research note. In D. Galliers & K. Stein (Eds.), The Routledge companion to management information systems New York: Routledge, 253–275).

Lyytinen, K., Yoo, Y., & Boland, R.J. 2016. Digital product innovation within four classes of innovation networks. Information Systems Journal, 26(1): 47–75.

Mabey, C., & Zhao, S. 2017. Managing five paradoxes of knowledge exchange in networked organizations: new priorities for HRM? Human Resource Management Journal, 27(1): 39–57.

Majchrzak, A., & Malhotra, A. 2013. Towards an information systems perspective and research agenda on crowdsourcing for innovation. The Journal of Strategic Information Systems, 22(4): 257–68.

Majchrzak, A., Griffith, T.L., 2020. The New Wave of Digital Innovation: The Need for A Theory of Sociotechnical Self-Orchestration. In: Nambisan, S., Lyytinen, K., Yoo, Y. (Eds.), Handbook of Digital Innovation. Edward Elgar Publishing, Cheltenham, UK, Northampton, MA, 17–40.

Majchrzak, A., Markus, M.L., Wareham, J., Lynne Markus, M., & Wareham, J. 2016. Designing for Digital Transformation: Lessons for Information Systems Research from the Study of ICT and Societal Challenges. MIS Quarterly, 40(2): 267–77.

Manovich, L. 2001. The language of new media. Cambridge, MA: MIT Press.

March, S., Hevner, A., & Ram, S. 2000. Research commentary: An agenda for information technology research in heterogeneous and distributed environments. Information Systems Research, 11(4): 327–41.

Mardon, R., & Belk, R. 2018. Materializing digital collecting: An extended view of digital materiality. Marketing Theory, 18(4): 543–70.

Massa, L., & Tucci, C.L.. 2014. Business model innovation. In M. Dodgson, D. Gann, N.

Phillips (Eds.), The Oxford Handbook of Innovation Management. New York: Oxford, 420-441.

Massa, L., Viscusi, G., & Tucci, C.L. 2018. Business models and complexity. Journal of Business Models, 6(1), 59-71.

Massa, L., Tucci, C.L. & Afuah, A., 2017. A critical assessment of business model research. Academy of Management Annals, 11(1), 73-104.

Matusik, S.F., & Mickel A.E.. 2011. Embracing or embattled by converged mobile devices? users' experiences with a contemporary connectivity technology. Human Relations, 64(8): 1001–30.

Mazmanian, M. 2013. Avoiding the trap of constant connectivity: When congruent frames allow for heterogeneous practices. Academy of Management Journal, 56(5): 1225–50.

Mazmanian, M., Orlikowski, W.J., & Yates, J. 2013. The autonomy paradox: The implications of mobile email devices for knowledge professionals. Organization Science, 24(5): 1337–57.

Meta Connect Conference. 2021. The Metaverse and How We'll Build It Together. Accessed December 15, 2021, https://www.facebookconnect.com/

Mousavi Baygi, R., Introna, L.D., Hultin, L., 2021. Everything Flows: Studying Continuous Sociotechnical Transformation in a Fluid and Dynamic Digital World. MIS Quarterly, 45(1), 423–452.

Nambisan, S., & Sawhney, M. 2007. A buyer's guide to the innovation bazaar. Harvard Business Review, 85(6): 109.

Nambisan, S., Lyytinen, K., & Yoo, Y. 2020. Digital innovation: towards a transdisciplinary perspective Handbook of digital innovation. In: Nambisan, S., Lyytinen, K., Yoo, Y. (Eds.), Handbook of Digital Innovation. Edward Elgar Publishing, Cheltenham, UK, Northampton, MA, 2-12.

Nambisan, S., Lyytinen, K., Majchrzak, A., Song, M. 2017. Digital Innovation Management: Reinventing Innovation Management Research in a Digital World. MIS Quarterly, 41(1), 223–238.

Ng, I.C.L., & Wakenshaw, S.Y.L. 2017. The Internet-of-Things: Review and research directions. International Journal of Research in Marketing, 34(1): 3–21.

Normann, R. 2001. Reframing business: When the map changes the landscape. Chichester: John Wiley & Sons.

Orlikowski, W.J., & Scott, S.V. 2016. The Algorithm and the Crowd: Considering the Materiality of Service Innovation. MIS Quarterly, 39(1): 201–16.

