Chapter

Mastering Digital Transformation with Service Dominant Architecture

Peter Weiß, Markus Warg and Andreas Zolnowski

Abstract

The paper presents insights from a longitudinal case study of an insurance company. Digital transformation requires companies to review their strategy. Today, information technologies fundamentally transform whole business models, products, and services. Innovations are an opportune strategy for companies to compete in the digital age and to transform their business models, taking a service perspective on their value creation. Service Dominant Architecture (SDA) offers practitioners a framework and environment to design and operate service systems and systems of engagement. Furthermore, it stimulates collaborative theorizing processes by involving decision-makers, managers, and practitioners in general as active participants in the research process (midrange-theory). Our focus is on evolving and applying our framework and IT artifact SDA. SDA provides guidance to practitioners and researchers, respectively, on how to build implementable and operable solution designs in real practice. Our research on SDA is primarily informed and guided by a Design Science Research (DSR) approach.

Keywords: digital transformation, engagement systems, service platform, service dominant architecture, service-dominant logic

1. Introduction

Digitization and digital transformation affect business in many companies. Companies are confronted with fast-changing markets and customer behavior because digital technologies affect the life events of consumers and producers [1]. Most practitioners perceive a gap and disconnect between the design of digital strategies and their execution. We will argue that building systems of engagement is central to key industries and evolve into a crucial role in service innovation. Service Dominant Architecture (SDA) aims to close this gap by translating the requirements of business initiatives into composable technical and business capabilities. SDA is implemented as a platform on top of existing IT infrastructures (systems of record) and offers new capabilities (systems of engagement) summarized as the foundation for strategy execution. SDA constitutes a conceptual framework and solution design, respectively. Management of actor engagement is seen as a key dynamic capability for companies to cope with the challenges of digital transformation. This research aims to expand the knowledge base and theoretical foundations of SDA.

The chapter provides an update on the current state of play of our ongoing research. We present new insights in relation to achievements and developments of previously conducted SDA research; both from a theoretical and practical point of view. We will provide an update of gained insights and will offer an outlook on future research challenges and the road ahead. We motivate the next steps and activities to evolve the SDA. The originality and value of SDA lie on the one hand in its concreteness and applicability and on the other hand in its link to the foundations of Service-Dominant Logic (S-D Logic) and Service Science.

The paper is structured as follows. The first two sections motivate our research and describe the research contribution, approach, and objectives. Then, we review and describe the digital transformation and its challenges highlighting in particular three decision areas. Next step, looks at required investments in new IT infrastructure capabilities building foundations for execution to realize envisioned digital strategies. Next, SDA is presented as a solution design and framework to guide strategy development and implementation of solutions in real practice. Finally, we summarize our research results and draw conclusions.

2. Research contribution, method and objectives

Our research on SDA is primarily informed and guided by a Design Science Research (DSR) approach [2–4]. Therefore, this chapter is organized according to the requirements and properties of a DSR project [4, 5]. Researchers have to understand the problems emerging in real-life projects and practice. Hevner et al. [2] have emphasized a design science approach that underscores a construction-oriented view of information systems (IS) research.

In particular, DSR puts emphasis on the relevance of research results to applications in business [3]. Accordingly, IS research is concerned with the development and use of IT artifacts in organizations [6]. Hence, the design, development, and evaluation of IT artifacts are at the core of the IS discipline [3, 5]. IS research deals with the development and use of information technology-related artifacts in human-machine systems [3]. DSR projects solve real-world problems involving the design of complex information systems. Hence, the IT artifact should be a focal point in most IS research [4]. Intervention activities are vital for building and evaluating effective systems designs in context as well as reflecting and generating design principles [4]. Suitably, presented research contributes to expand the knowledge of information systems design by technical action and making (**Figure 1**).

Conducted DSR projects covered both technical actions but as well generating a broader knowledge base about the phenomenon of digital transformation. In this way, we act in response to the requirements of DSR projects to advance existing knowledge in either a problem or solution domain [4]. Technical action is primarily focused on and determined by conceptualizing our IT artifact based on the purposed subsystems of SDA. Further, we concretize respective solution designs to meet the requirements of the given organizational context and the observable phenomenon of digital transformation [8]. SDA as a framework conceptualizes five distinguished subsystems. SDA solution design was developed and evolved incrementally and iteratively following an engineering (technical action) approach [7]. In addition, we have considered the requirements of Action Design Research (ADR) [6], service systems engineering [9],

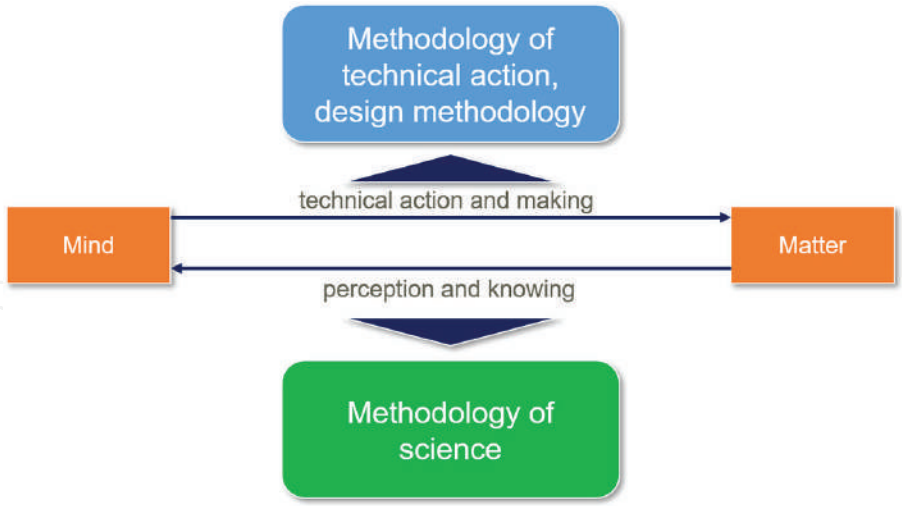

Figure 1.
Research approach and contribution: technical action [7].

and systems development [10, 11]. In order to develop the required understanding and generate knowledge about the state of the problem, we assessed current solutions and their efficacy in a selected organizational context [4].

Applying a longitudinal case study approach [12] allowed us to investigate the problem at hand, as well as to strive for a deeper and more comprehensive understanding of the given organizational context and its properties. This supports our ambition to generalize generated knowledge beyond the targeted application domain, namely the insurance business. We have been able to achieve the long-term commitment of participating organizations. Our case company is an insurance company with round about 12 thousand employees located in Germany.

In subsequent sections, we further concretize and determine the IT artifact's purpose, desired functionality, and its architecture as a base for technical action. Besides producing the novel artifact and instantiating respective processes and tasks, our DSR project aims to make in addition more general contributions to expand the knowledge base. This is achieved through elaborating on a midrange design theory about the phenomena of digital transformation [4].

As shown in **Figure 1** this relates to our evaluation activities which require a framework allowing to derive conclusions about created evidence. Our objective is to make a research contribution through the demonstration of the novel IT artifact. The IT artifact embodies design ideas and principles and theories which we aim to articulate on basis of our SDA framework. Our ambition is to reflect and generate design principles on basis of decisions made realizing the design proposal [4, 7]. Implemented use cases support evaluation activities comparing hypothetical predictions and facts with requirements [7].

We complement the DSR with an embedded single case study [12]. By analyzing different use cases within the longitudinal single case study of SDA and using more than one perspective, we broaden our scope aiming at a better understanding of the relevance of the solution design and long-term evaluation of the IT artifact created. Our research approach thus addresses the following pivotal research questions [13]:

1. How can digital strategies draw from a S-D Logic perspective and related principles to derive and build new capabilities to build unique value propositions based on service innovations?

2. What are respective capabilities to be derived to support business initiatives and strategic agility to design and operate co-creative business models incorporating digital technologies?

3. Digital transformation and insurance business

This section oversees digital transformation and describes the state of the problem. We start with a general description of the phenomenon of digital transformation. In a further step, we look then specifically into digital transformation in the context of the insurance business. We elucidate observable challenges and related problems. On this basis, we explain how we elaborated our solution design and derived relevant objectives for technical action (construction) and evaluation activities. An important step of the DSR process is to communicate the problem and its importance. This will be in the focus of subsequent sections before we describe our practical solution as a result of our DSR project [5].

3.1 Digital transformation: strategy, technology, value creation

Digital transformation can be defined as "[…] a process that aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication, and connectivity technologies" [8, 14]. Hence, digital transformation needs to be understood rather as a process than as a state (**Figure 2**) [8].

Digitalization and digital transformation are the "[…] main driver of innovation and change in all sectors of our economy" and are taking place at a rapid pace [14–18]. The effect of digital transformation is discussed to be a revolution that unleashes and develops disruptive powers to change existing structures and systems [8, 15, 19]. Today, we face dramatic change in the business world through rapid digitization and new innovative business models breaking down industry barriers [19, 20]. Digital

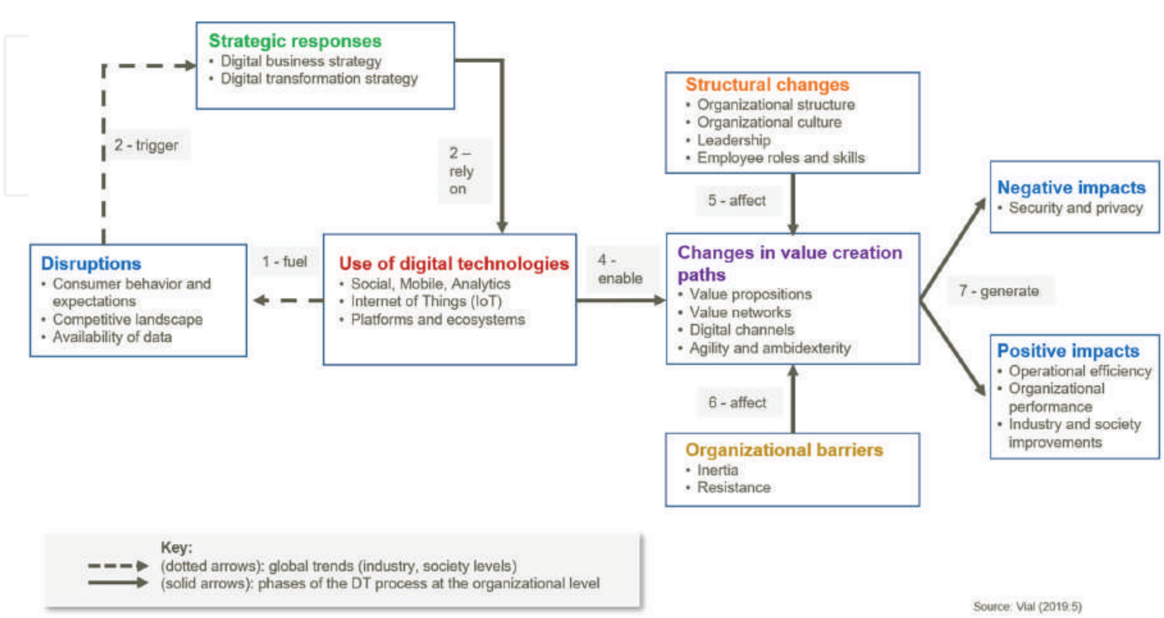

Figure 2.
Building blocks of the digital transformation process (own illustration based on [8]).

technologies are creating new opportunities but require a clear digital strategy [15, 21–23]. Based on a clear digital strategy, decisions concerning required IT investments and new infrastructure capabilities are achievable [1, 18].

Digital transformation is primarily about digital technologies and the conceptualization of their potential impact on a companies' current or future business. It is crucial for business leaders to understand the disruptive forces that digital technologies can unleash changing current business logic and value constellations [16, 17]. Digital disruption is a process, which creates dramatic change for industries or business branches based on the following attributes [19]: (1) rapidly digitizing, (2) breaking down industry barriers, (3) creating new opportunities, and (4) while destroying long-successful business models [1, 8].

In the remainder, we follow the proposed structure and elucidate related challenges in three particular areas shown in **Figure 2**, namely (1) strategy responses through digital strategy, (2) investment and use of digital technologies aligned with business strategy, and (3) changes in value creation activities and paths due to new business logics and changing markets.

3.2 Digital strategies and strategic responses

Digital responses to digital disruption encompass developing a digital business strategy and designing a digital transformation strategy [8]. Digital strategy is a business strategy inspired by the newly created IT infrastructure capabilities enabled by digital technologies (such as SMACIT: Social, Mobile, Analytics, Cloud, Internet of Things). The aim is to deliver unique, integrated business capabilities supporting strategic agility [23]. Hence, they have to be responsive to constantly change market conditions [23]. Thereby, companies seek ways to combine and augment existing capabilities with capabilities enabled by new digital technologies to create new value propositions [23].

Digital technologies remove long-established constraints of value creation activities, namely allowing new unprecedented reconfigurations of resources by applying new business logic such as platform-led strategies [24, 25]. Companies have to find appropriate strategic responses to resulting impacts and have to anticipate proactively future developments to be able to build required new digital capabilities.

Ross et al. [23] see in general two major directions to develop digital strategies, namely (1) customer engagement and (2) digitized solutions. Both directions allow to respond to described challenges [22, 23]. Digital business design relates to decisions oriented toward the support and realization of relevant business initiatives [15, 21]. Based on a vision of how the company will operate, business and IT have to agree and decide on key architectural requirements of the foundation for execution. Foundation for execution can be seen as a synonym for the Enterprise Architecture (EA). Each business initiative needs to highlight how it benefits from or contributes to the foundation for execution. Business initiatives can be either supplier-, customer- or internally oriented [26].

3.3 Digital technologies and new capabilities

Digital technologies constitute a central change driver fueling changes in value creation paths such as value propositions, value constellations or networks, digital channels, agility, and ambidexterity [8]. Digital technologies are linked in general to three types of disruptions: (1) change in customer behavior, preferences, and expectations, (2) new competitive landscape (new value constellations and removed barriers for competitors), and (3) availability of data [8].

Mastering the challenges of digital transformation, companies need to reflect and rethink their strategic positioning and by this their information systems and information technology strategy [23]. Enterprise architecture reflects the awareness that the design of information systems needs to be seen in a broader business and enterprise context. Business and IT need to be co-designed, and well-aligned to create foundations for execution [18, 27]. However, building foundations for execution requires companies to look at organizational design dimensions, which are often overlooked and not adequately considered in architectures that are aligned to the business strategy and the solution design [28]. Thus, digital technologies from our perspective open up new opportunity spaces for companies to interact in new ways with their customers and reach for new customer segments. However, this requires unprecedented levels of customer intimacy and a higher frequency of customer interactions. Digital technologies offer new strategic perspectives for companies to compete through service innovations substantiated in a shift from products to solutions to value-in-use. This translates into new practices of learning [4, p. 86] to arrive at more personalized, customized solutions and offerings, offering new strategic opportunities to operate as platform owner or "smart service provider".

Senior management has to make important decisions concerning infrastructure investments to introduce new strategic and operative capabilities for the company required to sustain in the digital age. Companies need to incorporate digital technologies to build new IT and business capabilities [18, 26] to achieve the required strategic agility and to create unique value propositions [15, 22].

Mastering digital transformation requires a clear understanding of the relationship as well as interdependencies between IT (infrastructure) capabilities of the enterprise and its "ability to implement its business initiatives" [26]. This relationship is addressed by an emerging discipline named EA Management (EAM) [21, 27, 29]. EA as discipline deals with "[…] controlling the complexity of the enterprise and its processes and systems" [29]. Hence, enterprise architecture defines principles, methods, and models resulting from the design of what constitutes the foundation for execution [21]. Weill et al. define strategic agility as "[…] set of business initiatives an enterprise can readily implement" [26]. Enterprise capability encompasses coordinating a respective set of elements such as customer base, brand, core competence, infrastructure, and employees, into an "integrated group of resources" [26].

Companies have to strive for strategic agility through building required IT infrastructure capabilities [18, 26]. However, what are the required IT infrastructure capabilities? Moore [30] motivates a new generation of enterprise IT systems based on interactive IT infrastructure capabilities which he summarizes as "systems of engagement" [13, 30, 31]. In essence, digital transformation requires a dramatic change in enterprise information systems (EIS).

3.4 Changes in value creation logics

Digital transformation is increasingly associated with a service imperative. However, this necessitates to establish respective mindsets and perspectives (**Figure 1**). Related developments are discussed increasingly as "digital servitization" [32–34] by augmenting existing offerings and value propositions with (digital) service elements. In the remainder, we argue a service perspective to overcome the challenges of digital transformation.

In this context, service innovations can be seen as an opportune strategy for companies to compete in the digital age [35]. Companies need to change their prevailing product-dominant mindset to a service-dominant one to develop digital strategies [15, 18, 22, 23]. New technologies introduce new capabilities, such as resource integration, that catalyze service innovations [18, 31]. Executing digital strategies is a major challenge for many companies as they rely on outdated, monolithic EIS. As a result, siloes prevent companies to mobilize and integrate valuable internal and external resources [36].

No doubt, the insurance business is currently undergoing dramatic change and is subject of digital disruptions (originating from new innovative service offerings and new market players ("digital attackers")) [1]. Consequently, insurers have to develop new visions of how to develop new value-adding offerings. This requires deeper customer insights and redesigning operations from the customer perspective. Incumbent insurers lack the required capabilities along with facing significant inertia and as a consequence are thus slow and not agile as their emerging competitors. Thereupon, incumbent insurers have launched new organizational entities freed from slowing and impeding restrictions such as compliance, regulations, and cultural barriers. Those new digital entities move faster, more agile, and adapt easier also more flexible to emerging changes such as customer preferences, behaviors, or new market segments (for example, car sharing, electric bikes, etc.) [37]. In consequence, incumbents have to find the right strategic responses to compete against digital attackers with more appealing, customer-centric, cheaper, more innovative products and services. To adapt and survive such digital Darwinism, insurers have to rediscover and renew their capabilities such as digitizing operations, imagining new customer journey, delighting their customers with excellent service, and reimagine their core systems and structures.

3.4.1 Service-dominant logic

As previously argued, digital technologies offer new opportunities for companies to innovate and to leverage their productivity. Taking a service lens on innovation and related processes is preferable, as it spurs new creative thinking through new mental models and creative business thinking by drawing from new perspectives on value creation activities.

