EPiC Series in Education Science
Volume 5, 2023, Pages 116–134
Proceedings of NEMISA Digital Skills Conference 2023: Scaling Data Skills For Multidisciplinary Impact

Understanding Digital Economy Dilemmas

Nixon Muganda Ochara
Wits Business School, University of Witwatersrand, Johannesburg, South Africa
Nixon.Ochara@wbs.ac.za

Abstract

Against the backdrop of escalating contradictions and critiques of the digital economy's trajectory, this study analyzes how the emerging digitalization issues might be philosophically understood from a systems viewpoint. Five systemic digitalization challenges including the circular economy (CE), cyberphysical systems (CPS), sharing economy (SE), digital transformation (DT), and smart systems were identified (SS). To investigate digitalization challenges, the machine, organism, cultural/political, societal/environmental, and interrelationship systems metaphors were used. The machine viewpoint demonstrates that the circular economy challenge may be examined utilizing Hard Systems Thinking (HST) methodologies, with a focus on sufficiency via product design and business model innovation. The organism approach demonstrated how the digital twin notion may be investigated using Socio-Technical Systems (STS) and the Viable System Model (VSM) to diagnose and forecast CPS viability in an increasingly linked Industry 4.5/5.0 environment. In analyzing SE's rentier capitalism, the cultural/political viewpoint demonstrated the applicability of purposeful systems techniques for "people complexity." The societal/environmental viewpoint stressed emancipatory systems approaches to "coercive complexity" as crucial to evaluating the perpetuation of digital exclusion by DT from an emancipatory systems perspective. The interrelationship viewpoint emphasized the significance of systems approaches for researching "structural complexity" in intelligent systems. These viewpoints aid decision-makers in identifying problem-solving strategies based on systems thinking.

1 Introduction

The digital economy is a key metaphor for understanding the Fourth Industrial Revolution (4IR) or Industry 4.0/5.0. Digital economy continues to impact global growth and reconfiguration of various sectors. According to Medynska et al., (2022) the digital economy contributes 15.5% to global GDP, but its effects vary widely across countries, industries, and sectors. At the macro-level, the influence of digitalization is visible in innovation ecosystems, and competitive and relational dynamics that have transformed how commerce (e.g., ecommerce/ e-business), public administration (e.g., digital government), and the current framing of the digital economy based on extensive global and national

H. Twinomurinzi, N.T. Msweli, T. Mawela and S. Thakur (eds.), DigitalSkills2023 (EPiC Series in Education Science, vol. 5), pp. 116–134

information infrastructures. Recent thinking and technological advances have 'smartified' markets, value chains, products, services, and material and non-material sectors (Appio et al., 2021). At the mesolevel, digital disruptions have influenced how organizations and agencies have restructured their capabilities, processes, and routines (Appio et al., 2021). How meso-level organizing units (regulatory bodies, stakeholder groups, R&D agencies, etc.) structure their dynamic capabilities in response to disruptive innovations is critical for framing digital transformation in these agencies and at national levels. The micro-level focuses on the individual and how digital transformation has changed life, work, and teams (Verhoef et al., 2021).

The prevalence of discourses on the digital economy suggests a change in socioeconomic values. These value shifts are correlated with the emergence of new digital innovations that now define a utopian vision: the digital world as a key resource for governments, businesses, and individuals where economic, political, and social value can be created equitably for the benefit of society. While these changes were largely inevitable, a lack of understanding of the digital economy's complex and systemic dilemmas and how to address them exacerbated social exclusion. Digital economy artifacts have fuelled digital exclusion, new forms of the digital divide, loss of trust, and discrimination (Harvey et al., 2021; Marshall et al., 2020; Ranchordás, 2020; Vartanova & Gladkova, 2019). The extensive list of failed digital transformation initiatives demonstrates how unprepared decision makers are for 'more recent' digital economy challenges (see Bucy et al., 2016). "Traditional" analysis may be constrained by "global" challenges, and systems thinking may be preferred for understanding digital economy issues. This paper employs systems thinking to understand the complexities of the digital economy better. The paper argues that traditional "reductionist" or "analytical" thought is inadequate for addressing problems in the digital economy.

To advance the argument for embracing systems thinking, the paper is structured as follows: first, synthesis, the systems-thinking mode, is differentiated from analysis, the dominant reductionist mode. After clarifying systems thinking, "complexity" is introduced as a key to understanding digital economy dilemmas. With the introduction of "Systems Thinking," the focus shifts to preparing contemporary decision makers to understand the current global systemic dilemmas and why "Systems Thinking" is "ripe" for the digital economy humanity now finds herself in. The paper concludes with reflections and recommendations for systems thinking.

If you already prepared your paper using a different style, you can find it very hard to conform to the EasyChair style. In this case, read Section **Error! Reference source not found.** of this document.

2 Global Complexity: From Reductionist to Systems Thinking

Reductionism or machine age thinking holds that all things and events, their attributes, and our experience and understanding of them are made up of ultimate constituents, indivisible pieces (Ackoff, 1997). Yi et al., (2022) argues that traditional reductionism is no longer applicable for understanding socially complex innovation systems of the contemporary world. Thus, systems thinking is increasingly recognized to be the appropriate lens for understanding complex systems with emergent properties. While the reductionist worldview is still prominent, Ackoff (2018) argues its limitations have always been acknowledged since the 1930s publication of von Bertalanffy's "General Systems Theory" (Bertalanffy, 1937). Thus, by rejecting reductionism as the dominant way of thought, synthetic or systems thinking emerged as a new worldview focused on systems, their expanding complexity, and the difficulties of controlling them successfully.

Systems are regarded as wholes which lose their essential properties when taken apart, implying that they are wholes that cannot be understood through analysis (Ackoff, 1979). Analysis of a system only reveals its *structure and how it works*; it yields know-how or knowledge, but not *understanding*, which explain why a system works the way it does (Ackoff, 1979). Therefore, in systems thinking, a phenomenon to be explained is viewed as part of a larger whole, a system, and is explained in terms of its role in that system (Daellenbach et al., 2012). Table 1 synthesis ideas of reductionism (*analysis*) and systemic thinking (*synthesis*) and differentiates these two world views in terms of their processes, outcomes of the processes, and the predominant source of explanation when describing the phenomena of interests.

Dimensions	Analysis (Reductionism)	Synthesis (Systems Thinking)
Process	1. Take system apart	1. Place the system as part of a larger system.
	2. Seek understanding of each part	2. Understand the containing system
	3. Aggregate the parts to the whole	3. Disaggregate the understanding of the whole to the parts
Source of Explanation	Internal - Closed System	External – Open System
Product	Knowledge of Structure	Understanding of Role and Function

Table 1: Reductionism versus Synthesis

The contrasts captured above reveals different modes of thought that are complementary to seeking an explanation to any phenomenon. Given the current age has been christened the "Systems Age" (Ackoff, 1973; Mitroff et al., 1974; Tarasenko, 2020; van Gigch, 1984; Zandi, 2000), the use of systems thinking tools for understanding current digital transformation dilemmas is not only apt but also fits well with the current age.

3 Complex Systemic Digital Economy Dilemmas

Table 2 synthesizes the critical global megatrends that are shaping the global and local discourses surrounding global dilemmas linked to the digital economy.

Global Megatrends	Emergent Systemic Dilemmas	References
Sustainability	Circular Economy	Geissdoerfer et al., 2017;Belmonte-Ureña et al., 2021; Nayal et al., 2022; Ogunmakinde et al., 2022
Industry 4.0/Society 5.0	Cyber-Physical Systems	Dantas et al., 2021; Hughes et al., 2022; Pourmehdi et al., 2022; Suleiman et al., 2022
Interconnected World	Sharing Economy; Social Exclusion	Ganapati & Reddick, 2018a; Reich, 2015; Srnicek, 2017
Digital Transformation	Sustaining versus Disruptive Innovations; Exploration versus Exploitation	Bodrožić & S. Adler, 2022; Clarke, 2019; Dickel & Schrape, 2017; Dunbar-Hester, 2019; Hensmans, 2021
Smart Systems	Synthetic Thinking, Emergence, Self-Organization, Context-Awareness	Hermann et al., 2016; Pascual et al., 2019; Romero et al., 2020; Valckenaers et al., 2003
System Complexity Growth	Distributed Modularization	Ethiraj & Levinthal, 2004; Gärtner & Schön, 2016; Micheli et al., 2019

Table 2: Systemic Digital Economy Dilemmas

These global megatrends, in the manner of Friedenthal et al., (2021), are being influenced by the global environment, currently shaped by human and societal needs; technologies that underly the evolution of societal systems; and stakeholder expectations, aligned to broader societal and technological trends. The systemic issues coming from humanity's struggle to reorient decision making in the face of these systemic challenges are predicated on digital transformation as a prerequisite for any system-level remedies envisioned by decision makers.