Orlikowski, W.J., & Scott, S.V. 2008. Sociomateriality: Challenging the Separation of Technology, Work and Organization. Academy of Management Annals, 2(1): 433–74.

Overby, E. 2008. Process virtualization theory and the impact of information technology. Organization Science, 19(2): 277–91.

Peppard, J. 2018. Rethinking the concept of the IS organization. Information Systems Journal, 28(1): 76–103.

Perreira, J., Viscusi, G., & Tucci, C.L. 2022. Crowd forms of organizing and generativity mechanisms. Working paper, Imperial College Business School.

Pil, F.K., & Cohen, S.K. 2006. Modularity: Implications for imitation, innovation, and sustained advantage. Academy of Management Review, 31(4): 995–1011.

Porter, M.E., & Heppelmann, J.E. 2017. Why every organization needs an augmented reality strategy. Harvard Business Review, 95(6): 46-57.

Porter, M.E., & Heppelmann, J.E. 2014. How smart, connected products are transforming competition. Harvard Business Review, 92(11): 64–89.

Porter, M.E., & Heppelmann, J.E. 2015. How smart, connected products are transforming companies. Harvard Business Review, 93(10): 53–71.

Rai, A., & Sambamurthy, V. 2006. Editorial notes-the growth of interest in services management: Opportunities for information systems scholars. Information Systems Research, 17(4): 327–31.

Rasool, J., Molka-Danielsen, J., & Smith, C.H. 2021. Transitioning from Transmedia to Transreality Storyboarding to Improve the Co-Creation of the Experience Space. In Proceedings of the 54th Hawaii International Conference on System Sciences (p. 648).

Sarker, S., Chatterjee, S., Xiao, X., Elbanna, A., 2019. The Sociotechnical Axis of Cohesion for the IS Discipline: Its Historical Legacy and its Continued Relevance. MIS Quarterly, 43(3), 695–719.

Schilling, M.A. 2000. Toward a general modular systems theory and its application to interfirm product modularity. Academy of Management Review, 25(2): 312–34.

Semeraro, C., Lezoche, M., Panetto, H., & Dassisti, M. 2021. Digital twin paradigm: A systematic literature review. Computers in Industry, 130, 103469.

Shapiro, C., & Varian, H.R. 1999. The art of standards wars. California Management Review, 41(2): 8–32.

Siggelkow, N., & Terwiesch, C. 2019. Connected strategy: Building continuous customer relationships for competitive advantage. Boston, MA: Harvard Business Press.

Siggelkow, N., & Rivkin, J.W. 2005. Speed and Search: Designing Organizations for Turbulence and Complexity. Organization Science, 16(2): 101–22.

Sørensen, C., & Landau, J.S. 2015. Academic agility in digital innovation research: The case of mobile ICT publications within information systems 2000-2014. Journal of Strategic Information Systems, 24(3): 158–70.

Robinson, J. 2017. The sci-fi guru who predicted google earth explains silicon valley's latest obsession. Accessed December 15, 2021, https://www.vanityfair.com/news/2017/06/neal-stephenson-metaverse-snow-crash-silicon-valley-virtual-reality

Svahn, F., & Henfridsson, O. 2012. The dual regimes of digital innovation management. In 45th Hawaii International Conference on System Sciences, 3347–56. Maui.

Tao, F., Cheng, J., Qi, Q., Zhang, M., Zhang, H., Fangyuan, S. 2018. Digital twin-driven product design, manufacturing and service with big data. The International Journal of Advanced Manufacturing Technology, 94(9-12), 3563-3576.

Teece, D.J. 2018. Profiting from innovation in the digital economy: Enabling technologies, standards, and licensing models in the wireless world. Research Policy, 47(8): 1367–87.

Teece, D.J., 2010. Business models, business strategy and innovation. Long Range Plann. 43, 172–194.

Tilson, D., Lyytinen, K., & Sorensen, C. 2010. Research Commentary--Digital Infrastructures: The Missing Is Research Agenda. Information Systems Research, 21(4): 748-759.

Tiwana, A. 2008. Does technological modularity substitute for control? A study of alliance performance in software outsourcing. Strategic Management Journal, 29(7): 769–80.

Tiwana, A., Konsynski, B., & Bush, A.A. 2010. Research Commentary: Platform Evolution: Coevolution of Platform Architecture, Governance, and Environmental Dynamics. Information Systems Research, 21(4): 675–87.