Service-Dominant (S-D) logic [38–40] grounds on a resource-based perspective. It differs from broadly established goods-dominant (G-D) logic thinking through prioritizing "operant resources" (competence, skills, and knowledge) against "operand" resources (physical assets, goods) to achieve competitive advantage. Accordingly, S-D logic puts emphasis on cocreation, actor-to-actor networks, and interactive processes of learning. Service is defined as the application of resources (in particular knowledge, skills, and competencies) to make changes that have value for another [38–42].

Table 1 shows the S-D logic axioms and foundational premises (FP) which formalize related value creation logics and principles [38–41, 43, 44]. The value co-creation takes place in service systems. Service systems are defined as dynamic value-cocreation configuration of resources, including people, organizations, shared information (language, laws, measures, methods), and technology, all connected internally and externally to other service systems by value propositions [9, 45, 46]. Accordingly, a service system is an open system (1) capable of improving the state of another system through sharing or applying its resources, and (2) capable of improving its own state by acquiring external resources [47]. Overall, service systems [45–47] foster a systems

Axiom	Description	Capability
A1/FP1 FP2 FP3 FP4 FP5	Service is the fundamental basis of exchange Indirect exchange masks the fundamental basis of exchange Goods are a distribution mechanism for service provision Operant resources are the fundamental source of competitive advantage All economies are service economies	Service-for-service exchange Operand resources Operant resources Service provision Service economies
A2/FP6 FP7 FP8	Value is co-created by multiple actors, always including the beneficiary The enterprise can only make value propositions A service-centered view is customer-oriented and relational	Value cocreation Interaction Relationship Learning Customer orientation Value propositions
A3/FP9	All social and economic actors are resource integrators	Resource integration Resource orchestration
A4/FP10	Value is always uniquely and phenomenologically determined by the beneficiary	Value-in-use Value-in-context Service experience
A5/FP11	Value co-creation is coordinated through actor-generated institutions and institutional arrangements	Coordination Value cocreation Service Ecosystem Collaboration Actor-to-actor network Institution, institutional arrangements

Table 1.
Service-dominant logic: axioms and foundational premises (FP) [38–41].

perspective for studying and understanding service ecosystems and their influence on service-for-service exchange and emerging digital markets. S-D logic provides guidance through its systemic perspective on value creation activities, through service-exchanging entities and underlying logic. From S-D logic perspective, service innovation is embedded in an actor-to-actor network, which underscores the importance of common organizational structures and sets of principles to facilitate resource integration and service exchange among those actors [35].

As proposed by Lusch and Nambisan [35], service innovation can be conceptualized through a tripartite framework consisting of three major concepts, namely service ecosystem, service platform, and value co-creation. S-D logic showed high relevance for the later development of our framework and respective design patterns. S-D logic serves as the theoretical foundation of Service Science.

Of particular relevance is the concept service platform. Platform concepts create systems or environments to engage with other actors and resources in mutual value creation activities (systems of engagement) [18, 31]. In this context, to identify and know about resources external to the firm and the services they are able to render are of vital importance and constitutes a major incentive to search for new external knowledge.

3.4.2 Building systems of engagement

As previously motivated digital strategies are based on customer engagement and digitalized solutions. Understanding customer engagement or more general actor engagement is a pivotal capability to master successfully digital transformation. Systems of Engagement (SoE) relate to service platforms and digital platforms, respectively. Hereinafter, we summarize briefly relevant contents and refer to previous publications for further details and studies [1, 18, 31, 48–51]. SoE is seen as the next stage of enterprise IT which bring companies new communication and collaboration capabilities to engage with their customers and suppliers, and vice versa, with a focus on communication to enable collaborative business in real-time with all the benefits of mobility and speed [18, 30, 48, 50]. In summary, SoE brings companies new communication and collaboration capabilities. SoE brings S-D logic to the fore as this type of systems will foster interactions and relationships with communities and in more general resources that are outside the enterprise. Actor engagement [31, 48, 50–52] can be conceptualized as microfoundation for value cocreation within service ecosystems [9, 53]. Engagement platforms are an interesting field of research as the concept is not yet clearly defined. Engagement platforms are defined as multisided intermediaries that actors leverage to engage with other actors to integrate resources. Engagement platforms can be both intermediary or mediator. Hence, resource integration [54] turns into a core business capability to run what Moore [30] phrases as social business systems [48]. **Table 1** shows a list of elicited capabilities that need to be addressed by systems of engagement.

4. Digital transformation and insurance business

Trends such as connected cars, automated driving, smart home, connected healthcare are just a few examples representing change and new requirements for the insurance business. Incumbent companies possess customer insights and can rely on strong relational ties to their customers and business partners. However, this advantage is lost increasingly to new players entering their markets and targeting for their profitable customer segments. Those companies are named "digital attackers" [55]. Digital technologies are lowering the barriers for digital attackers to enter those markets to exploit new opportunities by using their digital capabilities and related key competencies as an advantage. Digital attackers are faster, more focused on customers, and responsive to their particular needs. Insurers risk to lose prosperous customer segments—foremost the younger generation—to new emerging competitors such as insurtechs [49, 50].

4.1 Building foundations for execution

Digital strategy outlines and details besides the business aspects the respective steps forward and targeted investments in IT infrastructure capabilities [18, 21, 26]. Ross et al. identify five building blocks for a digital transformation: (1) operational backbone, (2) digital platform, (3) external developer platform, (4) shared customer insights, (5) accountability framework [15]. "The advantage of approaching digital business design as a set of building blocks is that it allows leaders to focus on specific manageable organizational changes while implementing holistic design" [15]. Bonnet and Westerman propose and describe new elements as the foundation of new digital capabilities [14]. The new elements are grouped into five areas: (1) business model-related capabilities, (2) customer experience, (3) operations, (4) employee experience, and (5) digital platform.

Building a digital platform is fundamental for mastering the challenges of digital transformation [14, 56]. Digital platform contains three components: (1) core platform (operational and transactional systems), (2) externally facing platform, and (3) data platform [14]. The core platform is the company's technology backbone [14]. Detailed requirements of platform-related capabilities are discussed and analyzed in Weiß et al. [18] and are here not further detailed [18, 56, 57]. Secondly, the externally facing platform realizes customer-facing experiments and enables personalized experiences [14]. Finally, the third component, data platform, offers enhanced data analytics capabilities, build and test algorithms, and enables processing of huge amounts of unstructured data [14].

4.2 Service dominant architecture

In this section, we summarize and refer to previous research results and updates documenting the evolution of the IT artifact [13, 18, 31, 36, 58].

SDA was derived from the knowledge base of the domain theories Service Science, S-D Logic, and Institutional Economics with the aim of putting the findings, logic, and processes into practice by enabling actors in the process of value co-creation. Used in practice SDA enables entities to purposeful build up capabilities and to engage in the process of service exchange and value co-creation [55, 58, 59]. SDA can be viewed from a conceptual and an applied perspective:

(1) firstly, SDA a design pattern or virtual order in the understanding of a structure of five systems [58]. (2) secondly, SDA a tangible structure instantiated by at least one entity [60].

The instantiated structure consists of five systems including the recently added SDA service catalog as the fifth system focusing on shared institutional arrangements. SDA applied within an actor-to-actor network facilitates the process and coordination of service exchange and mutual value creation [38, 58]. SDA as architecture operationalizes the core elements of S-D logic by focusing on co-creation and resource integration. The aim of this development is to facilitate the before-motivated SoE [30] by introducing an additional architectural layer. SDA proposes to operationalize requirements and characteristics for the planning, designing, and building of customer-centric solutions, which are characterized by value in use.

4.2.1 SDA conceptual framework

In order to meet these requirements, the SDA conceptual framework defines the design patterns of four purposed subsystems and a Data Lake (**Figure 3**). In the following, respective design patterns are introduced.

1. *System of operant resources:* The system of operant resources is the heart of the SDA framework. It represents the workbench, where the various ingredients (resources) are brought together and processed. For this, this system applies certain logic or processes. An important target of this system is to achieve the required resource density. Solutions are dependent on the achievable level of resource density as a high level of resource density impacts positively the emergence and creation of innovative and valuable solutions [58].

2. *System of interaction:* The system of interaction, enables a bidirectional data flow between the provider and the customer. The aim is to achieve consistent customer-centricity across all customer channels in parallel, also known as omnichannel

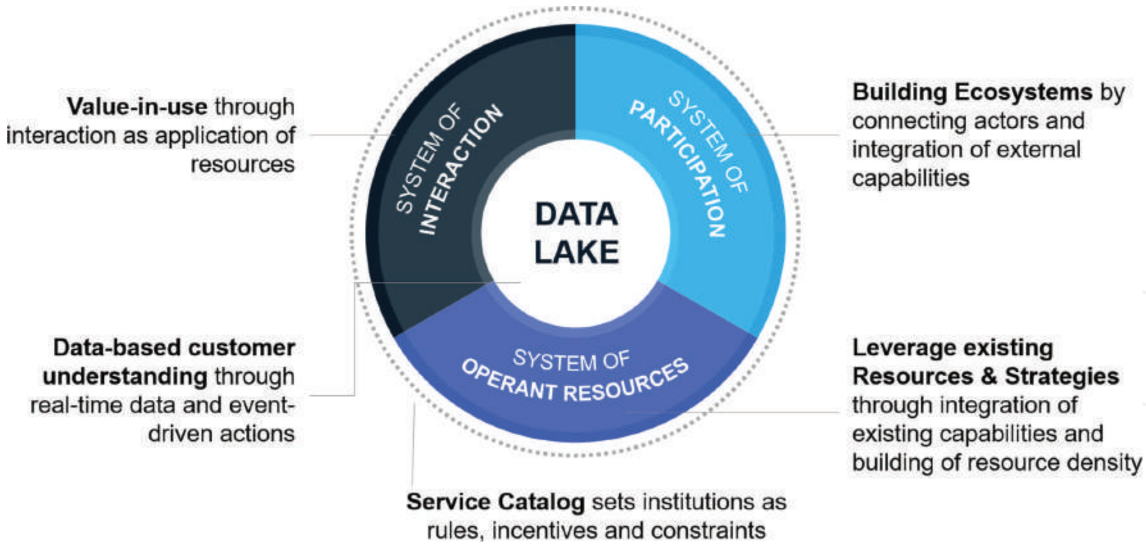

Figure 3.
Design pattern as architectural framework of service dominant architecture (SDA) (source: IfSD.Hamburg).

integration. In such an omnichannel integration layer is created, prerequisite for an interactive, uniform customer experience across all communication channels relevant to the customer.

3. *System of participation:* Ideally, the already presented concept of co-creation includes other co-producers in addition to the respective customer or more general actor. The system of participation enables actor-to-actor orientation and resource integration of third parties, i.e. other external resources.

4. *Data lake:* From a company's point of view, data received and generated by interacting with customers or in the value creation process should be systematically recorded and evaluated in real-time [58].

5. *System of institutional arrangements (service catalog):* As rules in use, institutions enable the coordination of actors as well as access to and use of resources. In conjunction with SDA design pattern, institutions enable the coordinated creation of solution designs by connecting actors and enabling the integration and application of resources [58].

4.2.2 SDA objectives and capabilities

In essence, SDA is the technical implementation of S-D logic (**Table 1**) and one of the most important elements for strategy execution to create valuable service experiences, called value in use. By combining a set of purposed subsystems, SDA provides a technical environment that combines external resources from customers and partners, for example, user data or market data, with internal resources, for example, customer relationship management data, or services.

Therefore, SDA links business architecture and IT architecture and achieves a shared understanding of EA and strategic priorities. Objectives of SDA design are reflecting business needs on technical side, including customer and service focus, collaboration, complexity containment, and agility [58].

5. Use case design, implementation and evaluation

The use cases of the first generation have been rather simple, but are essential to initiate learning processes and building required capabilities. **Table 2** displays the next generation of more demanding and advanced use cases. Each use case implements a set of respective capabilities operationalized by SDA. Selected use cases stem from the insurance business, namely an insurance company, which will be our application domain for experimenting and evaluating our developed IT artifact and solution design.

No.	Use case/service	Description	SDA capabilities/ S-D logic principles
1	Edith care	• Personal care assistant • Support for administrative activities • Application process: five minutes instead of six days	• Value cocreation • Resource integration • Resource density • Resource orchestration • Institutional arrangement/ rules in use
2	Claim notification	• Support services for managing claim requests and processes (focus on scalability requirements in case of natural catastrophe) • Integration of external services (e.g., Service/call centers, and AI-based services and partner (fraud management)	• Service ecosystem • Resource integration • Co-creation • Resource density
3	Stroke prevention (ai4medicine)	• Customer receives individual risk scoring and personalized recommendations and an action list • Personal health advisor app	• Value cocreation • Institutional arrangement/ rules in use • Resource integration • Resource density • Resource orchestration
4	Medicproof	• Assistance and information services for customers to manage medicamental treatments and drugs	• Co-creation • Resource integration • Service ecosystem
5	Cross carrier pension information	• Collected and aggregated data about customer status and forecast of pension request • Consolidation of data from various pension fonds based on historical data (career steps/status)	• Resource integration • Service ecosystem • Institutional arrangement/ rules in use • Value cocreation
6	Universally submission service	• Uploading and handing electronically documents and material by means of customer app • Supported by AI and chatbots.	• Value cocreation • Resource integration • Institutional arrangement/ rules in use

Table 2.
Evaluation: overview use cases (partly based on [13, 18, 58, 61].

5.1 Development and implementation

Before technical action is taken and concrete solutions are developed, DSR process foresees to determine desired functionality and architecture of actual solutions. S-D logic forms our core theory and allows us to derive objectives to design and develop the IT artifact [5]. Presented IT artifact aims to solve identified problems in the given organizational context. S-D Logic is used to identify new capabilities that are later operationalized through the IT artifact [4]. As previously stated, digital transformation necessitates to build new IT infrastructure capabilities to seize opportunities by launching business initiatives and to implement the company's digital business strategy [21, 26]. In this context, as already argued before business-IT alignment [62] plays a pivotal role to implement the foundation for execution. Nunamaker et al. [10] argue that systems development is one of the valid research methodologies and provides "proof-by-demonstration" [10]. Against this background, three stages of "last mile research" are eminent: (1) proof-of-concept, (2) proof-of-value, and (3) proof-of-use [11]. Researchers have to decide on the right balance of scientific rigor (formulation of design theories) and practical relevance (useful artifacts) [4, 11]. Nunamaker et al. [10] propose a multimethodological approach to IS research. Furthermore, we respond to corresponding research challenges as motivated by Böhmann et al. [9], foremost exploration of new and unknown service systems as well as call for "participatory design" and innovative "prototyping approaches".

5.2 Use case development

Table 2 overlooks selected use cases showing relevance as elaborated jointly with the case company. Shown use cases are used to evaluate produced IT artifacts in the given organizational context. Our aim is to strive for proof as motivated in the paragraph before. Continuous practitioner feedback and interaction with related organizational context is vital to adjust and find the right configuration of resources and people for aspired service systems.

Evaluation is considered a crucial task and will be conducted continuously. The evaluation depends on implementing exemplified use cases and derivable requirements by means of IT solutions based on SDA experimental prototypes. In this way, we will be able to launch appropriate experiments to strive for the required "proof of concept". Furthermore, our goal is to receive further feedback and data for next development iterations. Currently, SDA is evaluating various solution designs, various technologies, and SDA prototypes incrementally. At this stage of development, activities focus primarily on implementing SDA stable core. Purposed subsystems as described will be continuously expanded and further concretized through adding additional features and functionality. Various architectural paradigms have been tested and validated. As result, we foresee to launch further real-life experiments evaluating SDA in the context of available use cases, which stem from the digital transformation endeavors of our case company.

5.3 Example: use case stroke prevention

The following example is based on [58, 61]. SDA is reflected as a construction plan for microservices in respective technical stacks (as bundles of microservices). As motivated, SDA serves as medium, structure, and output for actor engagement.

SDA is implementable on various technology platforms. SDA instantiates processes of value co-creation in the given organizational context.

5.3.1 Implementing use cases: experimental designs

SDA provides ground for real-life experiments. SDA and related subsystems were implemented as experimental designs and prototypes (technical action). In this way, we aim to evaluate on basis of data and processes obtained from respective use cases. SDA informs about both required investments and how to build required new IT infrastructure capabilities. From a management perspective, SDA serves as a communication tool clarifying strategic directions. In addition, solution design has to meet required levels of agility enabling response to environmental changes. The central aim is to build a foundation for execution comprising an operational model, enterprise architecture/IS architecture, and related IT artifacts. Furthermore, this encompasses decisions concerning targeted investments to achieve required IT infrastructure capabilities. SDA provides guidance for the construction and planning of microservices in technical stacks (bundles of microservices). Current market competition enforces faster and more convenient development of solutions, strictly oriented toward customer requirements and embracing collaboration of business and IT within organizations [63]. Microservices and related technical concepts are not further detailed, we refer to previous publications and scientific literature [18, 63–65]. Microservices as a technical concept are associated with new development paradigms such as DevOps and agile development practices (such as SCRUM). Those new emerging paradigms allow us to build real-life solutions with a strong relation between business and information systems. This realizes required Business IT alignment and builds applications around business capabilities and use cases [63]. We provided a more detailed overview of the underlying conceptual base in Weiß et al. [18].

5.3.2 Institutional design and implementation: service catalog

Service Catalog is a new added system and element of SDA. Zolnowski and Frey [61] analyze requirements and develop relevant use cases such as ai4medicine comprising personal health advice service for stroke prevention in Germany (**Figure 4**).

The business model of ai4medicine is based on using an app to comprehensively assist customers in reducing potential stroke risk. Based on risk assessment, customers receive appropriate recommendations for behavioral changes contributing to reducing the risk of stroke. Solution develops recommendations based on customers' shared data aiming at adequate changes in customer behavior to prevent stroke. Service ai4medicine combines clinical and epidemiological data on stroke and generates domain knowledge to develop and train artificial intelligence models. Designed AI models and algorithms enable innovative, personalized value propositions and facilitate evidence-based, AI-powered stroke prevention guiding principles and strategies. Once customers have installed the respective mobile app on their devices, they can register and start using ai4 medicine application functionality. In addition, this application supports continuous consolidation of customers' historical health data accessible from partners' platforms (for example liaised insurance companies) and improves in this way continuously data quality and hence individual stroke prevention. Partner companies can seamlessly integrate ai4medicine into the application landscape, for example by offering additional functionality on run mobile apps.