Sustainability is humanity's attempt to right past wrongs to save the planet. Humanity faces environmental, economic, and social challenges under the megatrend of "sustainability" (Zander & Mosterman, 2013). Following the failure of the Millennium Development Goals (see McCloskey, 2015), a new international development agenda, the UN 2030 Agenda for Sustainable Development, was adopted in September 2015 (Johnston, 2016). The challenges humanity faces in achieving the 17 SDGs are less clear. The Circular Economy (CE) and Industry 4.0 are two emerging discourses that have the potential to contribute to the 17 SDGs. CE advocates for an economic system that separates environmental pressure from economic growth by switching from linear to circular production (Belmonte-Ureña et al., 2021; Sanguino et al., 2020). The current system is based on large-scale extraction, use, and disposal of materials, which is the root of intergenerational and intergovernmental issues such as waste disposal in natural areas, resource scarcity, and climate change (de Souza Junior et al., 2020). The CE paradigm is a "regenerative system that minimizes resource input and waste, emission, and energy leakage by slowing, closing, and narrowing material and energy loops." Maintenance, repair, reuse, remanufacturing, refurbishing, and recycling can all help (Geissdoerfer et al., 2017, p.759). Thus, CE has emerged as a strategic response to the challenges of a linear economy's sustainability, promoting a circular rationale centered on a "zero waste economy" (van Langen et al., 2021). But CE's theoretical, practical, and ideological foundations are questioned by critics. On the one hand, CE supporters envision sustainable futures based on planned circularity, circular modernism, bottom-up sufficiency, and peer-to-peer circularity; on the other hand, critics claim it is a myth that "paints" a "utopian" future (Bauwens et al., 2020; Corvellec et al., 2022).

The evolution of ***Industry 4.0/5.0*** is founded on the long-held belief that technological development and sustainable development are inextricably linked; despite criticism, the conceptualization of this link is neoliberal and Eurocentric in nature (Schelenz & Pawelec, 2022). In spite of this criticism, it is deemed essential to implement innovative technologies as a key factor in establishing a proactive, self-configured, and automated system for achieving sustainability objectives. Industry 4.0 refers to the evolution of industries toward cyber-physical systems, and Society 5.0 refers to the evolution of society toward socio-cyber-physical systems (Friedenthal et al., 2021). Industry 4.0 seeks to optimize production in productive sectors with its integrative and interconnected technologies (Berawi, 2019; Dantas et al., 2021; Ramakrishna et al., 2020). However, it remains unclear how to achieve *integration* and *interconnection* of Industry 4.0's core technologies (Hughes et al., 2022; Pourmehdi et al., 2022; Suleiman et al., 2022). Consequently, although there is substantial evidence linking Industry 4.0 and sustainable development, the identified impediments create roadblocks to the agenda's realization, posing difficult choices.

The global community is increasingly being facilitated by Industry 4.0 technologies, resulting in higher levels of socio-political and economic interdependence (Friedenthal et al., 2021). The increased global interdependence subsequently incites the need for *sharing of resources* and the ***interconnection of systems (Interconnectivity)*** in global partnerships (Friedenthal et al., 2021). The interconnected world has seen the rise of new economic business models such as the "sharing economy", whose focus is on the sharing of unused or underutilized capacity. While there is evidence that the ***sharing economy*** exists, critics view it as a questionable phenomenon that threatens existing markets and institutions (Codagnone & Martens, 2016). In this "*share-the-scraps-economy*" (Srnicek, 2017, p. 254), what is emerging is a new "precariat" labor class that is flexible but without work security (Standing, 2018).

The concept of ***"Digital Transformation"*** (DT) has emerged as a key metaphor for describing Industry 4.0/5.0. According to Bodrožić & S. Adler (2022), four competing and conflicting future trajectories of DT development are possible: digital authoritarianism, digital oligarchy, digital localism, and digital democracy (Figure 1). Because of the contradictory effects and benefits, this suggests a systemic dilemma. The desired scenario is a digital democracy, which combines a proactive system-building regime with a management paradigm based on community and collaboration (Bodroi & S. Adler, 2022). However, most DT implementations are based on digital authoritarianism, digital localism, and digital oligarchies, which exacerbate social exclusion. The DT dilemmas envisaged are couched in the Schumpeterian notion of' '***creative destruction***,' which is linked to the instability and emergence of new forms of economic cycles embedded in these contradictory DT trajectories.

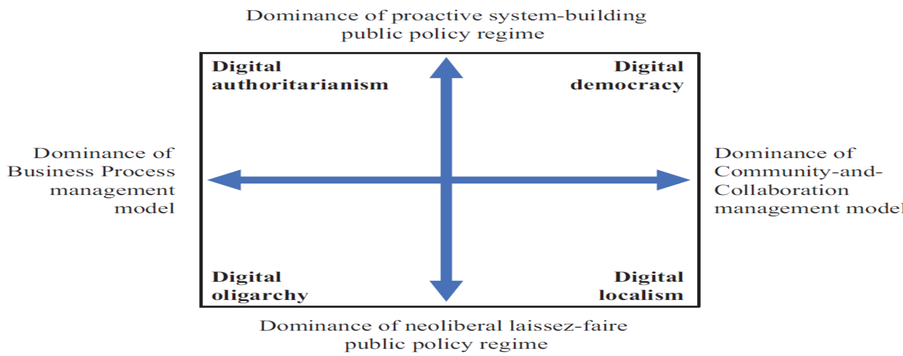

Figure 1: Four Scenarios for Digital Transformation (Source: Bodrožić & S. Adler, 2022)

Smartness entails the intentional development of devices, sociotechnical systems, and fully automated systems using Industry 4.0 technology. Smart systems can update their internal knowledge up to date to make the best decisions(Romero et al., 2020). User mobility, or the ability of the (smart) environment to continuously provide access to computational tasks and resources, is a critical attribute of smart systems. To link the dilemmas associated with smart systems to flexible modularization, an understanding of the *design principles* of Industry 4.0 is critical. Hermann et al., (2016) identifies six critical principles for designing Industry 4.0: *interoperability, virtualization, decentralization, real-time capability, service orientation* and *modularity*. Incorporating these design principles for Industry 4.0 will give rise to smart systems (and its elements) with the following characteristics*: communication capability, embedded knowledge, learning capability, reasoning capability, perception capability* and *control capability*. However, these smart systems are not static, and as the systems elements interact to exhibit the characteristics above, new characteristics and properties emerge. Contemporary methods to system design are still immersed in a "functional top-down design" paradigm founded on the false idea that complex systems design can be "managed." Valckenaers et al., (2003) argue that control in the design of complex systems is illusionary and that 'object-oriented design' moored on 'synthetic' reasoning is appropriate in VUCA situations. Adopting synthetic thinking in the design of complex smart CPS, based on Hermann et al., (2016)'s, systems design principles, is still a global dilemma. The 'Dilemma of Synthetic Design' describes the boundaries of existing smart system design ideas. The "***Dilemma of Synthetic Design***" challenges the limits of analytical thinking in designing complex systems.

4 Aligning Digital Economy Dilemmas to Systems Thinking

The "System of Systems Methodologies" (SOSM), founded in 1984, is frequently used to comprehend complexity (Jackson & Keys, 1984). The SOSM is presented as a grid (Table 3) with "systems" and "stakeholders" as the primary sources of complexity that decision makers must deal with (Jackson 2020). The vertical axis depicts system complexity as it progresses from simple to complex. A simple system is one with a linear cause-and-effect relationship and predictable outputs. Such a system requires best practices or simple decision-making methods (Jackson 2020). Cause and effect relationships in complex systems are frequently linked in difficult-to-follow chains that are separated in time and space. Decision-making scenarios involving complex systems necessitate the use of experts who can help understand the system's behavior using systems thinking tools such as system dynamics. There are several agents and relationships in complex systems that it is impossible to trace the interactions and outcomes. Despite the numerous cause and effect concatenations, the system typically produces emergent patterns of behavior that can be identified in retrospect (Jackson 2020).