Trantopoulos, K., von Krogh, G., Wallin, M.W., & Woerter, M. 2017. External knowledge and information technology: Implications for process innovation performance. MIS Quarterly, 41(1): 287–300.

United Nations. 2020. UN75: Social Contract 2020 - Toward Safety, Security, & Sustainability for AI World. New York: United Nations.

Villarroel, J.A., Taylor, J.E. & Tucci, C.L., 2013. Innovation and learning performance implications of free revealing and knowledge brokering in competing communities: insights from the Netflix Prize challenge. Computational and Mathematical Organization Theory, 19(1): 42-77.

Wajcman, J., & Rose, E. 2011. Constant connectivity: Rethinking interruptions at work. Organization Studies, 32(7): 941–61.

Wang, P., 2021. Connecting the parts with the whole: Toward an information ecology theory of digital innovation ecosystems. MIS Quarterly, 45(1), 397–422.

Wired. 2021. The Metaverse is coming. Accessed December 15, 2021, https://www.wired.co.uk/article/metaverse

World Economic Forum. 2020. Digital Transformation: Powering the Great Reset.

Xue, L., Zhang, C., Ling, H., & Zhao, X. 2013. Risk mitigation in supply chain digitization: System modularity and information technology governance. Journal of Management Information Systems, 30(1): 325–52.

Yoffie, D.B., 1996. Competing in the age of digital convergence. California Management Review, 38(4): 31-53.

Yoo, Y. 2010. Computing in everyday life: A call for research on experiential computing. MIS Quarterly, 34(2): 213–31.

Yoo, Y. 2012. Digital materiality and the emergence of an evolutionary science of the artificial. In Materiality and Organizing: Social interaction in a technological world, ed. P. M. Leonardi, B. A. Nardi, & J. Kallinikos, 134–54. Oxford: Oxford University Press.

Yoo, Y., Boland, R.J., Lyytinen, K. & Majchrzak, A., 2012. Organizing for innovation in the digitized world. Organization Science, 23(5), 1398-1408.

Yoo, Y., Henfridsson, O., & Lyytinen, K. 2010. The new organizing logic of digital innovation: An agenda for information systems research. Information Systems Research, 21(4): 724–35.

Zhang, L. 2016. Intellectual property strategy and the Long Tail: Evidence from the recorded music industry. Management Science, 64(1): 24–42.

Zhang, Z., Yoo, Y., Wattal, S., Zhang, B., & Kulathinal, R. 2014. Generative diffusion of innovations and knowledge networks in open source projects. In Thirty Fifth International Conference on Information Systems. Auckland, New Zealand.

Zittrain, J. L. 2006. The generative Internet. Harvard Law Review, 119(7): 1974–2040.

Zittrain, J. L. 2008. The future of the Internet and how to stop it. New Haven, CT: Yale University Press.

Figures

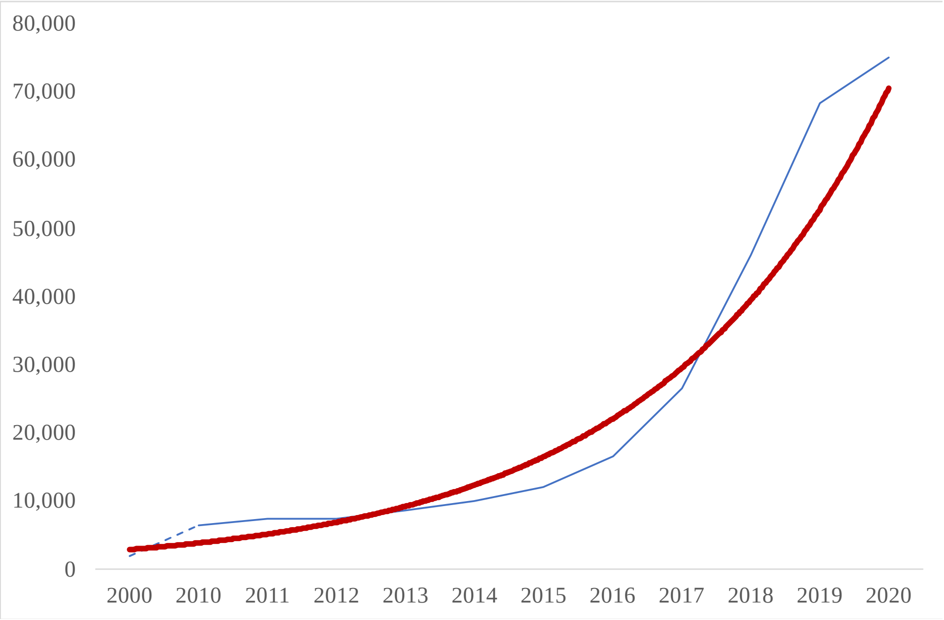

Figure 1 - Google Scholar results for "digitalization" or "digitalisation" over time