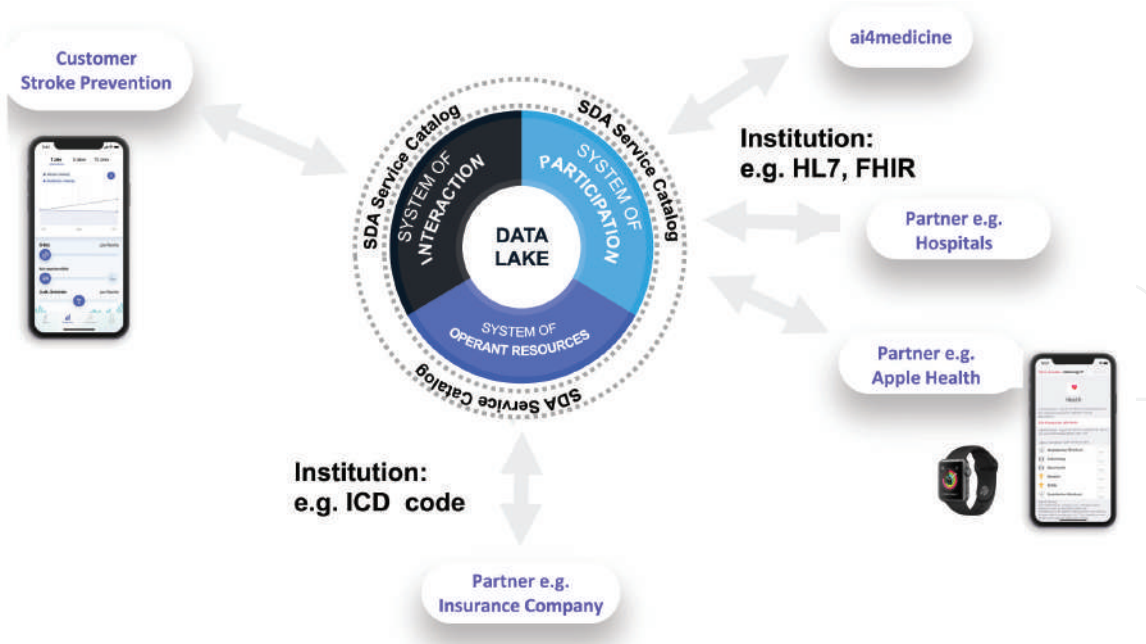

Figure 4.
Evaluation SDA: use case stroke prevention [58].

Furthermore, additional health data is supported to augment respective personal health data set, for example, data accessible from connected smart devices such as wearables, given appropriate interfaces and data interoperability. This reduces significantly additional efforts and pains related to manually entering data and keeping data updated [61].

6. Discussion

Design and execution of digital strategies [15, 21–23] are of utmost importance. New capabilities need to be built around emerging digital technologies and trends such as hybrid cloud, intelligent process automation, and artificial intelligence, in particular machine learning. Hence, building a robust digital platform turns into a core competence to be able to compete against digital attackers [37]. In response, companies alter their existing business models by incorporating digital technologies to arrive at new value propositions and new resource configurations [24, 32]. S-D logic [38–41, 66] offers valuable concepts and guidance on how to overcome the challenges of digital transformation. Executing and implementing digital strategies makes many incumbent companies struggle [23]. In the past, striving for higher efficiency and optimization for the foundation for execution has created a significant strategic advantage for incumbent companies against their competitors. In this way, those companies created an operational backbone based on a "[...] set of standardized, integrated systems, processes and data support a company's core operations" [15]. This constituted the main source of strategic advantage because smaller businesses or startups have not been able to rely on comparable resources and system performance, computing power as well as related IT infrastructure capabilities. However, nowadays, these historically grown and highly optimized systems are causing observable complexity in enterprise systems and are a reason for inertia to transform and react to rapidly changing market requirements and customer demands [15, 21, 67]. Investments in IT infrastructure capabilities should be driven by initiatives and business value. Strategic agility expresses the ability of a company to readily implement respective business initiatives. The more time and effort required to implement them indicates the existence of inconsistencies and reveals inappropriate alignment between business demand and previous investments in IT infrastructure capabilities. Hence, company's need to decide on the required capabilities to get future-ready [19, 20, 26] by investing in their foundation for execution [21]. Identified initiatives and measures are aggregated into a strategic roadmap. Initiatives are orchestrated through a high-level architectural vision shared and agreed upon by business and IT. In absence of an architectural vision explicated as EA, the company runs at risk to make isolated and siloed investments in its IT infrastructure, systems, and applications leading to "technical debt" [15, 68]. Technical debt is caused by previous pragmatic solutions or uncoordinated investments in IT infrastructure capabilities (often visible as "shadow IT"). Often new business initiatives had created demands which were solved through individual "rewiring" of system connections and creating uncoordinated on-demand interfaces to integrate systems. Consequently, the company's strategy development needs to clarify new capabilities required to compete in future digital markets, to exploit new opportunities and to nurture new customer segments.

7. Summary and conclusion

Digital transformation brings new requirements and challenges for companies to respond to market opportunities and take advantage of new digital technologies. We argued that the majority of companies aiming to address digital transformation, face challenges in developing appropriate digital strategies and struggle to shift from traditional goods-based to service-based focus [31].

Applying a DSR approach, SDA contains prescriptions for design and action in the form of a new design artifact, and in this way intends to formalize and generalize knowledge for the targeted problem and solution domain. Consequently, conducted research started with the developing of a novel artifact (namely SDA) in the given organizational context. We operationalized Service-Dominant Logic (S-D Logic) serving as descriptive or kernel theory that informs artifact construction [3]. Whereas S-D Logic is rather to be seen as a grand theory, SDA can serve as middle-range theory to overcome the perceived gap or disconnect between theory and practice [6]. However, this requires to fulfill respective requirements [3].

Following a DSR approach presented research aims to make clear contributions to real-world application environments [3]. Focus is set on technical action in the sense of an inside-out approach to stimulate and implement change [7]. In addition, we generate knowledge (outside-in) by studying the state of problem and current solutions and their efficacy. Our central aim was to create the artifactual solution in order to use it to solve identified problems not hitherto addressed [5]. Accordingly, we determined the artifacts desired functionality and its architecture. We created the actual artifact by applying S-D Logic and conceptualized offered concepts to move from objectives to solution design. Finally, we demonstrate and use the created IT artifact in a given organizational context [5]. DSR and ADR define concrete requirements and offer methodology for how this can be achieved. One particular effort can be seen in generalizing achieved outcomes and produced results. Our research objective is hence to further strengthen the theoretical foundations of SDA to transport design knowledge and guide digital strategy development as well investment decisions [3]. The IT artifact is a subject of continuous improvement and is being evolved primarily in its organizational context. In this way, we stimulate learning processes, create new knowledge and gain new insights studying the phenomenon of digital transformation.

Author details

Peter Weiß[1*], Markus Warg[2] and Andreas Zolnowski[3]

1 Pforzheim University, Pforzheim, Germany

2 Institute for Service Design (IfSD), Hamburg, Germany

3 Signal Iduna, Hamburg, Germany

*Address all correspondence to: peter.weiss@hs-pforzheim.de

References

[1] Warg M, Weiß P, Zolnowski A, Engel R. Service dominant architecture based on S-D logic for mastering digital transformation: The case of an insurance company. In: Proceedings 26th Annual RESER Conference. Naples, Italy: RESER, University of Naples "Federico II; 2016. pp. 807-826

[2] Hevner AR, March ST, Park J, Ram S. Design science in information systems research. MIS Quarterly. 2004;**28**:75-105

[3] Gregor S, Hevner AR. Positioning and presenting design science research for maximum impact. MISQ. 2013;**37**:337-355

[4] Baskerville R, Baiyere A, Gergor S, Hevner A, Rossi M. Design science research contributions: Finding a balance between artifact and theory. JAIS. 2018;**19**:358-376. DOI: 10.17705/1jais.00495

[5] Peffers K, Tuunanen T, Rothenberger MA, Chatterjee S. A design science research methodology for information systems research. Journal of Management Information Systems. 2007;**24**:45-77. DOI: 10.2753/MIS0742-1222240302

[6] Sein MK, Henfridsson O, Purao S, Rossi M, Lindgren R. Action design research. MIS Quarterly. 2011;**35**:37-56

[7] Eekels J, Roozenburg N. A methodological comparison of the structures of scientific research and engineering design: Their similarities and differences. Design Studies. 1991;**12**:197-203. DOI: 10.1016/0142-694X(91)90031-Q

[8] Vial G. Understanding digital transformation: A review and a research agenda. The Journal of Strategic Information Systems. 2019;**28**:118-144. DOI: 10.1016/j.jsis.2019.01.003

[9] Böhmann T, Leimeister JM, Möslein K. Service systems engineering. Business and Information Systems Engineering. 2014;**6**:73-79. DOI: 10.1007/s12599-014-0314-8

[10] Nunamaker JF, Chen M, Purdin TD. Systems development in information systems research. Journal of Management Information Systems. 1990;**7**:89-106. DOI: 10.1080/07421222.1990.11517898

[11] Nunamaker JF, Briggs RO, Derrick DC, Schwabe G. The last research mile: Achieving both rigor and relevance in information systems research. Journal of Management Information Systems. 2015;**32**:10-47. DOI: 10.1080/07421222.2015.1094961

[12] Yin RK. Case study research: Design and methods. 5th ed. SAGE: Los Angeles, London, New Delhi, Singapore, Washington, DC; 2014

[13] Weiß P, Zolnowski A, Warg M. Service dominant architecture to master digital transformation: Case of an insurance company. In: Proceedings 15th International Research Symposium on Service Excellence in Management (QUIS 2015). Porto, Portugal: QUIS, School of Engineering of University of Porto (FEUP); 2017. pp. 638-643

[14] Bonnet D, Westerman G. The New Elements of Digital Transformation: The authors revisit their landmark research and address how the competitive advantages offered by digital technology have evolved. MIT Sloan Management Review. Cambridge, MA, USA: The MIT Press; 2020

[15] Ross JW, Beath CM, Mocker M. Designed for digital: How to architect your business for sustained success. Cambridge Massachusetts, London England: The MIT Press; 2019

[16] Kane GC, Palmer D, Phillips AN, Kiron D, Buckley N. Achieving digital maturity: Adapting your company to a changing world. MIT Sloan Management Review / Deloitte University Press. Cambridge, MA, USA: The MIT Press; 2017

[17] Kane GC, Palmer D, Phillips AN, Kiron D, Buckley N. Strategy, Not Technology, Drives Digital Transformation: Becoming a digitally mature enterprise. MIT Sloan Management Review and Deloitte University Press. Cambridge, MA, USA: The MIT Press; 2015

[18] Weiß P, Zolnowski A, Warg M, Schuster T. Service dominant architecture: Conceptualizing the foundation for execution of digital strategies based on S-D logic. In: Proceedings of the 51st Hawaii International Conference on System Sciences. Hilton Waikoloa Village, Kona, Hawaii, USA: HICSS-51 AIS (Association for Information Systems), AIS Electronic Library (AISeL); 2018. pp. 1630-1639. DOI: 10.24251/HICSS.2018.204

[19] Weill P, Woerner SL. Thriving in an Increasingly digital ecosystem. MIT Sloan Management Review. Cambridge, MA, USA: The MIT Press; 2015;**56**:26-35

[20] Weill P, Woerner SL. Is your company ready for a digital future? MIT Sloan Management Review. Cambridge, MA, USA: The MIT Press; 2018;**59**:20-26

[21] Ross JW, Weill P, Robertson D. Enterprise Architecture As Strategy: Creating a Foundation for Business Execution. Boston: Harvard Business Review Press; 2006

[22] Ross JW, Sebastian IM, Beath CM. How to Develop a Great Digital Strategy. MIT Sloan Management Review. 2017

[23] Ross JW, Sebastian I, Beath C, Mocker M, Moloney K, Fonstad N. Designing and Executing Digital Strategies. In: Thirty Seventh International Conference on Information Systems, Dublin, AIS Electronic Library (AISeL); 2016. pp. 1-17

[24] Normann R. Reframing Business: When the Map Changes the Landscape. Chichester: Wiley; 2001

[25] Chesbrough HW. Open Services Innovation: Rethinking Your Business to Grow and Compete in a New Era. 1st ed. San Francisco, CA, USA: Jossey-Bass; 2011

[26] Weill P, Subramani M, Broadbent M. Building IT Infrastructure for Strategic Agility. MIT Sloan Management Review. 2002;**44**:57-66

[27] Proper H, Lankhorst MM. Enterprise Architecture—Towards Essential Sensemaking. Enterprise Modelling and Information Systems Architectures (EMISAJ) – International Journal of Conceptual Modeling. Bonn, Germany: German Informatics Society (GI); 2014;**9**(1):5-21. DOI: 10.18417/emisa.9.1.1. ISSN: 1866-3621

[28] Warg M, Zolnowski A, Frosch M, Weiß P. From product organization to platform organization: Observations of organizational development in the insurance industry. In: Proceedings of The 10 years Naples Forum on Service. Ischia, Italy; 2019

[29] Lankhorst M. Enterprise Architecture at Work: Modelling, Communication and Analysis. 4th ed. Berlin, Heidelberg: Springer; 2017. Available from:

https://link.springer.com/book/10.1007/978-3-662-53933-0#about

[30] Moore G. Systems of Engagement and The Future of Enterprise IT: A Sea Change in Enterprise IT. Silver Spring, MD, USA: Whitepaper; AIIM International; 2011. Available from: https://info.aiim.org/systems-of-engagement-and-the-future-of-enterprise-it [last visit 21.02.2022]

[31] Weiß P, Warg M, Zolnowski A. Building systems of engagement to overcome the challenges of digital transformation. In: Gummesson E, Mele C, Polese F, editors. Service Dominant Logic, Network and Systems Theory and Service Science: Integrating three Perspectives for a New Service Agenda. Proceedings of The 10 years Naples Forum on Service. Ischia, Italy: SIMAS di Salerno for Naples Forum on Service; 2019. ISBN: 978-88-31622-19-6. Available from: http://www.naplesforumonservice.it/public/index.php?node=258

[32] Kohtamäki M, Parida V, Oghazi P, Gebauer H, Baines T. Digital servitization business models in ecosystems: A theory of the firm. Journal of Business Research. 2019;**104**:380-392. DOI: 10.1016/j.jbusres.2019.06.027

[33] Tronvoll B, Sklyar A, Sörhammar D, Kowalkowski C. Transformational shifts through digital servitization. Industrial Marketing Management. 2020;**89**:293-305. DOI: 10.1016/j.indmarman.2020.02.005

[34] Gebauer H, Paiola M, Saccani N, Rapaccini M. Digital servitization: Crossing the perspectives of digitization and servitization. Industrial Marketing Management. 2021;**93**:382-388. DOI: 10.1016/j.indmarman.2020.05.011

[35] Lusch RF, Nambisan S. Service innovation: A service-dominant logic perspective. MISQ. 2015;**39**:155-175. DOI: 10.25300/MISQ/2015/39.1.07

[36] Zolnowski A, Warg M. Conceptualizing resource orchestration—The role of service platforms in facilitating service systems. In: Bui T, editor. Hawaii International Conference on System Sciences: Hawaii International Conference on System Sciences. Hilton Waikoloa Village, Kona, Hawaii, USA: HICSS-51 AIS (Association for Information Systems), AIS Electronic Library (AISeL); 2018. DOI: 10.24251/HICSS.2018.131

[37] IBM. 3 steps to reprogram Insurance Companies become future ready. 2021. Available from: https://www.ibm.com/blogs/digital-transformation/in-en/blog/3-steps-to-reprogram-insurance-companies-become-future-ready/. [Accessed: January 14, 2022]

[38] Vargo SL, Lusch RF. Evolving to a new dominant logic for marketing. Journal of Marketing. 2004;**68**:1-17. DOI: 10.1509/jmkg.68.1.1.24036

[39] Lusch RF, Vargo SL. Service-Dominant Logic: Premises, Perspectives, Possibilities. Cambridge: Cambridge University Press; 2014

[40] Maglio PP, Spohrer J. Toward a science of service systems. In: Handbook of Service Science. Boston, MA: Springer; 2010. pp. 157-194. DOI: 10.1007/978-1-4419-1628-0_9

[41] Vargo SL, Lusch RF. Service-dominant logic: Continuing the evolution. Journal of the Academy of Marketing Science. 2008;**36**:1-10. DOI: 10.1007/s11747-007-0069-6

[42] Michel S, Vargo SL, Lusch RF. Reconfiguration of the conceptual landscape: A tribute to the service logic of Richard Normann. Journal of the Academy of Marketing Science.