PROBLEM CONTEXTS	STAKEHOLDERS		
SYSTEMS	Unitary	Pluralist	Coercive
Complex	Complex–Unitary	Complex–Pluralist	Complex-Coercive
Complicated	Complicated–Unitary	Complicated–Pluralist	Complicated-Coercive
Simple	Simple–Unitary	Simple–Pluralist	Simple-Coercive

Table 3: "Ideal-Type" Grid of Problem Contexts (Jackson, 2020)

The horizontal axis depicts increasing complexity because of conflicting values and/or interests among problem stakeholders. The words "unitary," "pluralist," and "coercive" are used. Values, beliefs, and interests are shared by "unitary" stakeholders. Values and beliefs clash in a "pluralist" relationship, but basic interests are compatible. Among "coercive" stakeholders, there are competing interests as well as irreconcilable values and beliefs. Combining the dimensions of systems and stakeholders yields nine "ideal-type" problem contexts (Table 6). The "Ideal-Type" grid is then used to map aspects of the five previously identified digital economy dilemmas.

All identified digital dilemmas are volatile, uncertain, complex, and ambiguous (VUCA). Morin (2007) considers such dilemmas to be "general complexity" that must be managed by decision makers. CSP, a CST multimethodology, seeks to comprehend dilemmas of "general complexity." CSP embraces systems thinking on the grounds that reductionist thought cannot deal with complexity (Jackson, 2021). Jackson (2020) describes CSP using the acronym EPIC: Exploring the problem situation (E), Producing (P), Intervening flexibly (I), and Checking progress (C). Figure 3 summarizes and describes the EPIC stages of the CSP. The systems thinking approach requires you to use the first stage (Explore) to identify the critical issues of a digital dilemma and the second stage (Produce) to develop an intervention strategy for its resolution. The first stage of CSP demonstrates how to deconstruct a digital transformation dilemma to aid decision makers.

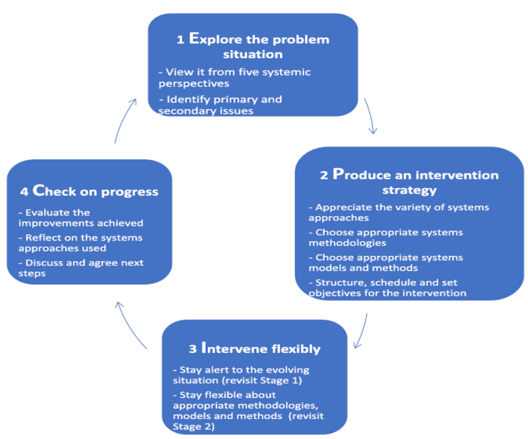

Figure 1:The four key EPIC Stages of CSP (Adopted from (Jackson, 2020a)

In its application for understanding complex problematical situations, CSP makes use of seven integrated and cohesive systemic perspectives that allow decision makers to make sense of specific dilemmas: *machine, organism, cultural, political, coercive system, environmental, interrelationships* (Jackson, 2021). These seven, integrated into five perspectives (See Jackson, 2020a) are the lenses that decision makers can use to 'structure' the dilemmas that they face to foster greater understanding, the goal of systems thinking. To demonstrate, these five systemic perspectives are employed to offer a broad exploration to foster understanding of *aspects* of five digital economies dilemmas identified above. A similar approach can be used for the exploration of any other problematical dilemma that exhibit VUCA characteristics or 'general complexity'.

4.1 Machine View: Exploring Goal Seeking Behavior

The machine perspective is used, exploratively, to identify the causes of faults in an existing problem situation and/or to design a better system (Jackson, 2020). According to this perspective, a problematical situation is like a complex machine made up of parts that work together to achieve a desired outcome. By focusing on how the problematic situation is like a "machine," it is possible to gain insight into the machine perspective. For instance, Morgan (1998) invites us to consider the organization as a machine. Considering the organization as a machine may create valuable insights about how an organization is structured to achieve predetermined results, though the human aspects may be ignored. This mechanical mode of thinking helps decision makers to picture challenging circumstances as interlocking components or elements, each with a clearly defined role in the whole (Kohnen, 1999). This involves identifying the system's aim and its causal connections and effects.

Consider the dilemma of the circular economy, whose potential to disrupt contemporary social institutions built on a linear rationale is being questioned by its detractors. In what ways can the circular economy be conceived using the machine metaphor? To demonstrate, we use Stahel's, (2016) conceptualization, which expands CE to be a performance economy in which items are marketed to consumers as services through rent, leasing, and sharing; while manufacturers and service providers retain ownership of the product and solutions and bear the cost of risks and waste. As a result, the performance economy emphasizes services over products and generates income through sufficiency, such as waste reduction, as well as design, reuse, and business model innovation to circular business models, or CBMs (Stahel, 2016). Using the machine metaphor, the emphasis should be on the structure of the CE to achieve sufficiency through design and business model innovations centred on sustainability yardsticks. Sustainability yardsticks are centred on a dynamic closed-loop system focusing on environmental protection, the full reuse of resources and the recycling of waste (Franco, 2019; Kazancoglu et al., 2021).

Following Jackson (2020), such precision in determining "cause-effect" relationships is linked to 'Hard Systems Thinking' (HST) approaches, notably Systems Analysis (SA), Operations Research/Management Science (OR/MS) and Systems Engineering (SE). For these three 'Hard Systems Thinking' (HST) methodologies, a problematical situation falls within a "simple-unitary" complexity domain (Table 3) where the systems, though having multiple interactions, are "simple"; while the stakeholders agree as to the "goal" of the system. As illustrated above, the goal-oriented nature of the machine metaphor fits well with thinking that underlie HST. However, the machine perspective will only reveal an aspect of the problematical situation where both cases are true, that is, when there is goal agreement and the systems to be designed are 'simple' in the manner of a complete understanding of cause-effect relationship. Prior research demonstrates the application of such HST approaches to understand CE from a machine perspective. Such research is premised on the caveat that the goal of any CE system is sufficiency through product design and business model innovation strategies, with emphasis on quantifiable "cause-and-effect" relationships or factors. For instance, Choi et al.,(2020) synthesizes findings from several research focusing on the sharing and circular economy that employ the use of OR and SE techniques. The machine perspective can help reveal a "slice" of the problematical situation that other perspectives cannot. "***Designing for Sufficiency***" is fundamental to the machine metaphor.

4.2 Organism View: Exploring System Viability

Von Bertalanffy (1937), the founder of General Systems Theory (GST) and the open system concept, is credited with the inception of the organism/organismic perspective. He offered these ideas in opposition to the then-dominant mechanistic and reductionist models in biology and psychology (Hammond, 2010). The organismic perspective shifts from goal-seeking to viability by diagnosing pathologies and suggesting system designs for survival (Jackson, 2020a). The underlying systems approach of the organismic perspective in the manner of von Bertalanffy is moored on the open system concept, in which he highlights the relationship between the organism and environment. The open system approach recognized that organisms are complex entities with many parts (or subsystems) that interact with each other and the environment. When thinking about the interaction of the various parts, the system boundary must be considered because it allows the exchange of materials, energy, and information with the external environment. The system boundary facilitates the exchange of materials, energy, and information with the external environment, according to the open system concept. As an open system that is dependent on its environment, the organism must maintain a dynamic equilibrium with the environment to survive and thrive (Jackson, 2020a). And the sub-systems that comprise the organism only make sense in terms of the functions that the individual parts play in the whole system. However, Sub-systems must have some autonomy or the "brain," which coordinates, will be overwhelmed.