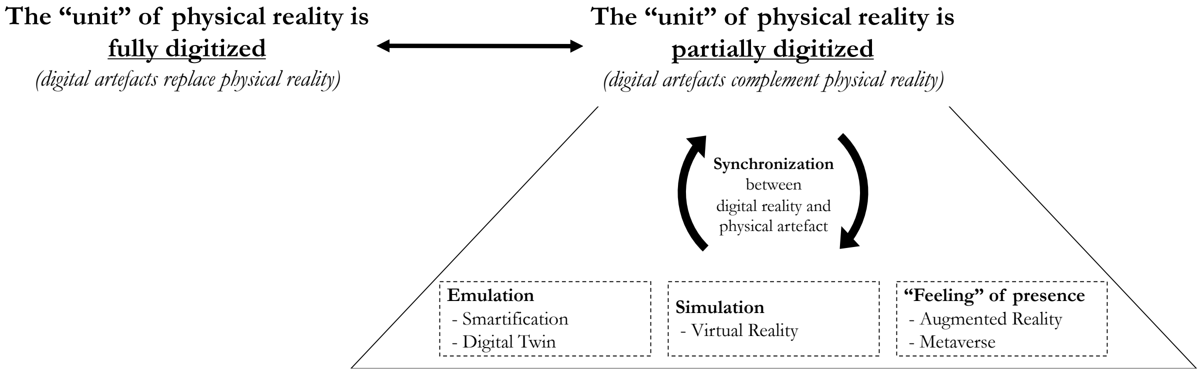

Figure 2 – Possible outcomes of digitalization of "units" of physical reality

	FULLY DIGITAL ARTEFACT	PARTIALLY DIGITAL ARTEFACT	PHYSICAL ARTEFACT
FULLY DIGITAL ARTEFACT	**I** Type of feedback loops among units: **Continuous, synchronous, and autonomous** **No gravity** Type of convergence: **DIGITAL CONVERGENCE** Potential outcomes: • **Autonomous realities** • **Emergence of new digital logics** • **Self-reinforcing loops**	**II** Type of feedback loops among units: **Continuous, yet not fully synchronous** **Gravity anchors** Type of convergence: **PHYGITAL CONVERGENCE** Potential outcomes: • **Dual clock-speed between digital and physical** • **Asynchronous**	**III** Type of feedback loops among units: **Unidirectional flow / no loops** **Gravity prevails** Type of convergence: **NO CONVERGENCE** Potential outcomes: • **Clock-speed between digital and physical diverging at scale** • **De-coupling**

Figure 3 - Outcomes of the interaction among units of digitalized physical reality