2008;**36**:152-155. DOI: 10.1007/s11747-007-0067-8

[43] Spohrer J, Maglio PP, Bailey J, Gruhl D. Steps toward a science of service systems. Computer. 2007;**40**:71-77. DOI: 10.1109/mc.2007.33

[44] Maglio PP, Spohrer J. Fundamentals of service science. Journal of the Academy of Marketing Science. 2008;**36**:18-20. DOI: 10.1007/s11747-007-0058-9

[45] Weiß P. Microfoundations for building systems of engagement: Enable actor engagement using service dominant architecture. In: Spohrer J, Leitner C, editors. Advances in the Human Side of Service Engineering. Cham: Springer International Publishing; 2020. pp. 116-122. DOI: 10.1007/978-3-030-51057-2_17

[46] Rittweger R, Kronibus A, Weiß P. Value co-creation as the core of service innovation: Impacts of a case study of a fully digitized health: Insurance company service dominant architecture. In: Spohrer J, Leitner C, editors. Advances in the Human Side of Service Engineering. Cham: Springer International Publishing; 2020. pp. 86-92

[47] Weiß P, Kronibus A, Riedel F, Rittweger R. Digital service innovation and actor engagement: A multilevel design perspective—Impacts from a case study of an insurtech. In: Leitner C, Ganz W, Satterfield D, Bassano C, editors. 1st ed. Cham: Springer International Publishing; 2021. pp. 273-279

[48] Bächtold N. Microfoundations of Value Cocdreation: Using a Multilevel Design Approach to Building Systems of Engagement by Utilizing Service Dominant Architecture [Masterthesis]. Ljubljana, Slowenia: University of Ljubljana; 2021

[49] Payne AF, Storbacka K, Frow P. Managing the co-creation of value. Journal of the Academy of Marketing Science. 2008;**36**:83-96. DOI: 10.1007/s11747-007-0070-0

[50] Grotherr C, Semmann M, Böhmann T. Using microfoundations of value co-creation to guide service systems design: A multilevel design framework. In: Proceedings of Thirty ninth International Conference on Information Systems. San Francisco, USA: AIS (Association for Information Systems); 2018. ICIS2018 Proceedings 978-0-9966831-7-3

[51] Peters LD, Löbler H, Brodie RJ, Breidbach CF, Hollebeek LD, Smith SD, et al. Theorizing about resource integration through service-dominant logic. Marketing Theory. 2014;**14**:249-268. DOI: 10.1177/1470593114534341

[52] Warg M, Engel R. Service-Dominierte Architektur (SDA): Kernkomponente digitaler Transformation. In: Zeitschrift für Versicherungswesen. Hamburg: Allgemeiner Fachverlag Dr. Rolf Mathern GmbH. pp. 391-395

[53] Hein A, Schreieck M, Riasanow T, Setzke DS, Wiesche M, Böhm M, et al. Digital platform ecosystems. Electron Markets. 2020;**30**:87-98. DOI: 10.1007/s12525-019-00377-4

[54] Parker GG, van Alstyne MW, Choudary SP. Platform Revolution: How Networked Markets Are Transforming the Economy and How to Make Them Work for You. New York: W. W. Norton & Company; 2016

[55] Warg M, Hans S. How to overcome organizational inertia by shaping institutions and value propositions: An analysis of the impact of

service-catalogs. In: Bienzeisler B, Peters K, Schletz A, editors. 31st RESER Conference, Fraunhofer IAO, Heilbronn. In: The Disruptive Role of Data, AI and Ecosystems in Services, Conference Proceedings of 31th RESER Conference. Heilbronn, Germany: RESER (European Association for Research on Services); 2021. pp. 61-79

[56] Warg M, Weiß P, Engel R. Whitepaper: Service Dominierte Architektur (SDA): Die digitale Transformation erfolgreich meistern. Wedel, Germany: University of Applied Sciences Wedel (Fachhochschule Wedel); 2015

[57] Giddens A. The constitution of society: Outline of the theory of structuration. 1st ed. Berkeley: Univ. of California Press; 1984

[58] Zolnowski A, Frey D. Analyzing the role of artificial intelligence in the development of human-centered service. In: Spohrer J, Leitner C, editors. Advances in the Human Side of Service Engineering. Cham: Springer International Publishing; 2020. pp. 123-130. DOI: 10.1007/978-3-030-51057-2_18

[59] Henderson JC, Venkatraman H. Strategic alignment: Leveraging information technology for transforming organizations. IBM Systems Journal. 1993;**32**:472-484. DOI: 10.1147/sj.382.0472

[60] Evans E. Domain-driven design: Tackling complexity in the heart of software. Upper Saddle River, NJ: Addison-Wesley; 2011

[61] Newman S. Monolith to Microservices: Evolutionary Patterns to Transform Your Monolith. Newton, MA: O'Reilly Media, Inc; 2019

[62] Burden A, van der Ouderaa E, Venkataraman R, Nyström T, Shukla PP. Technical debt might be hindering your digital transformation. MIT Sloan Management Review. Cambridge, MA, USA: The MIT Press; 2018;**60**:1-7

[63] Fritzsch J, Bogner J, Zimmermann A, Wagner S. From monolith to microservices: A classification of refactoring approaches. In: International Workshop on Software Engineering Aspects of Continuous Development and New Paradigms of Software Production and Deployment. Cham: Springer; 2018. pp. 128-141. DOI: 10.1007/978-3-030-06019-0_10

[64] Vargo SL, Lusch RF. The SAGE Handbook of Service-Dominant Logic. 1st ed. London: SAGE Publications; 2018

[65] Akaka MA, Vargo SL. Technology as an operant resource in service (eco)systems. Information Systems and e-Business Management. Berlin, Heidelberg: Springer-Verlag; 2014;**12**:367-384. DOI: 10.1007/s10257-013-0220-5. ISSN: 1617-9846

[66] Vargo SL, Lusch RF. Institutions and axioms: An extension and update of service-dominant logic. Journal of the Academy of Marketing Science. 2016;**44**:5-23. DOI: 10.1007/s11747-015-0456-3

[67] Vargo SL, Lusch RF. Inversions of service-dominant logic. Marketing Theory. 2014;**14**:239-248. DOI: 10.1177/1470593114534339

[68] Taneja H, Maney K. The End of Scale. MIT Sloan Management Review. 2018;**59**:66-73

Chapter

Utilization of Fintech Applications during the Covid-19 Pandemic

Özlem Olgu Akdeniz

Abstract

At the beginning of 2020, a new disease (Covid-19) has emerged and expanded swiftly all around the world. Currently, we are still living in unprecedented times in which we should have social distance from one another and mostly work from home to diminish the spreading speed of the Covid-19. While we are experiencing these limitations, businesses and organizations are expected to work without having any disruptions. At this point, entering new technologies into our lives was inevitable and in fact, these new technologies have helped us to eliminate the challenges caused by the precautions with fewer flaws. Even though Fintech applications have numerous advantages, nothing comes without its drawbacks. The empirical analysis in this chapter aims to evaluate selection of best Fintech-based investments in the Turkish banking sector with an application of a hybrid DANP-fuzzy TOPSIS technique. Empirical findings of the analysis indicate that Strategy 2 has the best rank among the alternatives, followed by Strategy 1 and Strategy 3, whilst Strategy 4 has the weakest importance among the strategy preferences. Our findings suggest that policy makers/bank managers should focus more to direct Fintech investments firstly to lending services followed by payment systems.

Keywords: Fintech, Covid-19, financial institutions, pandemic, Turkish banking

1. Introduction

> *"Ignoring technological change in a financial system based upon technology, is like a mouse starving to death because someone moved their cheese."*
>
> *Chris Skinne*

At the beginning of 2020, a new disease (Covid-19) has emerged and expanded swiftly all around the world. As the global spread got out of control, World Health Organization (WHO) announced the situation as a pandemic. Followingly, governments took numerous precautions such as closing boarders, banns on international transportation, restrictions on social distancing, mandatory face masks, and flexible working conditions such as working from home/online meetings. Although, these precautions were taken against the virus, it affected almost all industries. The use of technology and innovation has increased more to eliminate the challenges caused by the precautions. At this point, Fintech applications have stepped forwards to catalyze business and individual processes.

'FinTech' is a compound word of Fin(ancial) and Tech(nology). It is a general name to refer to new disruptive, revolutionary technological developments that are redefining the financial markets and changing the rules. Even though, the term has gained popularity in public not long ago, it has become one of the most researched topics as it has managed to influence almost every subsector ([1], p. 235). Fintech helps companies and consumers to operate their financial assets and processes in better conditions via using specialized software and algorithms by solely accessing through computers and smartphones. Alongside strengthening business and processing big data to meaningful data, Fintech is universal, cheaper, and more secure compared to conventional methods [2]. In addition, Fintech eliminates traditional intermediaries while offering financial services [3].

FinTech has many new and complex underlying technologies like blockchain, artificial intelligence, big data, and machine learning. With the new dynamics that these techs bring, FinTech offers various advantages that traditional institutions cannot compete with. Some of the most important advantages are the ability that Fintech start-ups can avoid intermediation costs and acquire minimum capital requirements usually associated with traditional banking services. On the other hand, big data analytics and data science transformed how data are captured, processed, and analyzed, which results in significant cost reduction [4]. Traditional ways of finance are being challenged continuously and long-established institutions should decide if they will embrace or fight it.

Artificial intelligence, machine learning, big data, data analytics, robotic process automation, and blockchain technologies have played and still are playing important roles in the creation of today's successful Fintech applications. These technologies have comprised the base for many Fintech applications, where they have enabled the creation of crowdfunding platforms, mobile payment systems, robo-advisors, insurance applications, budgeting applications, and Regulatory Technology (RegTech). As a result, financial markets, financial transactions, simpler money trade-offs, anything which can be thought on financial activities have become more convenient by the Fintech applications. Higher rates of convenience have brought also a higher number of new users and efficiency. Fintech applications also provide personalized services for people who require and want data and services. Indeed, personalization plays a subsidiary role for the enhancements of those Fintech applications; because via personalized services, the owners of the applications can learn what do their customers need. Those needs, afterwards, can be met by the new updates of the applications. Via the products of the new tech, the time it takes to make each of the transactions has lowered, encouraging people to be involved in more financial activities. Financial markets may benefit from new and more involved players.

According to Moden and Neufeld [5] the usage of Fintech applications increased by 72% in Europe since the first lockdown due to the Covid-19 pandemic. Fintech is one of the hottest topics in current finance and is thought to be the power that will shape the future. This chapter aims to investigate the utilization of Fintech applications during the COVID-19 pandemic, analyze the Fintech phenomenon, and show some of its main applications in financial markets such as cryptocurrency, crowdfunding, and mobile payments. Moreover, this chapter evaluates Fintech-based investments in Turkish banking with an application of the ANP and TOPSIS models. We aim to contribute to the existing literature by identifying the most important Fintech-based investment alternatives and to providing suggestions for policy makers to achieve higher financial performance in the Turkish banking sector. Our empirical findings illustrate that "payment" and "lending" systems are the most important Fintech-based investment alternatives. We recommend that Turkish banks should mainly focus on directing investments to Fintech applications on payment and lending services to attract more customers, decrease operational costs and achieve higher levels of customer satisfaction.

The rest of the chapter is organized as follows. Section 2 introduces a summary of the evolution of Fintech applications. Section 3 provides a literature review, followed by methodology and empirical findings. Lastly, Section 5 concludes the chapter.

2. Evolution of Fintech applications

The origins of Fintech go back to the mid-19th century. Although, it was initially designed for back-end systems of financial institutions, it has moved towards consumer-oriented services over time [6]. The development between finance and technology has always been hand to hand in history. A need, a deficiency in finance would provoke the technology to come up with a solution and the result would benefit both. Arner et al. [7] list the co-existence of financial services and technology in three eras as: Fintech 1, Fintech 2, and Fintech 3. The first period (Fintech 1) is between 1866 and 1967, which represents the period of transition from analog to digital applications. During this period, the foundations were laid for financial connections that would enable the rapid realization of financial information, transactions, and payments by means of telegraph, railways, canals, and transatlantic telegraph cables. In fact, laying of the transatlantic telegraph cable formed the infrastructure of the financial globalization process. Moreover, credit card applications started during this era and formed the basis for the next stage of Fintech development (Fintech 2).

The digitalization of technologies used in communication and commercial transactions triggered the Fintech 2 era, which refers to the 1967–2008 period. Products and services offered in the financial services sector started to be digitalized and internet banking applications (Wells Fargo-USA and ING Bank-Europe) and ATMs (1967-Barclays UK) were introduced over this period. The emergence of ATMs is accepted as the most important development revealing the relationship between finance and technology and as the first step towards digitalization of the financial services sector [8]. In addition, technology companies such as IBM emerged during this period [7]. Chronologically, over the following years, NASDAQ was established (1971), SWIFT application was commissioned (1973), Bloomberg was established (1981), the first mobile phones emerged (1983), and online banking applications started (1985). By 2001, the number of customers consuming these technologies reached to one million. In 2005, the first physically branchless banks such as ING Direct and HSBC Direct emerged in the UK. At the beginning of the 21st century, banks' internal processes, external systems, and interactions with their customers were completely digitalized [7].

Lastly, Fintech 3 era covers 2008 and beyond, which has the trigger point as the global economic crisis in 2008. Global economic crises caused distrust in financial markets and expanded the importance of Fintech applications. The public's anger with the banking system has created an excellent area of development for financial innovation. Taking advantage of the opportunity created by the crisis environment, Fintech providers offered services to their customers with low-cost, more transparent, and easier to use interfaces through well-designed platforms and mobile applications [9]. Although, Fintech 3 has emerged as a response to the financial crises in the West, similar Fintech developments were observed in Asia and Africa a bit later. The period in these two regions is described as Fintech 3.5 [7]. The elements that support the Fintech 3.5 era in these regions can be listed as high penetration of mobile devices among young and technology-savvy individuals, the growth of the middle class, unused market opportunities, lack of physical banking infrastructure, and low competition [7].

Fintech technologies are used in areas such as payments, digital currencies, insurance, investment management, credit, deposit, and lending. The cost of the services provided by this technology to the customer is low and easy to access. Fintech companies focus on the customer and take their actions in line with customer needs. According to a survey of BCBS, most Fintech services are in the category of payment, clearing and settlement; then, it was concluded that the activities of market support services and credit, deposit, capital-raising services respectively were high [10]. While Fintech companies operating on payment provide convenience to their customers in terms of payment, Fintech companies operating in the field of market support services are companies that provide financial support as the name suggests.

People who need a loan often go to banks; however, getting a loan is not that easy. Banks classify individuals according to their ability to pay, suspecting whether they can receive a refund. They expose individuals applying for loans to many questions such as income level, age, wealth status, illness status, credit rating, education level, and it becomes difficult to get a loan for someone with any disadvantage. However, for those who lost their jobs and lost their home; or for people who want to start a new venture but do not have capital, the situation is not very heartwarming. Besides, even if a loan will be given to the person applying for the loan, there may be a high-interest payment system. The Fintech industry has launched many technology applications and financial support services to create a new lending market, which will address all difficulties, support and meet most of the consumers' needs. To find solutions to such problems, Fintech developed its applications with its technological infrastructure and established its credit system, and even started to give loans to people deemed defective by banks. Unlike banks, some Fintech companies kept the interest on repayment low, did not ask long and detailed questions like banks. Instead, thanks to the algorithms developed, they started to use all the data that could be used, from the games played by the individuals who want to get a loan to the lifestyle they live, to get a preview.

Peer to Peer Lending, one of the models of these applications, served as a link between lenders and borrowers thanks to its highly developed technological infrastructure; In a way, it has undertaken the duties of other financial companies. Venmo app is a smartphone app used to make digital payments. Venmo, which was designed by targeting the Peer-to-Peer system, after some personal information is verified, personal bank accounts are connected to the application and allows individuals to easily transfer money among themselves. Another example of using Peer-to-Peer Lending systems is Sofi and Earnest. These two applications, help students to find individuals who give student loans.

Thanks to the technological applications developed by Fintech companies, making payments has now been transferred to the digital environment and requires easier and shorter transactions, which do not require physical transactions. People can now send money to another individual at the touch of a button, at any time and at any distance. For example, it used to be more difficult to send money to individuals living abroad. People who must go to the bank, answer a lot of questions, wait long lines, and deal with a lot of paperwork can now handle this issue much more comfortably. Mobile wallets are considered an Online Payment system. This system, which replaces the normal wallet, allows the use of most bank cards virtually with the technology it contains; It is designed for users to use comfortably and to save time, to avoid worries such as forgetting a wallet or shortage of cash. For this, the user only needs to download the application. There are mobile wallet applications such as Google

Wallet, Square Cash, Paypal, and it allows individuals to carry a virtual wallet. Also, Apple released Apple Pay using its technology and moved users' purchases and billing transactions to digital using only Touch ID (Truong, p. 20).

In addition, cryptocurrency is introduced as a virtual currency, which has no physical appearance, and allows customers to transfer money digitally. Cryptocurrencies are tools for investing, like gold or dollar, you can trade and sell it through various apps and websites. The high demand and big expectations helped these currencies to reach all-time highs and they are still rising. Furthermore, they are parts of major investment banks' portfolios even though some of the banks still question their future. JP Morgan had announced that it had made a 50-million-dollar investment in Bitcoin and explained that they believe it is an important asset. As if that was not enough, JP Morgan went a step further and explained it will release its cryptocurrency for payments, JPM Coin. Before JP Morgan, platforms such as Amazon, Craigslist, and eBay had already realized the advantage of cryptocurrency payments [11]. In addition to incredibly fast payments, they allowed it to reduce their costs in labor and documentation and eliminate intermediary fees. They use these savings to improve their services for the customers. Also, blockchain technology allowed companies to set "smart contracts" which are codes with conditions that are executed when certain conditions are met [11]. These helped companies to avoid mistakes, save time and overcome trust issues. For example, in trade finance parties can guarantee that they will get their payment as soon as the shipment has arrived at the buyer. With smart contracts, there is no need for confirmation calls or emails.

The first and most popular type of cryptocurrency is Bitcoin. Bitcoin is a virtual currency where people are traded among themselves, and it is tracked through online platform sites, whilst without any regulation. It is now in such a position in the lives of individuals that it can be received as Bitcoin payment in some businesses. To create a digital platform for Bitcoin transactions, Blockchain technology is introduced, which enables data to be organized in blocks and protects the data it collects. In simplest terms, blockchain is a decentralized and secure electronic ledger. This ledger is public and built around a P2P system where participants are anonymous and do not have to reveal any information. Each transaction is linked to the previous one like a chain and because entries are linked, tracking and verifying them become significantly easier. But, before transactions become a "block" of the chain, they must be confirmed. The striking point is the participants are the ones who confirm them instead of a central power who charges fees and has the power to call off a transaction. Blockchain aims to replace authorities by creating a safe environment that is based upon the secure nature of cryptography and the trust participants have for each other. So, the transactions will be cheaper and irreversible.

Especially, the Crowdfunding system which combines individuals who are looking for capital for a project or a start-up but who have difficulty in finding them with their future investors, is a tool to find the desired financial support using P2P, and no fees are required to use this system. Thus, individuals or small companies in need of financing save time and could find an investment that they normally cannot find. At the same time, it enables the investor to receive commission after a certain period. In addition, Fintech application such as Virtual Saving Jars belonging to the investment area enable people to make savings by transferring their budget, expenses, and income to digital. This development, made especially by focusing on the young audience, is perfect for those who cannot save. Another application type made by Fintech companies is portfolio management. These applications such as Acorns and Betterment measure the risk level using the investor's data and match the suitability against which assets. In creating a portfolio, Robot-Advisor can be used which uses the investor's data and tells the investor how to make a portfolio. The system uses questions that are designed to get to know the investor, then it recognizes the investor and offers suitable portfolio options through its algorithms.