The organism perspective on digital economy dilemmas requires understanding of organizational 'life' images. After the mechanistic view's limitations were realized, the organism vocabulary permeated organizational life discussions. The corporation is a biological concept rooted in a corpus, a body or organism (Ackoff, 1990). C-level executives have adopted organismic language. The CEO is the organization's "head." Other executives have adopted the 'head' vocabulary to represent various business functions, such as 'Head' of Human Capital, CIO as 'head' of Information Systems, etc. The organism metaphor in organizational life confirms Morgan's (1986) claim that "most modern organizational theorists look to nature to understand organizations" (p. 71). Following Morgan's (1986) claim, Prabhu (2022) observed a marked institutional shift on various dimensions (Table 7). The mechanistic perspective seeks efficiency, while the organismic perspective seeks adaptability to the environment (thus a focus on effectiveness). These organismic ideas can be used to understand 'human' systems, which have subsystems with their own purposes, unlike mechanistic systems.

Dimension	Mechanistic Model	Organismic Perspective
Aggregate view	Sum of efficient parts gives an efficient organization	Organization is greater than the sum of its parts
Management style	Analysis-driven (Activities broken down and managed at sub-unit level)	Synthesis-driven
Psychology	Worker is motivated solely by pay	Workers have a hierarchy of needs
Core focus	Efficiency (purpose-driven)	Effectiveness (adaptation-driven)
Hierarchy	Top-down flow of authority. Centralized	Bidirectional/multidirectional flow. Decentralized.

Table 4: Mechanistic versus Organismic Perspective

Consider the integration and interconnection of cyber-physical systems in Industry 4.0 and Society 5.0. CPSs can integrate computation, networking, and physical processes. CPS integration is complicated by heterogeneous components and interactions. While CPSs are promising systems for addressing societal and technical challenges, their success is dependent on a mindset shift to address collaboration and integration of heterogeneous components. The dilemmas of integration and interconnection of CPSs emerge from various sources. For instance, Wang et al., (2022) points to the lack of focus on human beings on initial designs of CPSs, yet they are meant for humans. Instead, they propose a human-cyber-physical systems (HCPS) perspective that elevates the role of human beings to overcome limitations of contemporary CPSs. Bonci et al., (2019) 'zeroes in' on "web technology" as a limiting "language" for the modern design of CPSs and argues for a shared human-to-machine and machine-to-machine language to actualize such a human-centric viewpoint on the architecture of CPSs. According to Potekhin et al., (2022), the viability of CPSs depends on how well physical objects are represented as digital twins to help manage large distributed systems. Using **digital twins**, it is possible to monitor and improve networked services, physical products, machines, and devices (Stary et al., 2022). Because digital twins intertwined with CPSs, evolving open social and technical systems must maintain a dynamic equilibrium with the changing environment (Jackson, 2020a). Adaptability, as the ‘goal seeking’ behavior, therefore becomes core for these large distributed CPSs, based on the digital twin’s concept. Digital twins are seen as integrators of the digital and physical worlds, as well as of the process of creating value both internally and outside (Barth et al., 2020).

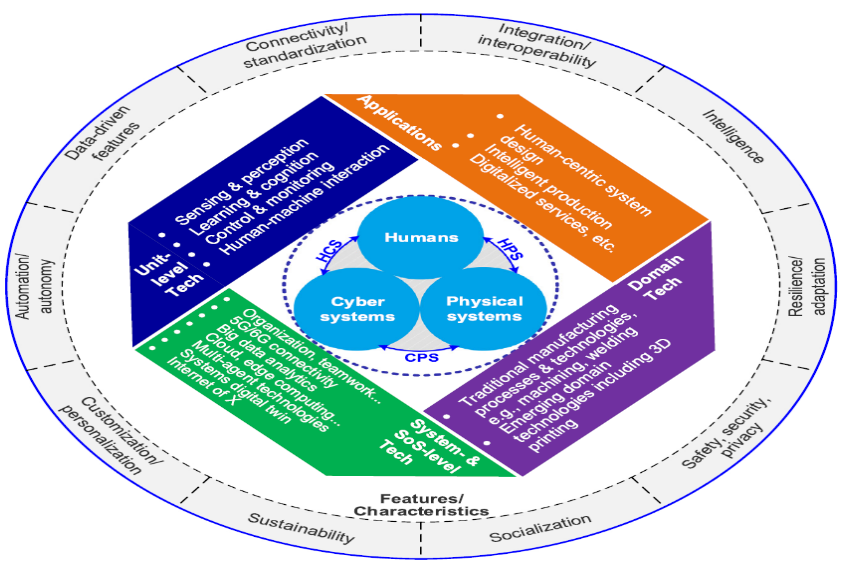

Figure 2: A Human-Cyber-Physical System (Source: Wang et al., 2022)

To overcome the dilemmas associated with distributed CPSs by supporting the proper theorization and design of digital twins to ensure CPSs are adaptable, the relevant systems approaches are Socio-Technical Systems (STS) techniques and the Viable Systems Model (VSM). In the manner of Jackson (2020), STSs and the VSM are associated with problematical situations, in which the systems are “complex”, while the stakeholder perspective is “unitary”. Complexity is exacerbated due to the heterogeneity of the devices; while the stakeholder perspective is unitary as the discursive practice settles on the “digital twin” concept to characterize distributed CPSs. Exemplars of the use of these two systems thinking approaches include the use of the VSM to create a holistic vision of a system-of-system based on the holon concept to simplify the design and implementation of a CPS architecture that exploits recursivity (Bonci et al., 2018) ; and the use of STS to incorporate the human-centric perspective in the design of distributed CPSs and to enhance the bi-directional and multidirectional control, aggregation and management of such systems (Anumba et al., 2022; Horváth, n.d.; Pessoa et al., 2022). Therefore, "**Designing for Viability**" remains a conundrum, even as CPSs infrastructures take hold in the evolving Industry 4.0/5.0 society.

4.3 Cultural/Political View: Exploring Inscribed Cultural Knowledge

The "sharing" economy, also called "platform capitalism," is gaining traction, revolutionizing product and service production and distribution (Sharif & Huang, 2019). However, "platform capitalism" has a darker side, christened the "*share-the-craps-economy*"(Reich, 2015), which continues to entrench the inequality loop linked to the self-reinforcing effect of digital and social exclusion (Ragnedda et al., 2022). Digital and social exclusion can be viewed through the prism of contemporary global society's dominant *cultural* and *political* narratives. However, it requires posing the question: *what is the dominant cultural/political representation in the current practice of platform capitalism?* A specific value extraction model is the by-product of the dominant cultural and political representations that are embedded in the digital turn towards platform capitalism. This model occurs when the technology surpasses its conventional connective and extractive functions (i.e., data as value) by translating *cultural knowledge as a key business practice* (Dal Maso et al., 2021). By extending the concept of "platform capitalism," Dal Maso et al., (2021) contends that this is a form of "*cultural platform capitalism*". That is, a Western paternalistic perspective underpins the platform business model, in which cultural representations in digital artifacts are based on a 'rentier capitalism' value extraction model.

Rentier capitalism entails creating and extracting value through the techno-economic expansion of ownership and/or control over assets, often due to artificial or natural scarcity, quality, or productivity(Birch, 2020). The hegemonic dominance of Western corporations in rentier capitalism is well established(Christophers, 2022; Klinge et al., 2022), so their 'cultural knowledge' is deeply embedded in the digital economy. Prior research shows that the hegemonic dominance of specific cultural representations via intermediary digital infrastructures has increased digital and social isolation for large segments of the population, as evidenced by the digital divide (Figueiredo & Borges, 2021; Kwet, 2022; Mihelj et al., 2019; Peters, 2022). This form of rentier capitalism, in which digital monopolies create and extract value, is contradictory and has been criticized (Birch et al., 2022). As a result, Western cultural platform capitalism has now become the shared culture, but diversity and differences in human interests continue to fuel resistance, conflict, and contestation of the digital space. Given that Western "cultural knowledge" dominates the digital monopolies shaping the trajectory of the sharing economy, the dilemma of rentier capitalism may be characterized as a "simple-pluralist" structure. Digital monopolies are "simple" because they follow a well-known cultural/political logic of their "cultural knowledge": a "Winner-Takes-All" approach in the design of the digital platform ecosystem. Considering that there are numerous parties involved in the digital platform ecosystem who hold various values, beliefs, and interests, the problem context for rentier capitalism is "pluralist." The cultural/political perspective emphasizes how a diverse groups of individuals become stablished, as they promote processes imprinted with their own interests, to become a "shared culture" (Jackson, 2020). "Winner Take It All" has become the shared cultural knowledge that anchors the sharing economy. To uncover assumptions that underpin such "shared cultures", possible questions to ask include: What assumptions are inscribed in digital platforms due to Western-oriented cultural platform capitalism? How can these assumptions be 'surfaced' to re-design digital artifacts that reduce social and digital exclusion? Uncovering stakeholders' assumptions in system design emphasizes the 'pluralist' dimension of people complexity. Systems methodologies that align well with problem context of

"*Digital Exclusion through Rentier Capitalism*" include *Strategic Assumption Surfacing and Testing (SAST), Interactive Planning (IP),* and *Soft Systems Methodology (SSM)*.