Appendix 1 – Properties of digital artefacts

Properties	**Exemplary References**
Editability	(Shapiro & Varian 1999; Zittrain 2006; Kane & Alavi 2007; Nambisan & Sawhney 2007; Garud et al. 2008; Zittrain 2008; Yoo 2010; Yoo et al. 2010; Kallinikos et al. 2013; Kaschig et al. 2016)
Replicability	(Elberse 2008; Kallinikos & Mariátegui 2011; Kallinikos et al. 2013; Zhang 2016; Ng & Wakenshaw 2017; Mardon & Belk 2018)
Modularity	(Baldwin & Clark 2000; Schilling 2000; Manovich 2001; Langlois 2002; Andersen 2006; Pil & Cohen 2006; Baldwin 2007; Dhar & Sundararajan 2007; Tiwana 2008; Zittrain 2008; Baldwin & Woodard 2009; Tiwana et al. 2010; Yoo et al. 2010; Bahrami & Evans 2011; Yoo 2012; Kallinikos et al. 2013; Xue et al. 2013; Nambisan et al. 2017)
Granularity	(Manovich 2001; Benkler 2006; Kallinikos 2009; Kallinikos et al. 2010; Tiwana et al. 2010; Yoo et al. 2010; Yoo 2012; Majchrzak & Malhotra 2013; Barrett et al. 2015; Chester et al. 2018) *Related constructs found in the literature:* **Decomposability**: (Yoo 2010; Yoo et al. 2010)
Re-programmability	(Kallinikos et al. 2010; Yoo 2010; Yoo et al. 2010; Faulkner & Runde 2009; 2011; Krogh et al. 2012; Lee & Berente 2012; Yoo et al. 2012; Yoo 2012; Kallinikos et al. 2013; Fichman et al. 2014; Henfridsson et al. 2014) *Related constructs found in the literature:* **Computation**: (Dhar & Sundararajan 2007; Kallinikos & Mariátegui 2011; Bailey et al. 2012)
Homogeneity	(Yoo et al. 2010; Yoo 2012; Yoo et al. 2012) *Related constructs found in the literature:* **Dematerialisation**: (Normann 2001; Lycett 2013)
Traceability	(Yoo 2010; Yoo et al. 2010; Kallinikos et al. 2013; Fichman et al. 2014; Lyytinen et al. 2016) *Related constructs found in the literature:* **Memorizability**: (Yoo 2010; Yoo et al. 2010)
Interoperability	(March et al. 2000; Bailey et al. 2010; Kallinikos et al. 2010; Yoo 2010; Yoo et al. 2010; Kallinikos & Mariátegui 2011; Yoo et al. 2012; Bharadwaj et al. 2013; Grover & Kohli 2013; Kallinikos et al. 2013; Porter & Heppelmann 2014; Porter & Heppelmann 2015; Majchrzak et al. 2016; Teece 2018)
Pervasiveness	(Lyytinen & Yoo 2002; Fleming & Sorenson 2004; Berente et al. 2007; Kolb 2008; Orlikowski & Scott 2008; Wajcman & Rose 2011; Afuah & Tucci 2012; Kolb et al. 2012; Yoo 2012; Yoo et al. 2012; Bharadwaj et al. 2013; Sørensen & Landau 2015; Mabey & Zhao 2017; Peppard 2018)
Speed	(Kambil & Van Heck 1998; Gosain et al. 2004; Siggelkow & Rivkin 2005; Lazer & Friedman 2007; Fang 2008; Leonardi & Bailey 2008; Leone & Reichstein 2012; Svahn & Henfridsson 2012; Yoo et al. 2012; Bharadwaj et al. 2013; Sørensen & Landau 2015; Caridi-Zahavi et al. 2016; Lyytinen et al. 2016; Teece 2018) *Related constructs found in the literature:* **Responsiveness**: (Matusik & Mickel 2011; Wajcman & Rose 2011; Mazmanian 2013; Mazmanian et al. 2013)

Synchronization	(Angwin & Vaara 2005; Chatterjee et al. 2006; Rai & Sambamurthy 2006; Overby 2008; Yoo et al. 2010; Yoo et al. 2010; Bose & Luo 2011; Wajcman & Rose 2011; Porter & Heppelmann 2014; Porter & Heppelmann 2015)
Accessibility	(Zittrain 2006; Boland et al. 2007; Overby 2008; Zittrain 2008; Yoo 2010; Yoo et al. 2010; Kallinikos & Mariátegui 2011; Matusik & Mickel 2011; Kallinikos et al. 2013; Mazmanian 2013; Mazmanian et al. 2013; Fichman et al. 2014; Barrett et al. 2015; Orlikowski & Scott 2016; Bardhi & Eckhardt 2017; Ng & Wakenshaw 2017) *Related constructs found in the literature:* **Addressability**: (Yoo 2010; Kallinikos et al. 2013; Fichman et al. 2014) **Findability**: (Kallinikos et al. 2010; Kallinikos & Mariátegui 2011; Kallinikos et al. 2013)
Transferability	(Cross et al. 2006; Boland et al. 2007; Leonardi & Bailey 2008; Zittrain 2008; Bailey et al. 2010; Breschi & Catalini 2010; Lee & Berente 2012; Kallinikos et al. 2013; Majchrzak & Malhotra 2013; Zhang et al. 2014; Cano-Kollmann et al. 2016; Mabey & Zhao 2017; Trantopoulos et al. 2017; Kim & Anand 2018; Forman & van Zeebroeck 2019)
Ubiquity	(Kolb 2008; Yoo 2010; Matusik & Mickel 2011; Wajcman & Rose 2011; Mazmanian et al. 2013; Iansiti & Lakhani 2014; Sørensen & Landau 2015; Mardon & Belk 2018)