Fintech companies also help personal finance transactions to be carried out more efficiently. Despite each company's own technological infrastructure, customers who are suspected of being defrauded feel compelled to check many websites at the same time. For this purpose, websites such as Mint.com and CreditKarma were enabled to see individual transactions and to reach different banks with free of charge from a single platform. Thus, customers were able to manage their finances and have access to transaction, banking and credit activities much more easily. In this respect, LearnVest is an online platform that supports its users to manage their finance and investment.

Likewise, Asset and Wealth Management (AWM) is another financial service that is expected to be revolutionized by Fintech. Since 2008, there has been a constant rise in the number of AWM start-ups, which aim to stand out from the traditional advisors by incorporating artificial intelligence and new data analytic techniques in the game. Lopez et al. [12] list the major innovations that are making a difference as:

1. 'Well-designed platforms focused on simplicity, speed, and intuitive workflows through digital and mobile offerings',

2. 'Compelling editorial content and financial education distributed openly online with focus on human connection, constant feedback on client's financial health',

3. 'Average fees between 25 and 50 basis points; free tools to analyze fees across accounts while offering cost-saving alternatives'.

One of the most important inventions in the process of automatizing and digitalizing investment management is robo-advisory. 'Robo-Advisors are digital platforms comprising interactive and intelligent user assistance components that use information technology to guide customers through an automated advisory process' ([13], p. 1). The new alternatives that were born with this technology can be divided into two branches as: (i) Fully-Automated and (ii) Advisor-Assisted ([12], p. 4). Betterment and Wealthfront are two of the Fully-Automated management firms where there is zero human elements. On the other hand, firms like Personal Capital—an important Advisor-Assisted system—a more comprehensive analysis of assets, and more detailed tracking and advisory on investments are offered with real human advisors who are evaluating and reporting the process. Eliminating the extra employee-based costs such as food, transportation and monthly salaries allow robo-advisory start-ups to accept customers without minimum investment limit. That's why especially the fully-automated firms have gained traction with millennials, which have an average account size of \$20,000–\$100,000 [12].

Small and Medium Enterprises (SMEs) and business ventures used to get financial support from banks. However, with the beginning of the 2008 financial crisis, banks decreased loan amounts and frequencies in order not to take risks in a non-growing economic condition. This becomes the revolutionary standpoint for crowdfunding [14]. Loans taken from banks are no longer being used, instead crowdfunding is used with the help of financial technologies for loan practices. Crowdfunding practices are fulfilled via internet crowdfunding websites and social media. These platforms ease lending transactions by eliminating difficult negotiations and time-consuming paperwork. Since crowdfunding platforms are easily usable and accessible, crowdfunding continues to develop.

Last but not the least, the mobile payment system is a monetary payment made through an electronic environment. This environment is mostly a smart device like a phone, tablet, laptop, etc. In the traditional payment model, there is a direct link with financial institutions; however, with FinTech, payments are connected to financial institutions via Information Technologies (IT) companies. Even if IT is also used in traditional services, it is not easily adaptable to FinTech payment services [15]. For each financial institution, different payment methods should be used because traditional payment services were not developed as user-specific. Several companies give mobile payment services. Apple, Samsung, and Google developed mobile applications named respectively as Apple pay, Samsung pay, and Google pay. These applications are implemented to ease payment procedures and enable instantaneous purchasing by using barcodes. Another well-known platform is PayPal, which is mostly used by small stores instead of traditional equipment such as barcode readers and Point of Sales Terminal (POS). Mobile payment enables easy purchasing for stores that are not able to use traditional equipment and provides paying options other than cash [15].

3. Literature review

When the literature about Fintech applications in the finance industry is investigated it has been identified that studies were completed by countries, and mainly focused on (i) how consumers can react to Fintech applications, (ii) what are the challenges and barriers of Fintech applications for a specific country, and (iii) how Fintech applications can be popularized in the target country.

Starting with the challenges faced by countries on Fintech applications, Narayanasamy et al. [16] explored factors affecting the adoption of Fintech applications with a dataset of 100 participants who use Fintech applications. They identified that security, income, and cost are the main concepts that affect the adaptation of Fintech. Saksonova and Kuzmina-Merlino [17] studied the usage level of Fintech applications in Latvia compared to Europe and offered several recommendations to managers of Fintech enterprises. The study revealed that people in Latvia are not very aware of the applications. Furthermore, they made several suggestions to populate Fintech applications in Latvia such as forming impressive marketing campaigns to enhance the public's awareness, offering tax initiatives to attach investment to the sector, training human resources to specialize in Fintech applications, and further informing the population. Moreover, Harrison and Jürjens [18] examined the factors which affect the expectations of both users and organizations to adopt Fintech. Their study showed that data security, customer trust, and user design interface have an impact on adopting Fintech applications and can be a challenge.

Fintech applications provide cost-effective and more efficient transactions and have a crucial role in the banking industry since it is beneficial for customers [19]. Rizvi et al. [20] studied factors that enable penetration and growth of Fintech applications in Pakistan. Prominent suggestions to popularize the Fintech applications in the banking industry are promoting the Fintech applications, establishing an ecosystem where Fintech providers and consumers trust each other and the government's support. In another study, Nguyen et al. [21] investigated Fintech applications' development in the Vietnamese banking industry alongside identifying challenges to promote

Fintech applications in the banking and finance systems in Vietnam. Legal corridor, infrastructure, Fintech companies, customers, and human resources are the main barriers that the Vietnamese banking industry deals with. Main solutions to overcome these problems are finalizing the regulatory framework, encouraging the research and implementation of block-chain technology, training human resources for gaining Fintech application specialty, and constant promotion about Fintech applications.

Ratten [22] investigated the factors determining the intention of users to adopt Fintech applications. The research focused on the effects of users' entrepreneurship and learning disposition on marketing and information related to mobile banking. The results obtained are aimed to reduce the risks faced by users of financial institutions in e-finance applications.

Another popular subject on Fintech is money laundering, which is a global problem that authorities have been desperately trying to prevent but still fail. Banks must follow protocols such as "Know-your-Customer," "Anti-Money Laundering," and "Combatting the Financing of Terrorism" [23]. So, the fact that participants of a blockchain are anonymous, drew criticism from all over the world as money laundering could get much easier. While it is true that following someone on the blockchain is impossible, blockchain can help fighting frauds as you must justify the source and destination of each transaction, and all transactions can be followed publicly. HSBC, OCBC Bank, IMDA and Mitsubishi Financial Groups are working on a pilot blockchain system to reduce duplication and increase transparency [23].

From the robo-advisory function of Fintech services, the operations are based on calculations and algorithms which minimize error and risk. First, you must fill out a form and survey for the system, so that your investor profile can be figured out. Then, a recommended portfolio is created according to your profile, which consists of different asset classes in risk and liquidity. There exist many different approaches for determining the portfolio weights, but most robo-advisors use modern portfolio theory [24]. Following the investment, algorithmic rebalancing provides stability of the portfolio weights and therefore the risk-level by shifting investments among asset classes to revert towards its predefined risk long-term equilibrium, when the weights of the portfolio change [24]. The speed and precision of artificial intelligence (AI) is incomparably higher than a human's capability and there is no emotional decision-making involved. Based on the advantages it creates, AI and Fintech applications have been the focus of financial institutions. For instance, banking is one of the leading sectors that digitalization is applied for saving time, diminishing operational costs, increasing profitability and simplifying transactions for customers [25]. Therefore, it usually requires renovation of financial structure (Yoo et al., 2010). The main aim is to extend customer satisfaction and outline future customer needs [26].

Digitalization in banking is also used to improve service quality and introduce new financial products. To catch up with this global trend is crucial for banks as new market participants like Fintechs are a great threat to their effectiveness. Fintech applications in the banking sector are applied in various fields such as payment and collections systems, money transferring, savings, budgeting and borrowing. Loebbecke and Picot [27] stated that the first Fintech applications were designed for payment services such as Paypal. However, introducing Fintech applications on lending services provided a competitive advantage for conventional banks. With new technologies, customer expectations of the banking system have changed. Thus, banks face the challenge of improving their efficiency with the boosted competition. Philippon [28] illustrated that Fintech applications increased productivity in financial services (outputs) and lowered operating costs (inputs).

In a recent study, Kou et al. [29] analyzed Fintech investments in European banking with an application of interval type-2 fuzzy DEMATEL and interval type-2 fuzzy TOPSIS models. Empirical findings illustrate that 'payment and money transferring systems' are the most important Fintech-based investment alternatives. It is suggested that the European banks should mainly direct their investments into these channels for higher customer satisfaction and improved profitability.

According to Fu and Mishra [30], the number of mobile app downloads across major categories has increased and finance applications download rates increased both in the first and second lockdowns during the Covid-19 pandemic. This might be expected as, during the first lockdown in Europe, people were discouraged to use banknotes and were encouraged to contactless payment methods [31]. In addition, people were also encouraged to stay at home, therefore they were motivated to complete their financial transactions via financial applications. Saraogi [32] listed countries that were most affected by Covid-19 as Belgium, Brazil, China, France, Germany, Italy, Netherland, Spain, Switzerland, Turkey, the United Kingdom, and the United States. Considering the implemented social distancing and other precautions against the Covid-19, it was expected to see the number of downloads of Fintech applications to increase. Recent research conducted by MasterCard revealed that 79% of people worldwide and 91% in the Asia Pacific prefer to use tap-and-go payments due to safety and cleanliness reasons [32].

To sum up, Fintech applications make a significant contribution to the financial system by reducing costs, providing higher quality services and increasing customer satisfaction. Since the beginning of the pandemic, the speed of applications has boosted significantly. However, due to the short time span on the availability of detailed data in numerous industries and countries, new studies play an essential role to identify the needs of individual sectors and improve Fintech investments.

4. Empirical analysis

The aim of the analysis in this chapter is to evaluate the selection of best Fintech-based investments in the Turkish banking sector with an application of a hybrid DANP-fuzzy TOPSIS (Technique for Ordering Preference by Similarity to Ideal Solution) technique. DANP determines the weights of the SWOT factors and the fuzzy TOPSIS selects the best strategy for the Turkish banking sector. We identified the best strategies for decision-makers using an integrated model of the fuzzy TOPSIS technique with SWOT and DANP. To achieve a competitive advantage with growing Fintech applications, banks should identify targeted financial activities for prioritized Fintech investments. **Table 1** presents the proposed strategies based on feedback from the experts in the banking industry and academia.

4.1 Hybrid model construction

The integrated model has been built to select the best Fintech investment strategies for the Turkish banking sector by using the DANP (a combination of Decision-Making Trial and Evaluation Laboratory (DEMATEL) method and Analytical Network Process (ANP) method) technique to determine the weights of the SWOT factors followed by the fuzzy-TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) technique to select the best strategy. In determining the criteria for strategy formulation in this study, four banking experts with 15–20 years of experience cooperated to design a

Proposed strategies	Explanation
Strategy 1	Directing investments to Fintech applications in payment systems
Strategy 2	Directing investments to Fintech applications in lending services
Strategy 3	Directing investments to Fintech applications in collection services
Strategy 4	Directing investments to Fintech applications in asset and wealth (investment) management
Source: Authors' own table.	

Table 1.
Formulating strategies.

set of strategies. Then, three academics constructed the problems and modified strategies based on the expert scales and linguistic variables to evaluate the relative importance of the criteria and to select the strategies. First step of the analysis begins with the DANP technique to create the averaged initial direct relationship matrix with results presented in **Table 2**. The relationship among the SWOT factors is based on experts scales evaluated by the decision-makers.

Strengths are identified as increased service speed, improved customer satisfaction and cost reduction while weaknesses are customer adoption to no human transactions, physicological factors such as trust, technological capacity of customers. On the other hand, opportunities cover speedy international transactions, being part of Open Banking which may help in credit scores and providing alternative instruments/services. And finally, threats are identified as high initial investment costs, security and coping with foreign bank competition.

The second step is the application of the fuzzy TOPSIS technique to rank the proposed strategies. After constructing the fuzzy decision matrix, we normalized and weighted the matrix with DANP. **Table 3** introduces the findings in ranking the

	ri	*yi*	*(ri + yi)*	*(ri − yi)*
S (strengths)	6.37	5.36	11.73	0.94
W (weaknesses)	5.01	5.78	10.81	−0.77
O (opportunities)	5.92	5.51	11.43	−0.31
T (threats)	5.43	5.91	11.34	−0.48
Source: Authors' own table.				

Table 2.
Impact-relationship degrees of dimension.

Strategies	*Di+*	*Di-*	*CCi*	Ranking
Strategy 1	9.585	1.531	0.132	2
Strategy 2	9.443	1.583	0.156	1
Strategy 3	9.649	1.449	0.112	3
Strategy 4	9.896	1.216	0.108	4
Source: Authors' own table.				

Table 3.
Selection of the best Fintech investment strategy.

proposed strategies. $Di+$, $Di-$ and CCi are the values indicating distances of each strategy alternative from the positive and negative ideal solution.

Empirical findings of the analysis indicate that Strategy 2 has the best rank among the alternatives, followed by Strategy 1 and Strategy 3, whilst Strategy 4 has the weakest importance among the strategy preferences. Our findings suggest that policy makers/bank managers should focus more to direct Fintech investments firstly to lending services followed by payment systems.

4.2 Empirical findings

We applied a hybrid DANP-fuzzy TOPSIS technique to evaluate the selection of best Fintech-based investments in the Turkish banking sector. Ranking of the strategies helps us to identify the importance/priority of the proposed strategies on directing Fintech investments to various activities of Turkish banks. Empirical findings illustrate that among the financial activities of Turkish banks, lending services are identified to signal the highest need for Fintech investments. Payment services also show a priority in attracting Fintech investments being ranked as the second strategy. Receivable collection services and investment management services are not categorized as prioritized as others. These results should be interpreted carefully as customer satisfaction and expectations may differ from one country to another based on cultural and economic differences as well as the level of education and access to technology. To sum up, empirical analysis in this chapter suggests that policy makers/bank managers should focus more on direct Fintech investments firstly to lending services followed by payment systems.

5. Conclusions

Life has started to flow very quickly with the advancement of technology and the financial sector has also followed these developments with Fintech applications. Financial activities can be done faster and more effectively than traditional methods. With the Fintech applications, operations can be handled at the desired place and time because smart devices and online platforms eliminate the need of going to a bank. With the decrease of trust in traditional order due to the unethical attitudes displayed by traditional intermediaries, the Fintech sector has gained quick popularity in our lives [33].

Besides its advantages, there are also several disadvantages of Fintech applications. The Fintech industry is still developing faster than expected and there is no distinct transition to Fintech industries from traditional intermediaries. Therefore; the governmental regulations are tailored according to traditional companies [33]. As a result, Fintech companies may act through their desires and consider the requests of customers freely since some Fintech companies did not become legalized. The replacement of humans by artificial intelligence has negative effects on people's attitudes. In some circumstances, personal interaction becomes a need for customers. Researches show that only 11% of persons trust on robo-advisors and 49% of people do not prefer to use robo-advisory without getting consultancy from a real person [24].

Every invention brings along questions about the future and Fintech is no exception. Small ventures and entrepreneurs have concerns because they may lose their brand value, popularity, and the likelihood of the company in the future when they prefer crowdfunding instead of traditional banks to obtain capital. Since the crowdfunding process requires an online platform, all the investors and by extension the public may get quick notifications about the companies' failures and successes. Thus, even if the project has a future, if there is less demand or interest to project for a little time, investors who are expected to continue to invest may reduce their support or even cut their support completely.

Currently, we are living in unprecedented times in which we should have social distance from one another and stay at home. While these are happening, still businesses and organizations are expected to work without having any disruptions. At this point, entering new technologies into our lives was inevitable and in fact, these new technologies have helped us to get over this process with fewer flaws. One of these technologies was Fintech applications. Although, we used these technologies beforehand, with the Covid-19 precautions, the frequency and intensity of the usage of Fintech applications increased enormously. A recent study conducted in Singapore revealed that 80% of the consumers will probably continue to use Fintech applications even after the pandemic [34]. As one of the most affected countries from Covid-19, Turkey follows a similar trend for the utilization of Fintech applications.

Considering the challenges that other countries are dealing with while adopting Fintech applications, they are solutions to their problem. For instance, Saksonova and Kuzmina-Merlino [17] identified that during the utilization of Fintech applications, tax-related issues can appear. Therefore, governments should form related laws and regulations to regulate Fintech applications. Furthermore, Harrison and Jürjens [18] revealed that security is another important issue during the adoption of Fintech applications. Thus, awareness about security must be improved by both governments and businesses, which use Fintech applications. Finally, Nguyen et al. [21] illustrated that both employees and consumers might not understand the Fintech applications fully. Thus, training can be offered to them to explain the abilities of the Fintech applications.