4.4 Societal/Environmental View: Explore 'Humanization' of Systems

The discourses of humanity's societal transition to Industry 4.0/5.0 are predominantly couched in the language of Digital transformation (DT). However, dilemmas associated with the pursuit of 'undemocratic' *ideal type DT process* point to outcomes that have exacerbated different manifestations of *social exclusion* (Figure 3). Prior research has determined that social exclusion is by design since 'smart' technologies, the bedrock of Industry 4.0/5.0, are currently being embedded into social systems that already have underlying inequalities (Park & Humphry, 2019). There is extensive support from scholarship that reveal that social exclusion is by design (see Goldstraw & Herrington, 2021; Good Gingrich, 2010; Jensen, 2021; Park & Humphry, 2019; Sin, 2019). Smart' technologies and systems, the cornerstone of Industry 4.0/5.0, are therefore being incorporated into social systems with underlying inequities. Addressing social exclusion through DT, which excludes certain segments of humanity, is a persistent problem in the transition to Industry 4.0/5.0. From an Industry 4.0/5.0 standpoint, understanding contemporary social inequities that perpetuate chronic social exclusion requires a systemic lens.

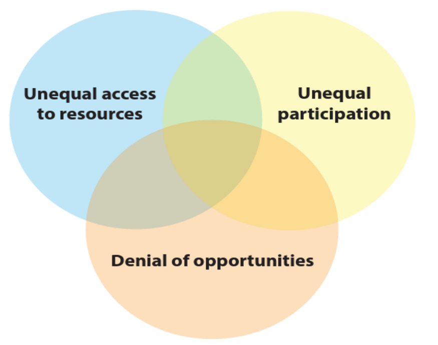

Figure 3:Social Exclusion (Source: Mayer et al., 1958)

The *social/environmental* approach may provide light on parts of the digital exclusion challenge, which is being addressed from a human-centric, sustainable, and resilient standpoint (Figure 4). The *social/environmental perspective*, as a systems thinking lens, fosters the understanding of discrimination and inequality in the context of 'neglected' stakeholders (Jackson, 2020). Social exclusion is a kind of hegemonic tyranny that reveals power dynamics. This kind of hegemonic tyranny dehumanizes by using coercive power via powerful 'digital intermediaries' to influence the DT process' trajectory and outcome. As Industry 5.0 takes shape, the dehumanizing ideas of Industry 4.0 are being disputed (Grabowska et al., 2022), and a new regime of 'humanization' is emerging in which the technological environment of Industry 4.0 is coupled with a human-centric approach to Industry 5.0. Humanism resists the authoritarian control of 'cultural platform capitalism' and strives to include human-centricity, resilience, and sustainability, which define modern debate for human survival. The most probable emancipatory systems lenses for understanding power dynamics in the design of simple, complicated, and complex systems under coercive stakeholder situations are Team Syntegrity (TS), Critical Systems Heuristics (CSH), and Liberating Systems Theory (LST).

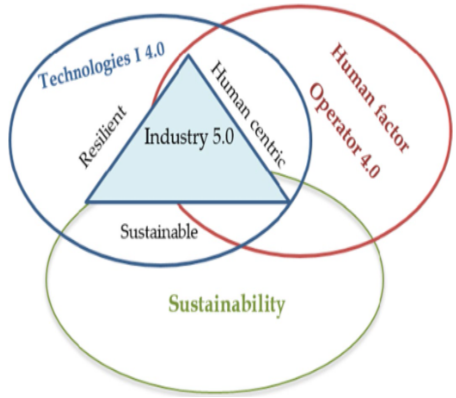

Figure 4: Framework of Industry 5.0 (Source: Grabowska et al., 2022)

4.5 Interrelationship View: Exploring Causality in Systems

As the legitimacy and mobilization for Industry 4.0/5.0 takes hold, it will become clear that the *raison d'être* for the digital transformation process is the development and integration of *smart systems* as the core components of the digital economy. Smart systems are not static, but are dynamic, open, and complex in design, while contemporary approaches to design of systems are still steeped in a 'functional top-down design' paradigm premised on the unrealistic assumption that complex systems design can be 'controlled. Further, smart systems, such as smart cities, smart buildings, and autonomous cars, are each essentially a System-of-Systems (SoS), which are dynamically established as alliances among independent and heterogeneous software systems to offer complex functionalities due to constituent interoperability (Neto et al., 2018). However, recent implementations of smart systems have elicited various challenges that point to a dilemma in how such systems are designed. For instance Mohammadi et al., (2022) cites the difficulty of decision making in smart environments due to the high direct and indirect *dimensional factors*. Following Medina-Borja (2015)'s conceptualization of "smart service systems", Alter, (2020) characterizes the smartness of systems into four categories with several dimensions: *information processing* (six dimensions), *internal regulation* (five dimensions), *knowledge acquisition* (six dimensions), and *action in the world* (six dimensions). Due to the high dimensionality of these smart systems, computational intensity is extremely high in dimensionality which consequently creates a data storage burden at every smart devices due to their different capabilities (Kamruzzaman, 2021). Also, with the broader push towards Industry 4.0/5.0, there are open security and privacy challenges that have heightened, with an increase in the frequency and sophistication of cyber-physical attacks posing significant threats to organizations globally (Williams et al., 2023). The intrinsic dilemma of designing smart systems arises from the high dimensionality of the concept of 'smartness' used to characterize to what extent a system is smart (Figure 5).

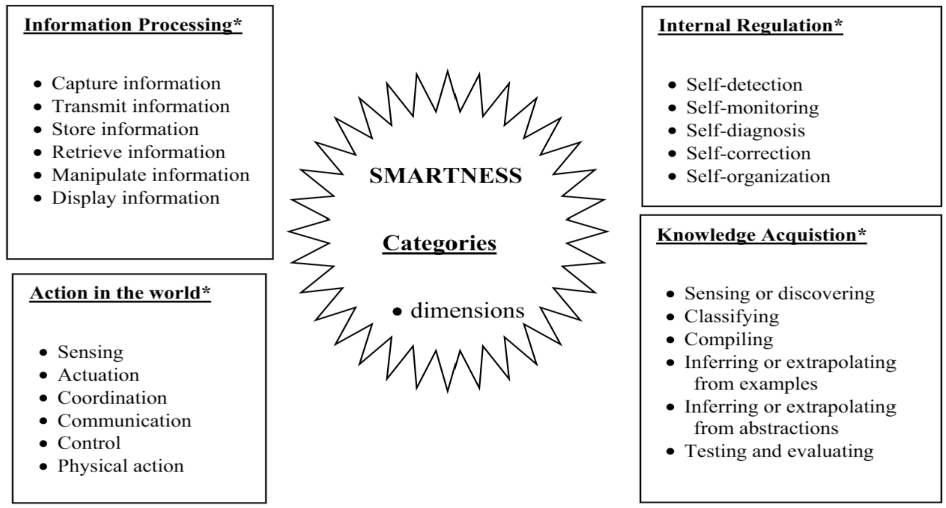

Figure 5: Dimensions of Smartness (Source: Alter, 2020)

Understanding how smart system dimensions interact can shed light on their nature and improve design. The aspects of interest would focus on causal linkages between the dimensions and how such linkages influence the ‘smartness’ of the smart system. The *interrelationship perspective*, a lens of systems thinking, can be an effective approach for structuring such causal linkages of smart systems. The foundation of the interrelationship perspective is that all *issues* (*factors, dimensions*) identified in a problematical scenario are interconnected in chains of reciprocal causation, which suggest the possibility of unintended *consequences* or serve as leverage points for improved design (Jackson, 2020). To understand the 'smartness' of systems, *System Dynamics (SD)* can simulate such known causal relationships. To diagnose smart systems or improve their design, prior research shows how SD may be utilized as a modeling tool. Prior research shows that SD can be used to diagnose or improve smart system design. Khalid Khan et al., (2022) used SD to model the cause-effect relationships and mechanisms of Connected and Autonomous Vehicles (CAVs) cybersecurity and system behavior to create a road map for an optimized, self-regulating, and resilient cyber-safe CAV system. Recent contributions using SD include modeling of smart tourism ecosystems (Sedarati et al., 2022; Shafiee et al., 2022); understanding the relationship between information management barriers and collaborative technologies adoption factors, and sustainability-related policy analysis in the built environment (Amin et al., 2022; Francis & Thomas, 2022); and an exploration of factors that foster smart city success, as well as the cause-and-effect relationships among these determinants (Nunes et al., 2021). Although not exhaustive, these contributions show the proven usage of SD for modeling difficult diagnostic or prognostic cause-effect situations. The *interrelationship perspective* offered through SD makes it an ideal systems methodology for structuring such problematical situations with cause-effect relationships.