Author details

Özlem Olgu Akdeniz
College of Administrative Sciences and Economics, Koç University, Istanbul, Turkey

*Address all correspondence to: oolgu@ku.edu.tr

References

[1] Alt R, Beck R, Smits MT. FinTech and the transformation of the financial industry. Electronic Markets. 2018;**28**:235-243. DOI: 10.1007/s12525-018-0310-9

[2] Lee I, Shin YJ. Fintech: Ecosystem, business models, investment decisions, and challenges. Business Horizons. 2018;**61**:35-46

[3] Thakor AV. Fintech and banking: What do we know? Journal of Financial Intermediation. 2020;**41**:100833

[4] Iman N, Tan AWK. The rise and rise of financial technology: The good, the bad, and the verdict. Cogent Business & Management. 2020;**7**:1. DOI: 10.1080/23311975.2020.1725309

[5] Moden N, Neufeld P. How Covid-19 has sped up digitalization for the banking sector. 2020. Available from: https://www.ey.com/en_gl/financial-services-emeia/how-covid-19-has-sped-up-digitization-for-the-banking-sector

[6] Kagan J. Financial technology—Fintech. 2020. Available from: https://www.investopedia.com/terms/f/Fintech.asp#:~:text=%E2%80%8B%E2%80%8B%E2%80%8BAt%20its,combination%20of%20%22financial%20technology%22

[7] Arner D, Barberris J, Buckley R. The evolution of Fintech: A new post-crisis paradigm? University of Hong Kong Faculty of Law. Research Paper No. 2015/047. 2015

[8] Nicoletti B. The Future of Fintech: Integrating Finance and Technology in Financial Services. Cham: Palgrave Macmillan; 2017

[9] Menat R. Why we're so excited about Fintech. In: Chishti S, Barberris J, editors. The Fintech Book. London: John Wiley and Sons; 2016. pp. 46-51

[10] Bank of International Settlements. Promoting Global Monetary and Financial Stability. Annual Economic Report; 2018

[11] Ertz M, Boily E. The rise of the digital economy: Thoughts on blockchain technology and cryptocurrencies for the collaborative economy. International Journal of Innovation Studies. 2020;**3**:84-93. DOI: 10.1016/j.ijis.2019.12.002

[12] Lopez JC, Babcic S, De La Ossa A. Advice goes virtual: How new digital investment services are changing the wealth management landscape. 2017. Retrieved from: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3084057

[13] Jung D, Dorner V, Glaser F, Morana S. Robo-Advisory: Digitalization and Automation of Financial Advisory. Business and Information Systems Engineering. 2018;**60**(1):81-86. DOI: 10.1007/s12599-018-0521-9

[14] Fenwick M, McCahery J, Vermeulen E. Fintech and the financing of entrepreneurs: From crowdfunding to marketplace lending. 2017

[15] Kang J. Mobile payment in Fintech environment: Trends, security challenges, and services. Human-centric Computing and Information Sciences. 2018;**8**:32. DOI: 10.1186/s13673-018-0155-4

[16] Narayanasamy K, Rasiah D, Tan TM. The adoption and concerns of e-finance in Malaysia. Electronic Commerce Research. 2011;**11**(4):383

[17] Saksonova S, Kuzmina-Merlino I. Fintech as financial innovation—The possibilities and problems of implementation. European Research Studies Journal. 2017;**20**(3A):961-973

[18] Harrison S, Jürjens J. Data security and consumer trust in Fintech in

innovation in Germany. Information and Computer Security. 2018;**26**(1):109-128

[19] Cheng MA, Wu Q, Yang B. How valuable is FinTech innovation? The Review of Financial Studies. 2019;**32**(5):2062-2106

[20] Rizvi SKA, Naqvi B, Tanveer F. Is Pakistan ready to embrace Fintech innovation? The Lahore Journal of Economics. 2018;**23**(2):151-182

[21] Nguyen DD, Dinh HC, Nguyen DV. Promotion of Fintech application for the modernization of banking-finance system in Vietnam. Journal of Asian Finance, Economics and Business. 2020;**7**(6):127-131

[22] Ratten V. Entrepreneurship, e-finance and mobile banking. International Journal of Electronic Finance. 2012;**6**(1):1-12

[23] Suominen K, Chatzky A, Reinsch W, Robison J. (Rep.). Center for Strategic and International Studies (CSIS). 2018. DOI:10.2307/resrep22491

[24] Jung D, Glaser F, Köpplin W. Robo-advisory: Opportunities and risks for the future of financial advisory: Recent findings and practical cases. 2019. DOI: 10.1007/978-3-319-95999-3_20

[25] Bhutani S, Paliwal Y. Digitalization: A step from sustainable development. OIDA International Journal of Sustainable Development. 2015;**8**(12):11-24

[26] Valenduc G, Vendramin P. Digitalisation, between disruption and evolution. European Review of Labour and Reserach. 2017;**23**(2):121-134

[27] Loebbecke C, Picot A. Reflections on societal and business model transformation arising from digitization and big data analytics: A research agenda. Journal of Strategic Information Systems; 2015

[28] Philippon T. The Fintech Opportunity. BIS Working Paper No. 655. 2017

[29] Kou G, Akdeniz OO, Dincer H, Yuksel S. FinTech investments in European banks: A hybrid IT2 fuzzy multidimensional decision-making approach. Financial Innovation. 2021;**7**:39

[30] Fu J, Mishra M. Fintech in the time of Covid-19: Trust and technological adoption during crises. Swiss Finance Institute Research Paper No. 20-38. 2020. Available from: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3588453

[31] Cocheo S. More consumers prefer contactless payments for pandemic purchases. 2020. Available from: https://thefinancialbrand.com/101415/payment-contactless-card-mobile-wallet-digital-coronavirus-covid-19-pandemic-trend/

[32] Saraogi V. Contactless payments will be the new normal for shoppers in the post Covid-19 world. 2020. Available from: https://newsroom.mastercard.com/asia-pacific/2020/05/20/contactless-payments-will-be-the-new-normal-for-shoppers-in-the-post-covid-19-world/

[33] Pejkovska M. Potential negative effects of Fintech on the financial services sector examples from the European Unıon, Indıa and the United States of America. 2018. Retrieved from: https://www.theseus.fi/bitstream/handle/10024/148416/Maja_Pejkovska_Theseus.pdf?sequence=1andisAllowed=y

[34] Gene NK. 8 in 10 will continue banking online after pandemic: Survey. 2020. Available from: https://www.straitstimes.com/singapore/8-in-10-will-continue-banking-online-after-pandemic-survey

Chapter

Digital Maturity of University Libraries in Nigeria

Akinniyi A. Adeleke, Yemisi Ojokuku and Joshua Onaade Ojo

Abstract

This chapter reports the findings of a survey of the level of digital maturity of university libraries in Nigeria. Forty-eight university libraries responded to an online survey based on the framework for digital mature schools (FDMS). The findings reveal that the libraries are e-enabled but yet to attain digital maturity. The paper also shows that the dimensions of ICT planning, management and leadership, and ICT infrastructural development statistically predict the digital maturity status of university libraries.

Keywords: academic libraries, digital maturity, digital transformation, university libraries, Nigeria

1. Introduction

University education is one sector of national economies tremendously influenced by digital transformation. According to Fosu [1], "the 21st century global digital and knowledge-based economies evolution powered by the rapid advancement of ICT with its gadgets have brought about a global wave of change in the education sector". With the current COVID-19 pandemic speeding up the hitherto steady developments, university campuses become more innovative by using virtual learning environments and digital communication platforms for teaching and learning; and applying knowledge and business analytics for decision making.

The incursion of the digital revolution into teaching, learning and research presents university libraries with opportunities and challenges to cope with changing information behaviours, resources and sources of their patrons, majorly students and faculty members. The ICT evolution and revolution, on the one hand, present university libraries with the opportunities of:

- using various gadgets and applications to present information sources and resources to patrons;

- using multiple platforms to communicate, collaborate and cooperate with patrons and other libraries in resource sharing and networking.

On the other hand, university libraries are grappling with how users access and use information which warrants that every library content is on electronic platforms.

Such demands require deploying substantial human and capital resources that are scarcely available and accessible to university libraries, particularly in developing countries like Nigeria.

University libraries are organised to support their host institutions' teaching, learning, and research activities, and to satisfy the ever-changing needs of their patrons fully, they take steps to integrate digital technologies with their operations and services. However, the pace of digital transformation in university libraries varies from institution to institution, country to country and region to region. Hence the libraries are at different degrees of their abilities to respond and take advantage of technological developments in their operations and services, a phenomenon referred to as digital maturity.

This book chapter seeks to interrogate and report on the digital maturity of university libraries in Nigeria. It attempts to review the libraries' efforts to adopt digital technologies and techniques for creating and adding value to their services to understand their levels of abilities to respond to the environment created by the evolving digital economy. The whole essence of this adventure is to determine the existence in the libraries of the capabilities, competencies, tools and infrastructure required to understand and respond to the needs and desires of the information user in the unfolding digital environment. In the final analysis, the discourse would establish the reality or fallacy of the digital maturity of university libraries in Nigeria. It will help the institutions and their owners understand the statuses of their digital compliance and determine how commensurate with their digital technologies investments is their ability to respond to the digital economy's demands.

Although university libraries were doing amazing things with ICTs, the library and information science literature reports only few of university libraries in Nigeria making deliberate efforts to adopt, deploy and use digital technologies and strategies for the digitalisation of information services and resources to address some peculiar challenges. For instance, Adeleke [2] reported how Tekena Tamuno Library, Redeemer's University, Ede resolved staff-patron conflicts with digitising past examination questions. The paper reiterates the power of the digital economy to remove interpersonal conflicts and establish peaceful co-existence among members of a community. The dearth of reports about university libraries in Nigeria deliberately implementing digital solutions to address research, teaching and learning issues informs the present attempt to investigate the digital maturity of the libraries.

A digitally mature library uses appropriate information and communications technologies for efficient and transparent management of resources and services, develops the digital competence of its personnel for innovative services, and develops its users' digital capacity to be life-long users of information in any environment. In short, digitally mature libraries have a high level of integration of ICTs in their routine operations and services and systematically approach the deployment of ICT in supporting the teaching, learning and research mandates of their parent institutions to adapt to the evolving digital environment.

The concept of digital maturity refers to the formation of specific capabilities to manage digital transformation in an organisation. Digital maturity represents the degree of adoption and application of digital technologies in business models. Kane et al. [3] see digital maturity as a systematic way for an organisation to transform digitally. Digital maturity incorporates managerial aspects of ICTs to describe what a company has already done and will do in digital transformation efforts that involve products, services, processes, skills, culture and abilities regarding the mastery of change processes [4]. Westermann et al. [5] assumed that developing specific digital capabilities leads to higher digital maturity.

Digital maturity is a systematic way for an organisation to transform digitally [3]. An organisation can take on digital transformation, not only from the standpoint of digital technology but organisation-wide, including people, culture, and processes, to achieve business outcomes [6]. According to Westermann et al. [5], an organisation's digital maturity is its ability to use digital technologies to drive significantly higher profit, productivity, and performance. The digital maturity of university libraries will imply the power of a library to use digital technologies to conduct its services and manage its resources to productively engage, educate and empower its users who have different information needs and diverse behaviours. A digitally mature library will excel at developing digital capabilities to work differently and the leadership capabilities required to achieve a vision. Digital maturity is a journey. Therefore, as university libraries realise the power of digital technologies to expand access to collections and enable their wide use for research, teaching and learning, they gradually build capacities and competencies to harness the opportunities in the current technology market to transform their services.

University libraries are not ranked among the most digitally mature organisations in the business technology literature, even in developed countries. Therefore, it is pertinent to understand how technology is adopted and used in university libraries because of its significance in supporting their parent institutions' teaching, learning, and research activities.

The expectations of today's library users and the ubiquitous and evolving nature of technology compel university libraries to re-imagine and redesign their operations and services to support the curricula and mandates of their parent institutions. Anuradha [7] asserts that digital sophistication is a criterion for any academic library to remain a relevant part of the educational experience of its ever-changing users.

The National Universities Commission (NUC) is the institution saddled with the responsibilities of licencing and regulating the operations of both public and private universities in Nigeria. The NUC, by law, has in part the burden of establishing minimum standards for all academic programmes that lead to awards of degrees in universities in Nigeria. The Commission also ensures that quality is maintained in the Nigerian university system. Owing to its prime position in achieving a university's teaching, learning and research mandates, the NUC earmarks a whopping 70% of the total accreditation scores for library facilities as the minimum requirement for an academic programme to attain full accreditation status [8]. Part of the library facilities often assessed by the NUC accreditation teams includes physical library collection or holdings on the programme being visited, seating capacity, subscription to electronic information resources, internet connection, etc.

Recently, NUC accreditation panels emphasise digital collections and connections more before approving a university to proceed with an academic programme. The accentuation of the requirements shows that the Commission acknowledges the necessity of integrating university education with digital technologies. And that the university campus cannot isolate itself from the evolving digital economy. To identify with the digital revolution, the NUC established a digital library project that aimed at digitising information materials and making them available to both public and private universities in Nigeria. The initiative was to encourage universities to build capacities to harness the enormous advantages of the ICT to teaching, learning and research. Meanwhile, university libraries in Nigeria confront with enormous challenges that have hindered them from making the best of the opportunities extended to them by ICT and its applications.

Baro, Oyeniran, and Ateboh [9] identified challenges confronting university libraries deploying ICTs in Nigeria. The problems include unstable internet connection, irregular power supply, poor funding, incompetent personnel, etc. These challenges may hinder the libraries' efforts to attain maturity in their parent institutions' digital transformation. Maturity models are used widely in information systems research [10, 11]; and are developed with a particular focus on the conditions and implications of digital transformation [12]. However, applications in educational contexts are scarce [13]. The available models are limited to the management of information systems in educational organisations, which are still at the initial stage of development [14].

Rossmann [15] conceptualised and operationalised a theoretical understanding of digital maturity to develop a scale for analysing digital transformation and continuous control. The framework is an extension of the work of Westermann et al. [5] and others such as Isaev et al. [16] and Poruban [17], and it is more appropriate for business organisations.

Durek et al. [18] developed a digital maturity framework for assessing the maturity level of higher education institutions in Croatia [18]. Using the analytic hierarchy process/analytic network process (AHP/ANP), Durek et al. identified seven main areas and 43 elements prioritised by the framework. The seven areas are 1.) leadership, planning and measurement; 2.) quality assurance; 3.) scientific research work; 4.) technology transfer and service to society; 5.) learning and teaching; 6.) ICT culture; and 7.) ICT resources and infrastructure.

Similarly, Begicevic Redjep, Balaban and Zugec [19] proposed and validated a framework for digitally mature schools (FDMS). The framework recognises five different levels of maturity in the form of a rubric. Begicevic et al.'s FDMS collapsed Durek et al.'s [18] framework into five dimensions namely; 1) planning, management and leadership, 2) ICT in learning and teaching, 3) development of digital competencies, 4) ICT culture, and 5) ICT infrastructure. The framework and the ensuing instrument support educational institutions in assessing, promoting and integrating digital technologies in teaching, learning and organisational practices.

Love et al.'s [20] maturity model for ePortfolios recognises five levels of digital maturity of organisations, with each one providing a stepping-stone for the next one. However, Begicevic Redjep et al. [19] warned that we should not read the different levels as judgemental but consider them as stages of the maturation process since maturity is a journey.

Based on their common characteristics, Begicevic Redjep et al. [21], in their paper: Framework for Digitally Mature Schools, named and described the five levels of digital maturity as Basic, Initial, e-Enabled, e-Confident and e-Mature. Basic is the school that is not aware of the possibility of using ICT in learning and teaching or management processes. Therefore, the school does not consider ICT when planning its growth and development. It does not use ICT in learning and teaching and does not provide ICT infrastructure yet, and computers are used only in a few classrooms in the school. Thus, online communication with the school is generally not possible.

At the initial stage of digital maturity, the school is aware of the possibility of using ICT in learning, teaching and management processes, but it has not yet been implemented. A small number of teachers use ICT in learning and teaching. There is awareness of the need to enhance the digital competencies of teachers and students. However, the system for the professional development of digital competencies still does not exist. The ICT infrastructure is generally undeveloped, with limited access to ICT resources and internet access available only in a few classrooms.

The school that is e-Enabled is aware of the possibility of using ICT in all its activities. It participates in small ICT-focused projects and guides the development of its strategic documents and integration of ICT into these documents. It uses ICT for working with students with special educational needs. Teachers can advance their digital competencies, develop digital content, and introduce innovative teaching methods. The school provides access to different ICT resources in most classrooms and gives special attention to equipment maintenance and the control of software licencing.

Begicevic Redjep et al. [21] described an e-Confident school as recognising the advantages of ICT usage in its activities and integrating the ICT implementation into strategic documents and everyday activities such as ICT projects. Teachers use ICT for advanced teaching and assessment methods and develop their own content and protect the same by copyright. It plans and performs the continuous professional training of teachers to acquire digital competencies. Students are encouraged to develop those competencies. The school provides access to different ICT resources in most classrooms, with shared repositories for all participants and plans the procurement and maintenance of the ICT resources. The school is also very active online in content presentation and communication. It controls software licencing and considers the security aspects of ICT use.

An e-Mature school very clearly recognises and requires ICT in all activities in its strategic documents and development plans. The management practice relies on integrating and obtaining data from all school information systems. The approach to enhancing the digital competencies of teachers and students is systematic, and professional training for teachers and additional course activities for students are available. Teachers use ICT within advanced teaching methods to develop new course content and assess student achievements. The school independently plans and acquires ICT resources available in nearly all classrooms and other rooms in the school. The entire school has a developed network infrastructure. An information security system has been designed, and software licencing is systematically controlled and planned. The school is characterised by varied ICT project activities and cooperation between teachers and students and other schools and stakeholders.

Just as it is uncertain if any university library in Nigeria can claim digital maturity because of the apparent challenges confronting them, no study in the extant literature reported any model or framework used to assess libraries' digital maturity. The study reported in this chapter attempts to address this gap in the literature using the framework for digital mature schools by Begicevi Redjep et al. [21]. The specific objectives of the study are to:

1. gauge the level of digital maturity in the university libraries in Nigeria;

2. determine the dimensions of the digital maturity framework that predict the level of digital maturity of university libraries in Nigeria and

Based on objectives two and three, three null hypotheses are tested in the paper. They are:

1. The dimensions of the digital maturity framework do not significantly influence the level of digital maturity in university libraries in Nigeria.

2. There is no significant relationship between the digital maturity and age of university libraries in Nigeria.

2. Methodology

The paper adopts a quantitative approach to determine the stage attained by university libraries in their digital transformation efforts to be in tune with the realities of the digital economy using an online structured questionnaire to collect data. The questionnaire has seven sections. Section A elicits information about the institution and the responding personnel.

Since university libraries support their parent institutions to achieve the mandate of teaching, learning, and research, this study adopts Begicevic Redjep et al.'s [19] framework to determine the digital transformation status in university libraries in Nigeria in Sections B to F of the questionnaire. The 38 items distributed among the five dimensions of the framework from Sections B to F are re-worded to reflect digital technology applications to library operations and services. Dimensions 1–4 of the framework in Sections B to E have seven times each, while the fifth in Section F has 10 items. The final instrument requests the participants to confirm or otherwise how applicable the questionnaire's statements the five sections are to their libraries on a scale of five (1 = does not apply to 5 = totally applies). The mean score of the responses represents the level of digital transformation in the library (where 1 = very low, 2 = low, 3 = moderate, 4 = high, 5 = very high).

The section G requires the respondents to categorically rate the level of maturity of their libraries on a scale of five (5) (1 = basic, 2 = initial, 3 = enabled, 4 = confident, and 5 = mature) based on how well they believed the statements in Sections B to F apply to their libraries.

The researchers used the Googe Form app to prepare the questionnaire and sent it to participants via social media platforms, including Whatsapp, Facebook and Telegram. The researchers sent the link to the survey to the email addresses of some heads of university libraries. The survey was on for four weeks. The study used the Statistical Package for Social Science (SPSS) version 16 to analyse the data collected, and the results are presented in the results section.

3. Results

Forty-eight universities (64% public and 36% private) responded to the online survey. About 37% and 33% of the libraries are between 25 and 50 years old and 10 to 24 years old. The respondents are heads of the libraries and library personnel in charge of the deployment and management of ICT facilities (59% females and 41% males), most of whom have worked in the libraries for more than ten years (59.6%). The participants are purposively selected for the study because they are believed to implement and drive the digital transformation of their respective libraries.

University libraries, in general, adopt digital technologies for meeting the diverse information needs of clients and creating inspiring spaces and innovative services to support the teaching, learning and research mandates of their parent institutions. The assertion may explain why all the university libraries that participated in this study integrate ICTs into their operations and services. All the universities integrate ICTs with their services and processes at different times but not less than five years ago. **Figure 1** presents the history of ICT integration in university libraries in Nigeria. The mean age of ICT implementation in all university libraries is between 5 and 15 years ago; meaning that most of the libraries started integrating ICT with their operations and services less than 20 years ago.

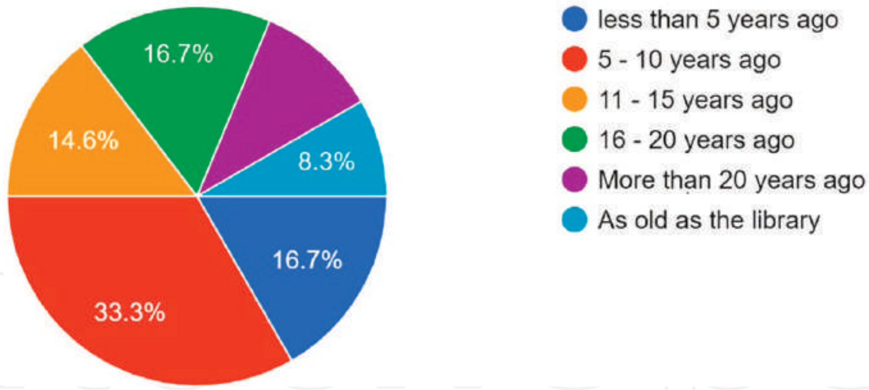

Figure 1.
History of ICT integration in university libraries in Nigeria.

3.1 Digital maturity of university libraries in Nigeria

The study's first objective is to gauge the digital maturity of university libraries in Nigeria. To achieve the purpose, the survey requests the participants to rank their libraries on a scale of five (1 = basic, 2 = initial, 3 = e-enabled, 4 = e-confident and 5 = e-mature). **Figure 2** shows the response distribution of the participants with a mean of 3.25 and a standard deviation of 1.06. The chart shows that most libraries are e-enabled, meaning that they are aware of the possibility of the libraries being e-enabled, meaning that they are aware of using ICT in all their activities. They participate in small ICT-focused projects and use ICT for working with patrons with special

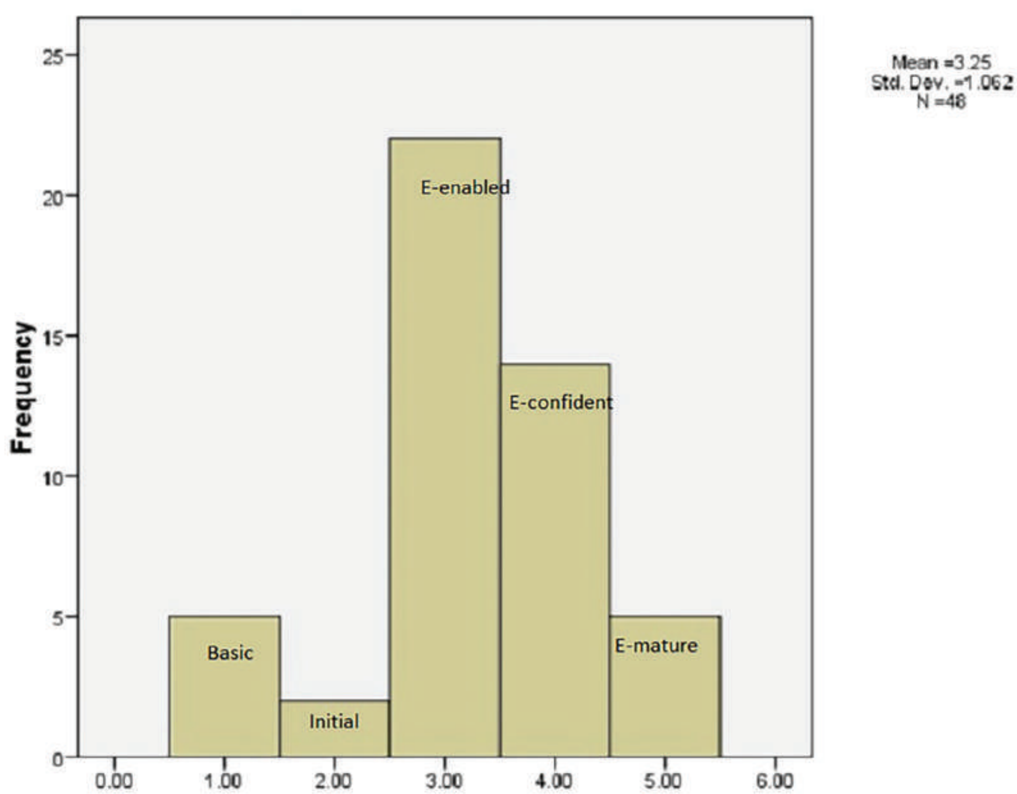

Figure 2.
Level of digital maturity of university libraries in Nigeria.

Variables	N	Mean	Standard deviation	df	R	R^2	F	Sig
Level of Digital maturity	48	3.27	1.07	5	0.85	0.73	22.68	0.00
ICT planning, management and leadership	48	3.79	0.90					
ICT Use in Library operations and services	48	4.06	0.85					
ICT competence development	48	3.42	0.93					
ICT culture	48	3.75	0.87					
ICT infrastructure	48	3.54	0.94					

Source: Data Analysis from the Study.

Table 1.
Relationships between the level of digital maturity and ICT dimensions in university libraries in Nigeria.

information needs. Also, the librarians can advance their digital competencies, develop digital content, and introduce innovative services by providing different ICT-based resources and giving special attention to equipment maintenance and the control of software licencing. The finding supports the report of Makori and Mauti [22]. They noted university libraries in Kenya (public and private) implement various technological approaches to provide for the information needs of their users. Such practices include social computing, internet and web-based services, information portals and digital repositories. Others are modern information environments, social media networks and multimedia applications. Although, the present study did not investigate the types of digital technologies and strategies used by university libraries in Nigeria, one may infer that their experiences are not different from their Kenyan counterparts.

The study's second objective is to determine the dimensions of the ICT framework that predict the digital maturity of university libraries in Nigeria. **Table 1** presents the result of the Regression analysis to explain the relationships among the level of digital maturity and the ICT dimensions in the university libraries.

There is a strong correlation between digital maturity and ICT dimensions in university libraries. The result presented in the Table shows that the five dimensions jointly predict 73% of the changes in the digital maturity of the libraries ($R^2 = 0.73$; $F = 22.68$ at $p < 0.05$). The study also finds that the dimensions of ICT planning, management and leadership ($\beta = 0.34$, $t = 2.40$ at $p < 0.05$) and ICT infrastructure ($\beta = 0.55$, $t = 3.68$ at $p < 0.05$) have significant individual effects on the level of digital maturity in university libraries in Nigeria.

4. Discussions

The study's finding shows that many libraries have passed the basic and initial stages of digital maturity, and a majority are at the e-Enabled level. This implies that the libraries are aware of the possibility of using ICT for their operations and services. They participate in small ICT-focused projects and use ICT for working with patrons with special information needs. Librarians can advance their digital competencies, develop digital content, and introduce innovative services by providing different ICT-based resources and giving special attention to equipment maintenance and the control of software licencing.

The dimensions of planning, strategy and leadership and building ICT infrastructure are positively significant to the level of maturity of the libraries in their efforts towards digital transformation. The observed statistical relationship implies that the libraries must consciously and deliberately pay attention to including strategic ICT implementation in their organisational planning and development. The libraries also must build capacity for leadership to drive their digital transformation agenda and acquire appropriate infrastructure for its successful implementation.

As illustrated by **Table 2**, the dimension of planning, management and leadership in ICT integration predicts the level of digital maturity in university libraries in Nigeria by 34% (β = 0.34). This finding suggests that developing leadership capabilities in planning and management is crucial to successfully integrate digital technologies and strategies into library operations and services. The result confirms the significant role of planning, management and leadership in the digital transformation of organisations as espoused in the literature, such as Begicevic Redjep et al. [19]. However, it was uncertain if the university libraries have formal documents stating their vision and guidelines towards digital transformation because the researchers did not include this aspect in the study. It will be worth the while for future studies to visit the physical location of the libraries to review their organisational structures to confirm the existence of actual policy documents, leadership drive and specific roadmap designed for deploying and implementing digital strategies and technologies in the institutions. The researchers' personal experience shows that implementation of ICTs in most university libraries is always dependent on the ICT strategies of their parent institutions, implying that the libraries do not usually have control over the planning and management of technology infrastructure. The development may take a toll on their efforts towards attaining digital maturity.

In their book, *Leading Digital: Turning Technology into Business Transformation*, Westermann, Bonnet, & McAfee [5] assert that "technology can remove obstacles and extend organisational capabilities, but it is not an end in itself." For an organisation to attain digital mastery, it needs to focus on its business and not the technology to enhance customers' experience, streamline operations or transform business models. As observed in the study, university libraries in Nigeria are well aware of the possibilities of using ICTs in their activities and management processes and also recognise the immense benefits of digital technologies. However, not many university libraries are at

Model	Unstandardized coefficients		Standardised coefficients	t	Sig
	B	Std Error			
(Constant)	−0.80	0.43		−1.88	0.07
ICT planning, management and leadership	0.41	0.17	0.34	2.40	0.02
ICT Use in Library operations and services	0.16	0.21	0.14	0.85	0.40
ICT competence development	−0.12	0.16	−0.10	−0.73	0.77
ICT culture	0.01	0.20	0.00	0.03	0.98
ICT infrastructure	0.63	0.17	0.55	3.68	0.00

Dependent variable: Digital maturity of university libraries in Nigeria.

Table 2.
Coefficients.

the strategic implementation of ICTs to operations and services. University libraries in Nigeria are still at a level of awareness and appreciation of ICT and not yet taking full advantage of its potential to enhance service delivery and extend operational capabilities. For instance, just about 40% of the survey participants agreed and strongly agreed to the claim that "the library personnel use ICT for advanced services". The observed response pattern corroborates the work of Idhalama and Ifidon [23]. They found only a few university libraries in Nigeria implementing cutting-edge ICT facilities to manage their library resources and services. This development is very much unlike what is obtainable in developed countries of Europe, North America and parts of Asia.

One of the major problems militating against digital transformation in many developing countries like Nigeria is the shortage of ICT infrastructure and facilities. Several authors across Africa, including Chizenga [24], Oketunji [25], Okiy [26], Gbaje [27], Akanni [28] and Okiy [29], lamented the problem which still lingers to date. The researchers' personal experiences reveal that many university libraries in Nigeria experience epileptic power supply, which is an essential requirement for the digital transformation agenda of any organisation. University libraries in Nigeria often consider ICT infrastructure as acquiring computer machines, installing library management software, internet access, and subscriptions to electronic information resources. Although many libraries invest in these facilities, particularly the public universities with access to the Tertiary Education Tax Funds (TETFUND), power failure hampers their functionality.

Another significant infrastructural deficit in the digital transformation efforts of libraries in Nigeria is the lack of provisions for physically challenged individuals. Iroeze et al. [30] report in their study of library services for the physically challenged in Nigeria that such services are inadequate, outdated and provided in poorly architectural designed facilities. The respondents to the current study corroborated the gloomy picture painted by Iroeze et al. [30] because only a few believe that their libraries have dedicated digital resources and facilities for unique users such as people living with disabilities. The finding is also similar to that of Lawal-Solarin [31], who noticed that the architectural designs of most academic libraries in Ogun State, Nigeria, did not consider the peculiarities of the physically challenged persons.

The digital transformation agenda of any organisation should be all-inclusive. It must not discriminate against any individual peculiarities. The effort should cater to every community member's disabilities, strengths, and weaknesses. Unfortunately, Martinez and Vemuru, in a blog post at World Bank.org, noted that "persons with disabilities in Nigeria persistently face stigma, discrimination, and barriers to accessing essential social services and economic opportunities" [32]. This assertion might explain why library services usually exclude physically challenged people in Nigeria. Therefore, if Nigerian university libraries would attain maturity in their digital transformation efforts, they need to invest in strategic, all-inclusive and robust ICT infrastructure to drive their operations and services.

A critical indicator of digital transformation is the development of digital competencies; however, it does not significantly affect the level of digital maturity of university libraries in Nigeria. Digital competence, according to the recommendation of the European Parliament on the critical competencies for lifelong learning, is the confident and necessary use of Information Society Technology (IST) for work, leisure and communication [33]. It encompasses a set of attitudes, knowledge, skills, awareness, and values that are of great importance when utilising disruptive digital technologies and tools in an organisation [34].

Digital technologies shape how organisations interact with their internal and external stakeholders. Thus, a new culture that influences organisational values and norms emanates from digital technologies and tools. Digital culture emerged with the process of shared experience in digital environments. Organisations with a robust digital culture use digital tools and data-powered insights to drive decisions and unlock value [35]. In a nutshell, digital culture helps organisations integrate environmental, social and governance commitments and action across the organisation.

The extent to which ICT shapes the environment and experience of work in university libraries is critical to the digital transformation journey of an organisation. According to Akintunde [36], "many libraries in Nigeria still operate in the traditional service pattern where librarians are in charge in main service points of circulation, reference, serials, acquisition, cataloguing and documents without any emphasis on academic disciplines". Akintunde's standpoint confirms the embryonic state of digital culture in Nigerian university libraries. The slow pace of imbibing the ICT culture is borne out of a lack of competencies among academic librarians, as Okiy [29] observed in her paper titled *Globalisation and ICT in academic libraries in Nigeria: the way forward*. For academic librarians to render more effective services in the new digital environment, Okiy submits that they need to brace up to the unique challenges of ICT competencies. Her submission corroborated Okorie and Ekere [37] that if information professionals do not keep abreast of the changing technologies, they will be unable to manage the different types of information resources and cope with the users' ever-growing information needs in this electronic age.

One limitation of this paper is that the researchers did not visit the libraries to have an on-site assessment of their work environment to understand the digital lifestyle of the community. However, our personal experiences as one-time students and current workers in two of the universities that participated in the survey confirm that ICT culture is underway in Nigerian university libraries. Therefore, assimilating digital culture in Nigerian university libraries is a function of the readiness of academic librarians to build capacities for effective ICT use.

5. Conclusion

This chapter establishes that the journey to digital maturity in Nigerian university libraries is ongoing and at the embryonic stage. For Nigeria to achieve its vision and mission for transformation to a digital economy that will promote prosperity and security, the collaboration between academia and the industry is of the essence. According to Inyene Ibanga,

> *"academia serves as the centre for generating new knowledge and imparting education to students. Industry focuses on applying skills and efficient management to address solutions that have commercial value. Combining these two can lead to accelerated advances in innovation and entrepreneurship. This will, in turn, yield economic growth, capital formation and other attendant benefits" [38].*

Nigerian universities need to continue developing staff and institutional capacities to meet with the fast-changing digital innovations to proffer solutions to societal problems and challenges. For the universities to be positioned for this role, researchers must access current and relevant information resources and services their libraries provide. Therefore, the digital transformation efforts in academia must include deliberate empowerment of the library institutions and personnel if the universities would fulfil their mandates of research, teaching, learning and community development services.

Although, university libraries in Nigeria are deploying various ICT equipment and solutions to render services and enhance their operations, our study's findings revealed that the majority are yet to attain digital maturity. As Nigeria transforms into a digital economy, capacity building for libraries of higher institutions should occupy a prime position in the country's digital transformation agenda. The infrastructural deficit in most public universities, particularly irregular power supply, needs urgent attention and fixing to produce the required and relevant workforce for the emerging digital economy.