5 Conclusions

Systems-based approaches can be used to explore digital dilemmas from five different perspectives: machine, organism, cultural/political, societal/environmental, and interrelationship. The machine perspective emphasizes "design for sufficiency" as an efficiency goal; the organism perspective emphasizes system survival and viability; and the cultural/political perspective reveals how embedded "cultural knowledge" influences system design, use, and control. Understanding discrimination and inequality in the context of 'neglected' stakeholders is facilitated by a social/environmental perspective

(Jackson, 2020a). The interrelationship perspective can be used to effectively to structure causal linkages of smart systems with interconnected parts. The synthesis revealed that a 'winner-takes-all' Western-oriented "shared culture" pervades digital artifact design. Systems thinking can assist in bringing to light hegemonic assumptions in digital artifacts of the digital economy. Complementing analytical approaches with systemic perspectives and methodologies can improve complex system diagnosis and design.

References

Ackoff, R. L. (1973). Science in the systems age: Beyond IE, OR, and MS. *Operations Research*, *21*(3), 661–671.

Ackoff, R. L. (1979). The future of operational research is past. *Journal of the Operational Research Society*, *30*(2), 93–104.

Ackoff, R. L. (1990). The management of change and the changes it requires of management. *Systems Practice*, *3*(5), 427–440. https://doi.org/10.1007/BF01064153

Ackoff, R. L. (1997). Systems, messes and interactive planning. *The Societal Engagement of Social Science*, *3*(1997), 417–438.

Alter, S. (2020). Making Sense of Smartness in the Context of Smart Devices and Smart Systems. *Information Systems Frontiers*, *22*(2), 381–393. https://doi.org/10.1007/s10796-019-09919-9

Amin, F., Khan, K. I. A., Ullah, F., Alqurashi, M., & Alsulami, B. T. (2022). Key Adoption Factors for Collaborative Technologies and Barriers to Information Management in Construction Supply Chains: A System Dynamics Approach. *Buildings*, *12*(6), 766.

Anumba, C. J., Lu, Q., & Kan, C. (2022). Beyond building information modeling: the role of cyber-physical systems and digital twins. *Research Companion to Building Information Modeling*, 650–670.

Appio, F. P., Frattini, F., Petruzzelli, A. M., & Neirotti, P. (2021). Digital transformation and innovation management: a synthesis of existing research and an agenda for future studies. *Journal of Product Innovation Management*, *38*(1), 4–20. https://doi.org/10.1111/jpim.12562

Barth, L., Ehrat, M., Fuchs, R., & Haarmann, J. (2020). Systematization of digital twins: Ontology and conceptual framework. *Proceedings of the 2020 The 3rd International Conference on Information Science and System*, 13–23.

Bauwens, T., Hekkert, M., & Kirchherr, J. (2020). Circular futures: what will they look like? *Ecological Economics*, *175*, 106703.

Belmonte-Ureña, L. J., Plaza-Úbeda, J. A., Vazquez-Brust, D., & Yakovleva, N. (2021). Circular economy, degrowth and green growth as pathways for research on sustainable development goals: A global analysis and future agenda. *Ecological Economics*, *185*(March). https://doi.org/10.1016/j.ecolecon.2021.107050

Berawi, M. A. (2019). The role of industry 4.0 in achieving Sustainable Development Goals. *International Journal of Technology*, *10*(4), 644–647.

Bertalanffy, L. von. (1937). The organismic conception. *Perspectives on General Systems Theory: Scientific-Philosophical Studies*, 97–102.

Birch, K. (2020). Technoscience rent: Toward a theory of rentiership for technoscientific capitalism. *Science, Technology, \& Human Values*, *45*(1), 3–33.

Birch, K., Ward, C., & Tretter, E. (2022). Introduction: new frontiers of techno-economic rentiership. *Competition \& Change*, 10245294221082244.

Bodrožić, Z., & S. Adler, P. (2022). Alternative futures for the digital transformation: A macro-level Schumpeterian perspective. *Organization Science*, *33*(1), 105–125.

Bonci, A., Carbonari, A., Cucchiarelli, A., Messi, L., Pirani, M., & Vaccarini, M. (2019). A cyber-physical system approach for building efficiency monitoring. *Automation in Construction*, *102*(January), 68–85. https://doi.org/10.1016/j.autcon.2019.02.010

Bonci, A., Pirani, M., Cucchiarelli, A., Carbonari, A., Naticchia, B., & Longhi, S. (2018). A review of recursive holarchies for viable systems in CPSs. *2018 IEEE 16th International Conference on Industrial Informatics (INDIN)*, 37–42.

Bucy, M., Finlayson, A., Kelly, G., & Moye, C. (2016). *The 'how' of transformation*.

Choi, T. M., Taleizadeh, A. A., & Yue, X. (2020). Game theory applications in production research in the sharing and circular economy era. *International Journal of Production Research*, *58*(1), 118–127. https://doi.org/10.1080/00207543.2019.1681137

Christophers, B. (2022). *Rentier capitalism: Who owns the economy, and who pays for it?* Verso Books.

Clarke, T. (2019). Creative destruction, technology disruption, and growth. In *Oxford Research Encyclopedia of Economics and Finance*.

Codagnone, C., & Martens, B. (2016). Scoping the sharing economy: Origins, definitions, impact and regulatory issues. *Cristiano Codagnone and Bertin Martens (2016). Scoping the Sharing Economy: Origins, Definitions, Impact and Regulatory Issues. Institute for Prospective Technological Studies Digital Economy Working Paper*, *1*.

Corvellec, H., Stowell, A. F., & Johansson, N. (2022). Critiques of the circular economy. *Journal of Industrial Ecology*, *26*(2), 421–432. https://doi.org/10.1111/jiec.13187

Daellenbach, H., McNickle, D., & Dye, S. (2012). *Management science: decision-making through systems thinking*. Palgrave macmillan.

Dal Maso, G., Robertson, S., & Rogers, D. (2021). Cultural platform capitalism: Extracting value from cultural asymmetries in RealTech. *Social \& Cultural Geography*, *22*(4), 565–580.

Dantas, T. E. T., de-Souza, E. D., Destro, I. R., Hammes, G., Rodriguez, C. M. T., & Soares, S. R. (2021). How the combination of Circular Economy and Industry 4.0 can contribute towards achieving the Sustainable Development Goals. *Sustainable Production and Consumption*, *26*, 213–227. https://doi.org/10.1016/j.spc.2020.10.005

de Souza Junior, H. R. A., Dantas, T. E. T., Zanghelini, G. M., Cherubini, E., & Soares, S. R. (2020). Measuring the environmental performance of a circular system: Emergy and LCA approach on a recycle polystyrene system. *Science of The Total Environment*, *726*, 138111.

Dickel, S., & Schrape, J.-F. (2017). The logic of digital utopianism. *NanoEthics*, *11*(1), 47–58.

Dunbar-Hester, C. (2019). Challenging digital utopianism. *Media Management and Digital Transformation*.

Ethiraj, S. K., & Levinthal, D. (2004). Modularity and innovation in complex systems. *Management Science*, *50*(2), 159–173.

Figueiredo, T., & Borges, A. L. A. (2021). "And then the pandemic happened...": the digital divide in education in times of Covid-19 and critical information literacy as a route for the exercise of citizenship. *International Review of Information Ethics*, *30*, 8.

Francis, A., & Thomas, A. (2022). System dynamics modelling coupled with multi-criteria decision-making (MCDM) for sustainability-related policy analysis and decision-making in the built environment. *Smart and Sustainable Built Environment*, *Mcdm*. https://doi.org/10.1108/SASBE-09-2021-0156

Franco, M. A. (2019). A system dynamics approach to product design and business model strategies for the circular economy. *Journal of Cleaner Production*, *241*, 118327. https://doi.org/10.1016/j.jclepro.2019.118327

Friedenthal, S., Davey, C., Nielsen, P., Schreinemakers, P., Oster, C., Sparks, E., Matthews, S., Riethle, T., Stoewer, H., Nichols, D., & Roedler, G. (2021). *Systems Engineering Vision 2035*. www.incose.org/sevision

Ganapati, S., & Reddick, C. G. (2018). Prospects and challenges of sharing economy for the public sector. *Government Information Quarterly*, *35*(1), 77–87. https://doi.org/10.1016/j.giq.2018.01.001

Gärtner, C., & Schön, O. (2016). Modularizing business models: between strategic flexibility and path dependence. *Journal of Strategy and Management*.

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*, *143*, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Goldstraw, K., & Herrington, T. (2021). *Socially Distanced Activism: Voices of Lived Experience of Poverty During COVID-19*. Policy Press.

Good Gingrich, L. (2010). The symbolic economy of trans-border governance: A case study of subjective exclusion and migrant women from Mexico. *Refugee Survey Quarterly*, *29*(1), 161–184.

Grabowska, S., Saniuk, S., & Gajdzik, B. (2022). Industry 5.0: improving humanization and sustainability of Industry 4.0. *Scientometrics*, 1–28.

Hammond, D. (2010). *The science of synthesis: Exploring the social implications of general systems theory*. University Press of Colorado.

Harvey, M., Hastings, D. P., & Chowdhury, G. (2021). Understanding the costs and challenges of the digital divide through UK council services. *Journal of Information Science*, 01655515211040664.

Hensmans, M. (2021). How digital fantasy work induces organizational ideal reversal? Long-term conditioning and enactment of digital transformation fantasies at a large alternative bank (1963--2019). *Organization*, *28*(1), 132–163.

Hermann, M., Pentek, T., & Otto, B. (2016). Design principles for industrie 4.0 scenarios. *2016 49th Hawaii International Conference on System Sciences (HICSS)*, 3928–3937.

Horváth, I. (n.d.). Designing next-generation cyber-physical systems: Why is it an issue? *Journal of Integrated Design and Process Science*, *Preprint*, 1–33.

Hughes, L., Dwivedi, Y. K., Rana, N. P., Williams, M. D., & Raghavan, V. (2022). Perspectives on the future of manufacturing within the Industry 4.0 era. *Production Planning \& Control*, *33*(2–3), 138–158.

Jackson, M. C. (2020a). Critical systems practice 1: Explore—Starting a multimethodological intervention. *Systems Research and Behavioral Science*, *37*(5), 839–858.

Jackson, M. C. (2020b). How we understand "complexity" makes a difference: Lessons from critical systems thinking and the Covid-19 pandemic in the UK. *Systems*, *8*(4), 52.

Jackson, M. C. (2021). Deploying systems thinking to create a triple-crown business school. In *How to lead academic departments successfully*. Edward Elgar Publishing.

Jackson, M. C., & Keys, P. (1984). Towards a system of systems methodologies. *Journal of the Operational Research Society*, *35*(6), 473–486.

Jensen, O. B. (2021). Urban mobilities and power: Social exclusion by design in the city. In *Hybrid Mobilities* (pp. 37–55). Routledge.

Johnston, R. B. (2016). Arsenic and the 2030 Agenda for sustainable development. *Arsenic Research and Global Sustainability - Proceedings of the 6th International Congress on Arsenic in the Environment, AS 2016*, 12–14. https://doi.org/10.1201/b20466-7

Kamruzzaman, M. M. (2021). New Opportunities, Challenges, and Applications of Edge-AI for Connected Healthcare in Smart Cities. *2021 IEEE Globecom Workshops, GC Wkshps 2021 - Proceedings*, *2022*. https://doi.org/10.1109/GCWkshps52748.2021.9682055

Kazancoglu, Y., Ekinci, E., Mangla, S. K., Sezer, M. D., & Kayikci, Y. (2021). Performance evaluation of reverse logistics in food supply chains in a circular economy using system dynamics. *Business Strategy and the Environment*, *30*(1), 71–91. https://doi.org/10.1002/bse.2610

Khalid Khan, S., Shiwakoti, N., & Stasinopoulos, P. (2022). A conceptual system dynamics model for cybersecurity assessment of connected and autonomous vehicles. *Accident Analysis and Prevention*, *165*(June 2021), 106515. https://doi.org/10.1016/j.aap.2021.106515

Klinge, T. J., Hendrikse, R., Fernandez, R., & Adriaans, I. (2022). Augmenting digital monopolies: A corporate financialization perspective on the rise of Big Tech. *Competition \& Change*, 10245294221105572.

Kwet, M. (2022). The Digital Tech Deal: a socialist framework for the twenty-first century. *Race \& Class*, *63*(3), 63–84.

Marshall, A., Dezuanni, M., Burgess, J., Thomas, J., & Wilson, C. K. (2020). Australian farmers left behind in the digital economy--Insights from the Australian Digital Inclusion Index. *Journal of Rural Studies*, *80*, 195–210.

Mayer, K. B., Bureau of Social Affairs, Secretariat, U. N., Office, I. L., Food and Agriculture Organization, & Organization, W. H. (1958). Report on the World Social Situation. *American Sociological Review*, *23*(2), 238. https://doi.org/10.2307/2089039

McCloskey, S. (2015). From MDGs to SDGs: We need a critical awakening to succeed. *Policy \& Practice-A Development Education Review*, *20*.

Medina-Borja, A. (2015). Smart things as service providers: A call for convergence of disciplines to build a research agenda for the service systems of the future. *Service Science*, *7*(1), ii–v. https://doi.org/10.1287/serv.2014.0090

Medynska, T., Sai, L., Akimkin, O., Kruchak, L., & Doroshenko, T. (2022). Characteristics of the Problems of Socio-Economic Development in the Conditions of Digital Economy. *IJCSNS*, *22*(2), 297.

Micheli, G. J. L., Trucco, P., Sabri, Y., & Mancini, M. (2019). Modularization as a system life cycle management strategy: Drivers, barriers, mechanisms and impacts. *International Journal of Engineering Business Management*, *11*, 1847979018825041.

Mihelj, S., Leguina, A., & Downey, J. (2019). Culture is digital: Cultural participation, diversity and the digital divide. *New Media \& Society*, *21*(7), 1465–1485.

Mitroff, I. I., Betz, F., Pondy, L. R., & Sagasti, F. (1974). On managing science in the systems age: two schemas for the study of science as a whole systems phenomenon. *Interfaces*, *4*(3), 46–58.

Mohammadi, F. G., Shenavarmasouleh, F., Amini, M. H., & Reza Arabnia, H. (2022). Data analytics for smart cities: Challenges and promises. *Cyberphysical Smart Cities Infrastructures: Optimal Operation and Intelligent Decision Making*, 13–27.

Morgan, G. (1986). Images of organization London. *UK Sage*.

Morgan, G. (1998). Images of organization: The executive edition. *Thousand Oaks, CA*.

Morin, E. (2007). Restricted complexity, general complexity. *Science and Us: Philosophy and Complexity. Singapore: World Scientific*, 1–25.

Nayal, K., Kumar, S., Raut, R. D., Queiroz, M. M., Priyadarshinee, P., & Narkhede, B. E. (2022). Supply chain firm performance in circular economy and digital era to achieve sustainable development goals. *Business Strategy and the Environment*, *31*(3), 1058–1073. https://doi.org/10.1002/bse.2935

Neto, V. V. G., Garcés, L., Guessi, M., Paes, C. E. B., Manzano, W., Oquendo, F., & Nakagawa, E. (2018). ASAS: An approach to support simulation of smart systems. *Proceedings of the Annual Hawaii International Conference on System Sciences*, *2018-January*, 5777–5786. https://doi.org/10.24251/hicss.2018.724

Nunes, S. A. S., Ferreira, F. A. F., Govindan, K., & Pereira, L. F. (2021). "Cities go smart!": A system dynamics-based approach to smart city conceptualization. *Journal of Cleaner Production*, *313*, 127683.

Ogunmakinde, O. E., Egbelakin, T., & Sher, W. (2022). Contributions of the circular economy to the UN sustainable development goals through sustainable construction. *Resources, Conservation and Recycling*, *178*(October 2021), 106023. https://doi.org/10.1016/j.resconrec.2021.106023

Park, S., & Humphry, J. (2019). Exclusion by design: intersections of social, digital and data exclusion. *Information, Communication \& Society*, *22*(7), 934–953.

Pascual, D. G., Daponte, P., & Kumar, U. (2019). *Handbook of Industry 4.0 and SMART Systems*. CRC Press.

Pessoa, M. V. P., Pires, L. F., Moreira, J. L. R., & Wu, C. (2022). Model-Based Digital Threads for Socio-Technical Systems. In *Machine Learning for Smart Environments/Cities* (pp. 27–52).

Springer.
Peters, M. A. (2022). Digital trade, digital economy and the digital economy partnership agreement (DEPA). In *Educational Philosophy and Theory* (pp. 1–9). Taylor \& Francis.
Potekhin, V. V., Selivanova, E. N., & Katalinič, B. (2022). Development of a digital transformation model for industrial cyber-physical systems. *AIP Conference Proceedings*, *2456*(January). https://doi.org/10.1063/5.0075038
Pourmehdi, M., Paydar, M. M., Ghadimi, P., & Azadnia, A. H. (2022). Analysis and evaluation of challenges in the integration of Industry 4.0 and sustainable steel reverse logistics network. *Computers and Industrial Engineering*, *163*(October 2021), 107808. https://doi.org/10.1016/j.cie.2021.107808
Prabhu, V. N. (2022). Organ, Organism, Organization: A Study in the Evolution of the Organismic Metaphor. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.4031673
Ragnedda, M., Laura, M., & Addeo, F. (2022). Telematics and Informatics The self-reinforcing effect of digital and social exclusion : The inequality loop. *Telematics and Informatics*, *72*(May), 101852. https://doi.org/10.1016/j.tele.2022.101852
Ramakrishna, S., Ngowi, A., Jager, H. De, & Awuzie, B. O. (2020). Emerging industrial revolution: Symbiosis of Industry 4.0 and circular economy: The role of universities. *Science, Technology and Society*, *25*(3), 505–525.
Ranchordás, S. (2020). Connected but still excluded? Digital exclusion beyond internet access. *The Cambridge Handbook of Life Sciences, Informative Technology and Human Rights (Cambridge University Press, 2021, Forthcoming), University of Groningen Faculty of Law Research Paper*, *40*.
Reich, R. (2015). The share-the-scraps economy. *Robert Reich*, *2*(2), 2015.
Romero, M., Guédria, W., Panetto, H., & Barafort, B. (2020). Towards a Characterisation of Smart Systems: A Systematic Literature Review. *Computers in Industry*, *120*, 1–23. https://doi.org/10.1016/j.compind.2020.103224
Sanguino, R., Barroso, A., Fernández-Rodríguez, S., & Sánchez-Hernández, M. I. (2020). Current trends in economy, sustainable development, and energy: a circular economy view. *Environmental Science and Pollution Research*, *27*(1), 1–7. https://doi.org/10.1007/s11356-019-07074-x
Schelenz, L., & Pawelec, M. (2022). Information and Communication Technologies for Development (ICT4D) critique. *Information Technology for Development*, *28*(1), 165–188. https://doi.org/10.1080/02681102.2021.1937473
Sedarati, P., Serra, F., & Jere Jakulin, T. (2022). Systems approach to model smart tourism ecosystems. *International Journal for Quality Research*, *16*(1), 285–306.
Shafiee, S., Jahanyan, S., Ghatari, A. R., & Hasanzadeh, A. (2022). Developing sustainable tourism destinations through smart technologies: A system dynamics approach. *Journal of Simulation*, 1–22.
Sharif, N., & Huang, Y. (2019). Introduction: Innovation and Work in East Asia. In *Science, Technology and Society* (Vol. 24, Issue 2, pp. 193–198). SAGE Publications Sage India: New Delhi, India.
Sin, J. (2019). Designing the Divide: A Book Report on the Ultimate Handbook on Designing the Digital Divide. *At CHI4Evil Workshop at the 2019 CHI Conference on Human Factors in Computing Systems. ACM*.
Srnicek, N. (2017). The challenges of platform capitalism: Understanding the logic of a new business model. *Juncture*, *23*(4), 254–257.
Stahel, W. R. (2016). Circular economy - A new relationship with our goods and materials would save resources and energy and create local jobs. *Nature*, *531*, 435–438. https://www.nature.com/articles/531435a.pdf
Standing, G. (2018). The precariat: Today's transformative class? *Development*, *61*(1), 115–121.
Stary, C., Elstermann, M., Fleischmann, A., & Schmidt, W. (2022). Behavior-Centered Digital-Twin

Design for Dynamic Cyber-Physical System Development. *Complex Systems Informatics and Modeling Quarterly*, *30*, 31–52. https://doi.org/10.7250/csimq.2022-30.02

Suleiman, Z., Shaikholla, S., Dikhanbayeva, D., Shehab, E., & Turkyilmaz, A. (2022). Industry 4.0: Clustering of concepts and characteristics. *Cogent Engineering*, *9*(1), 0–26. https://doi.org/10.1080/23311916.2022.2034264

Tarasenko, F. P. (2020). The Current Stage of Development of Systems Thinking: The Transition from the Ideology of the Machine Age to the Ideology of the Systems Age. In *Applied Systems Analysis* (pp. 167–173). CRC Press.

Valckenaers, P., Van Brussel, H., Hadeli, Bochmann, O., Germain, B. Saint, & Zamfirescu, C. (2003). On the design of emergent systems: An investigation of integration and interoperability issues. *Engineering Applications of Artificial Intelligence*, *16*(4), 377–393. https://doi.org/10.1016/S0952-1976(03)00080-0

van Gigch, J. P. (1984). The meaning of truth in the systems age. *Human Systems Management*, *4*(3), 220–225.

van Langen, S. K., Vassillo, C., Ghisellini, P., Restaino, D., Passaro, R., & Ulgiati, S. (2021). Promoting circular economy transition: A study about perceptions and awareness by different stakeholders groups. *Journal of Cleaner Production*, *316*, 128166.

Vartanova, E. L., & Gladkova, A. A. (2019). New forms of the digital divide. In *Digital Media Inequalities: Policies against Divides, Distrust and Discrimination* (pp. 193–213).

Verhoef, P. C., Broekhuizen, T., Bart, Y., Bhattacharya, A., Dong, J. Q., Fabian, N., & Haenlein, M. (2021). Digital transformation: A multidisciplinary reflection and research agenda. *Journal of Business Research*, *122*, 889–901.

Wang, B., Zheng, P., Yin, Y., Shih, A., & Wang, L. (2022). Toward human-centric smart manufacturing: A human-cyber-physical systems (HCPS) perspective. *Journal of Manufacturing Systems*, *63*(March), 471–490. https://doi.org/10.1016/j.jmsy.2022.05.005

Williams, B., Soulet, M., & Siraj, A. (2023). A Taxonomy of Cyber Attacks in Smart Manufacturing Systems. *6th EAI International Conference on Management of Manufacturing Systems*, 77–97.

Yi, S., Zaoli, Y., Xuemei, X., & Harish, G. (2022). Complex System Models and Their Application in Industrial Cluster and Innovation Systems. In *Complexity* (Vol. 2022). Hindawi.

Zander, J., & Mosterman, P. J. (2013). *Computation for humanity: Information technology to advance society*. CRC Press.

Zandi, I. (2000). Science and engineering in the age of systems. *What Is Systems Engineering*.