Author details

Akinniyi A. Adeleke[1*], Yemisi Ojokuku[2] and Joshua Onaade Ojo[3]

1 Tekena Tamuno Library, Redeemer's University, Ede, Nigeria

2 Department of Library & Information Science, Federal Polytechnic, Ede, Nigeria

3 University Library, University of Lagos, Lagos, Nigeria

*Address all correspondence to: adelekea@run.edu.ng

References

[1] Fosu A. Readiness of Universities for the 21st Century digital economies: A look at selected lecturers from Universities in Buffalo City Metropolitan in Eastern Cape Province South Africa. International Journal of Community Development & Management Studies, 2019;**3**:65-77. Retrieved from: http://ijcdms.org/Volume03/v3p065-077Fosu5523.pdf

[2] Adeleke AA. Resolving staff-patron conflicts with digitization: 'One' 'library's experience. New York: Library Hi Tech News. 2019;**36**(2):17-20. DOI: 10.1108/LHTN-09-2018-0060

[3] Kane G, Palmer D, Devine G. Achieving digital maturity. In: Research Report Summer 2017. New York. MIT Sloan Management Review & Deloitte University Press; 2017

[4] Chanias S, Hess T. How digital are we? "Maturity models for assessment of a company" 'company's status in digital transformation. In: LMU Munich Management Report 2/2016. Munich, Germany: Munich School of Management; 2016

[5] Westermann G, Bonnet D, McAfee A. Leading Digital: Turning Technology into Business Transformation. Boston, Massachusetts: Havard Business Review Press; 2014

[6] Rutkowski D. Digital Maturity: What it Is, How to Achieve it, and the Digital Maturity Model to Drive Business Transformation. 2022. Retrieved from Performance Improvement Partners: https://www.pipartners.com/digital-maturity/

[7] Anuradha P. Digital transformation of academic libraries: Opportunities and challenges. IP Indian Journal of Library Science and Information Technology. 2018;**3**(1):8-10

[8] NUC. "Nigerian Universities Approved by the NUC", National Universities Commission. Switzerland. 2012. Available at: www.nuc.edu.ng/pages/universities

[9] Baro EE, Oyeniran GK, Ateboh B. Digitization projects in university libraries in Nigeria: The journey so far. Library Hi Tech News. 2013;**30**(9):21-26. DOI: 10.1108/LHTN-09-2013-0049

[10] Proença DB. Information security management systems - a maturity model based on ISO/IEC 27001. In: Proença DB, Abramowicz W, Paschke A, editors. Business Information Systems. Switzerland: Springer; 2018. pp. 102-114

[11] Proença DV. A maturity model for information governance. In: Proença DV, Fuhr LKN, editors. Research and Advanced Technology for Digital Libraries. Vol. 9819. Cham, Switzerland: Springer; 2016. pp. 15-26

[12] Remane GH. Digital maturity in traditional industries: An exploratory analysis. In: 25th European Conference on Information Systems. Guimaraes, Portugal: ECIS; 2017

[13] Ifenthaler DE. Development and implementation of a maturity model of digital transformation. Tech Trends. 2020;**64**:302-309. DOI: 10.1007/s11528-019-00457-4

[14] Carvalho JV. A comparative study on maturity models for information systems in higher education institutions. In: Carvalho JV, Rocha TA, editors. Digital Science. DSIC18 2018. Advances in Intelligent Systems and Computing. Cham: Springer. 2019;**850**:150-158. pp. 150-158

[15] Rossmann A. Digital Maturity: Conceptualization and Measurement Model. 39th International Conference on Information Systems. San Fracisco: Association of Information Systems; 2018. pp. 1-9. Retrieved from https://aisel.aisnet.org/icis2018/governance/Presentations/8/

[16] Isaev EA, Korovkina NL, and Tabakova MS. "Evaluation of the readiness of a company's IT department for digital business transformation," Business Informatics (44:2), 2018. pp. 55-64. https://doi.org/10.17323/1998-0663.2018.2.55.64

[17] Poruban S. "Achieving digital maturity," Oil & Gas Journal (115:7), 2017. p. 14

[18] Durek V, Kadoic N, Redep BN. Assessing the digital maturity level of higher education institutions. In: 41st International Convention on ICT, Electronics and Microelectronics. Varazdin: Objavljena verzija rada; 2018. pp. 747-752. Retrieved from https://urn.nsk.hr/urn:nbn:hr:211:384585

[19] Begicevic Redjep NP, Balaban I & Zugec B. Assessing digital maturity of schools: Framework and instrument. Technology, Pedagogy and Education. 2021;**30**(5):1-17. DOI: 10.1080/1475939X.2021.1944291

[20] Love D, McKean G, Gathercoal P. Portfolios to webfolios and beyond: Levels of maturation. Educause Quarterly. 2004;**27**(2):24-37. Retrieved from https://er.educause.edu/-/media/files/articles/2004/4/eqm0423.pdf?la=en%26hash=4FB40C07FBFB46A3DC3AE34FD938937856288E07

[21] Begicevi Redjep N, Balaban I, Zugec B, Klacmer Calopa M, Divjak B. Framework for digitally mature schools. In: Proceedings of the European Distance and E-Learning Network 2017 Annual Conference. Jonkopng, Sweden: European Distance and E-Learning Network; 2017. pp. 360-371

[22] Makori EO and Mauti NO. Digital technology acceptance in transformation of university libraries and higher education institutions in Kenya. Library Philosophy and Practice, 1;2016

[23] Idhalama O, Ifidon EI. Information and communications technology (ICT) use in libraries: A plus or minus to academic libraries in Nigeria? Sumerianz Journal of Social Science. 2019;**2**(6):68-73. Retrieved from https://www.sumerianz.com/

[24] Chizenga I. Global information and libraries In sub-Sahara Africa. Library Management. 2000;**21**(4):174-187

[25] Oketunji I. Agenda for putting information technology to work In Nigerian libraries In the new millennium. In: Compendium of Papers Presented at Annual National Conference and AGM. Owerri: Nigerian Library Association; 2000. pp. 17-21

[26] Okiy RB. Towards improving the relevance of Nigerian academic libraries and librarians in the knowledge age. The Academic Forum. 2003;**4**(3):63-68

[27] Gbaje E. Provision of online information services In Nigerian academic libraries. Nigerian Libraries. 2007;**40**:1-4

[28] Akanni SB. Globalization: Challenges and opportunities for Nigerian libraries. In: Compendium of Papers Presented at the 46th Annual National Conference and AGM of the Nigerian Library Association. Kaduna: Nigerian Library Association; 2008. pp. 1-12

[29] Okiy RB. Globalization and ICT in academic libraries in Nigeria:

The way forward. Library Philosophy and Practice (e-journal). 2010;**501**: 1-11 (online). Retrieved from https://digitalcommons.unl.edu/libphilprac?utm_source=digitalcommons.unl.edu%2Flibphilprac%2F501&utm_medium=PDF&utm_campaign=PDFCoverPages

[30] Iroeze P, Umunnakwe GC, Eze JU. Library Services for the Physically Challenged in south-East Nigeria: Origin and challenges. International Journal for Advanced Library and Information Science. 2017;**5**(1):393-405 Retrieved from https://bit.ly/34hRMhw

[31] Lawal-Solarin EO. A survey of library and information services to physically-challenged students in academic libraries in Ogun state, Nigeria. Library Philosophy and Practice (e-Journal). 2012. Retrieved from https://bit.ly/3r8TcUp

[32] Martinez RM & Vemuru V. World Bank Blogs. 2020. Retrieved from World Bank.Org: https://blogs.worldbank.org/nasikiliza/social-inclusion-persons-disabilities-nigeria-challenges-and-opportunities

[33] European Union. Recommendation of the European Parliament and of the Council of 18 December 2006 on Key Competencesfor Lifelong Learning 2006/962/EC. Brussels: European Union: Official Journal of the European Union; 2006

[34] Dzingirai M. Demystifying corporate restructuring strategy through digital transformation: Lessons learned from the banking sector of Zimbabwe. Sandhu K. In: Emerging Challenges, Solutions, and Best Practices for Digital Enterprise Transformation Hershey, Pennsylvania: IGI Global. 2021. pp.164-181. doi:10.4018/978-1-7998-8587-0.ch009

[35] World Economic Forum. Digital Culture: The Driving Force of Digital Transformation. 2021. Retrieved from Digital Culture Guidebook: https://www.weforum.org/docs/WEF_Digital_Culture_Guidebook_2021.pdf

[36] Akintunde SA. State of ICTs in tertiary institutions in Nigeria: Window on the universities. In: Compendium of Papers Presented at the 44th Annual National Conference and AGM of Nigerian Library Association. Abuja: Nigerian Library Association; 2006. pp. 123-137

[37] Okorie AM, Ekere JN. Information professional and knowledge Management in Global Library and Information Service. In: Compendium of Papers Presented at the 46th Annual National Conference and AGM of the Nigerian Library Association. Kaduna: Nigerian Library Association; 2008. pp. 53-62

[38] Ibanga I. Promoting Universities and Tech Industry Collaboration. Lagos, Nigeria: Premium Times; 2021. Retrieved from https://bit.ly/3AQJ8TA

Chapter

Modelling Digital Economy Implications on Long-Run Economic Development

Elsadig Musa Ahmed

Abstract

This chapter develops frameworks and models to examine digital transformation into digital economies via digital technologies' applications at both the macro and micro levels via both positive and negative externalities generated by digital technologies and pollutant emissions. A productivity mixed method approach has been developed based on the chapter modified frameworks and models to be employed at both the macro and micro levels to utilise the digital technology applications that will help in transforming digital economies to sustain their economic development. The study provided digital economy frameworks and policies to help in implementing digital transformation and to develop and use the new technologies needed for sustainable economic growth through technological progress, human capital skills development and environmental protection via green productivity technological progress. The study contributes to the knowledge body via proposed productivity mixed method frameworks and models that examine digitisation processes. The aggregate economies, industries, companies and other businesses will be provided with frameworks and guidelines to implement digital technologies' applications that will help them to be transformed into digital sustainable economies. The most significant contribution of this study is treating digital technology cybersecurity negative externalities spill over effects similar to their negative externalities of pollutants' emissions counterparts, besides developing capital productivity framework and model that were ignored in most of the studies.

Keywords: digital economies, externalities, digital transformation, cybersecurity, green productivity, COVID-19 implications

1. Introduction

Economics like other social sciences has no one standard definition of the digital economy due to the subjective nature of the social sciences as has been mentioned by [1]. Conversely, a satisfactory definition must place importance on the generation and exploitation of digital knowledge over digital technology applications to create new value in the economy. Undeniably, knowledge is information that is put to productive work through digital technology applications. Knowledge includes information in any form, know-how and know-why among others. The digital economy is not confined to information and communication technology (ICT) digital applications. Before the evolution of the digital technologies, it was the knowledge that remained embodied in human beings' 'human capital' and technology that was embodied in the capital investment undertaken by the Asian economies that brought about the so-called Asian miracle [2].

In this respect, cybersecurity economics is the economics that discourses the concerns of protection of digital technology applications that premeditated to enable the economic activities that are ordinariness face cybercrimes that cost the individuals, companies and the countries enormous amount of money and interrupt the economic and financial activities around the world as it has been indicated in ICT-based sustainable development as reported in [ICT & Sustainable Development Goals (SDGs) report, 2015]. ICT-based sustainable development reports the ICT role in attaining SDGs that is presented by the United Nations (UN) for its members to achieve SDGs that are planned to be implemented comprehensively within 2030. Besides, the report points apprehension of the potential shortcomings of ICT-based sustainable development, these trace on at least six broad areas such as the online world will literally reshape brain development, possibly leading to a loss of human skills. Moreover, the virtual or online communities will somehow crow out, meaning that real human communities heading to a decline in human interactions, trust and sociality; this is will lead to what so-called 'bowling alone' phenomenon as assumed by sociologist Robert Putnam. Further, the robots are estimated to relocate human work to the point of initiating bulk unemployment and economic pessimism. This point faced the argument that there might be the sheen of truth in such arguments, but the central circumstance is that with suitable public policies, technological advances develop well-being as this is measured to be the positive externalities of digital technology that formed the digital economy around the world. Nevertheless, the negative externalities allied through the advance of this technology are the cybersecurity negative externalities and the disparity of the human skills to optimise the digital dividends created in terms of a long-run sustainable economic growth involvement via the digital technology contributions to produce economic well-being [2].

Meanwhile, the fourth concern, the digital economy is subject to network failures than a production-based economy that is overtaken by a knowledge-based economy due to ICT revaluation and currently by a digital economy via the emergent digital technologies such as giant performance catastrophes due to the Internet or power network could bring the economy to irresistible incursion. Additionally, the next concern is that the interruption of the networked economy will become deliberate turns of cyber-warfare or what so-called cybercrimes [1]. The last concern is of excessive nervousness as that the digital-technology-based economy is a surveillance economy, with worldwide snooping and detriment of privacy. The infiltration might be by government giant digital technologies organisations or a smart partnership of the two or a grouping both everywhere [2]. These depictions of cybersecurity externalities' uncertainties were offered disgraceful validation by Edward Snowden, as not of the least of which was the ambiguous and trickeries of endorsed institutions concerning their surveillance policies [2].

The abovementioned fears will be used in this study to corroborate the cybersecurity negative externalities' concerns associated with digital-technologies-based economic activities corresponding with their environmental externalities' complements that both created as unwanted output alongside the chief product that negatively impacted the economies worldwide and made vast economic mortalities and even formed uncertainty on the democracy and election results as the alleged Russian interruption in US Presidential election and the Chinese Giant mobile company products of Huawei that is prohibited from using the Google system for its 5G products concerning spying activities among others. The innovation made by the digital revolution led by digital-technologies-based accompanying by obstacles deliberated above that should be overwhelmed particularly the cybersecurity negative externalities correlated to security concerns that cost the economies and endangered them to innovate. Contradictory, the humankind's know-how with technology dating back to the commencement of the industrial revolution that disregards the unintended shortcomings of technology to unlimited peril, the digital revolution should offer responsible resolutions to overcome the cybersecurity negative externalities of these obstacles to progress in accomplishing the SDGs as planned to be flourished by 2030 [2].

Regarding the negative externalities associated with environmental damages, Ahmed [3] presents that the concept of Green Productivity (GP) is drawn from the incorporation of two central progressive strategies, namely productivity enhancement and environmental safeguard. Productivity offers the framework for boundless progress, whereas environmental precaution delivers the underpinning for long-run economic growth and sustainable development [3].

Consequently, GP is an approach for enhancing productivity and environmental performance for inclusive socio-economic development. GP is an influential strategy that can complement economic growth and environmental protection for long-run economic growth and sustainable development. It presents small and medium businesses with a methodology to attain a competitive advantage by existence of improved business models. It is consequently an accurate approach to upsurge productivity and safeguard the environment simultaneously [3].

Furthermore, the United Nations (UN) Sustainable Development Summit held in New York in September 2015 approved the goal of the sustainable development agenda by 2030 [4]. The UN summit proposed a new indicator framework, accompanying with global and collective indicators, for international partnership and cooperation to accomplish sustainable development for the period of 2015 and 2030, including 17 new Sustainable Development Goals (SDGs). In fact, every country should arrange these 17 SDGs based on its country need and development stages not only as arranged by UN. For example, some countries need to implement goal 16 (peace, justice and strong insinuations), other goals took place as the institutional failure, bad leadership and governance among others.

It should be recalled that before implementing the 17 SDGs, this study proposes that these 17 SDGs should be revised as some of them outdated due to the digital economy issues brought by industrial revaluation 4.0 digital technologies and new businesses models associated with COIVD-19 implications.

Meanwhile, changes in productivity considered are key concerns in any economy due to the connection between productivity and living standards [2–6]. The definitive aims of productivity improvement are countless competitiveness, greater profitability, upper living standards and well economic and social fortune. In this regard, Total Factor Productivity (TFP), labelled as the combined contribution of the factors of production qualities, is an indicator of the technological progress that displays the spillover effects that must transfer the technology to the hosting economy and upgrade the skills of its human capital, which is what is named productivity-driven. TFP can explain the growth in a digital economy since it captures endogenous technical change and other features of the digital economy, including diffusion of digital knowledge, organisation, restructuring, networking and new business models that would contribute to market efficiency and productivity [2, 3, 5].

According to [7], digital technology in the form of the Internet, mobile phones and all the other digital tools used to collect, store, analyse and share information digitally consumes and has grown swiftly everywhere in the world. It has been projected that 70% of the households have mobile phones than have access to electricity and clean water in developing countries. Moreover, Internet users' number has more than tripled in a decade appraised to be in the range of 1 billion in 2005, 3.2 billons by the end of 2015. This means businesses, people and governments are more connected than before the digital revolution. The digital divide displays the gap in access to ICT applications within nation or between nations. In this respect, digital dividends (the income generated via using digital technology applications) are the broader development that benefits from using digital technologies. In several occurrences, digital technologies enhanced growth, expanded opportunities and better-quality service delivery. The digital dividends aggregate effect has dropped little and is unequally disseminated. For the digital technologies to benefit everybody everywhere in the world, it would be needed to close the residual digital divide, particularly in Internet access as it has been shown during COVID-19, many countries and business are not able to run online during movement control orders. Though, countless digital adoption will not be enough if it has not created value-added digital dividends from the economic activities.

2. Digital economy flagships and pillars

Digital economy flagships and pillars should be established as the groundwork for the digital economy institutions and facilities needed for its activities. With respect to digital economy flagships and pillars, certain countries are in an advanced stage in establishing digital economy flagships and pillars, some are in the starting stage and some have not thought about it. For instance, Malaysia developed their knowledge economy master plan in 1996 and embedded the digital economy flagships in stages that should be completed in 2020. Some other countries are ongoing in developing the digital economy foundation, and some are in the initial stages of digital economy flagships and pillars progress. Reviewing the countries' experiences that scheduled and established their economies into digital economies, such as countries in America, Europe and Southeast Asia, this study found that Malaysia's experience is a upright sample to monitor as the country prearranged comprehensively for the digital economy foundations. Multimedia Super Corridor (MSC) was developed for knowledge economy flagships and pillars, among economic corridors in several Malaysian states that are upgraded to digital economy flagships and pillars with a revised digital economy master plan [6].

To acquire significant advantage from the digital technologies, countries also need to work on the analog matches; such as strengthening regulations that guarantee competition between businesses, by adapting workers' digital skills to the demands of the digital economy and by guaranteeing that institutions are accountable. It should be noted that increasing human capital (skilled workers) particularly digital skills is a perquisite of progressing and realising digital technologies' applications in economic sectors and companies. With the accurate digital human skills, digital technologies will enable economic activities, due to the fact that technology in general and digital technologies' applications in particular are architects that need the right human skills to function [6].

To develop a competitive edge in a digital economy would need a highly skilled digital human capital besides other skilled workers. Highly skilled and talented human capital is likewise energy to grow the digital economy. The ‘know-how’ that goes into the production of innovative products to enable companies, businesses, organisations and countries to be competitive in the global market habitation will be provided by their exceptional skills. Besides, out-migration drains the limited talent pool: several professionals and technical personnel and students overseas have migrated to the countries that provided chances to progress; achieve their mental satisfaction to contribute and to enjoy their achievements senses among other benefits missed in their home countries. Another chance is to bring in the indispensable skilled human from overseas to the home countries which is liberalising recruitment with chances and benefits equal to what have enjoyed overseas to progress in their home countries. The education institutions should play a significant role as the foundation of the human capital development that is considered to be one of the important pillars to develop a digital economy [8].

Additional significant challenge that will be faced in the determination to transfer to a digital economy would be the capability to construct an innovative capacity in the country; hence, innovative goods and services could be developed for the digital economy [8]. With amplified liberalisation of economies and the elimination of tariff barriers via trade agreements and economic unions, goods and services produced by companies and countries will have to compete with corporations and national companies in general and specifically Small and Medium Enterprises (SMEs).

Research and Development (R&D) present amount of financial and other resources allocated in most of the countries as a percentage of GDP is minor compared with other countries that developed their economies into digital economies. The governments must foster an environment where creative and innovative thinking are fulfilled. Encouragements should be prearranged to persons and companies who originated cutting-edge concepts, innovative technologies and products in recognition to such inventions, innovations and outstanding discoveries. These prizes and credit should be firmly for the contribution of an innovative products and processes that would enrich innovative capacity and competitive standing in the universal marketplace [7].

Particular countries are highly qualified to be education centres that attract students around the globe, with the existing condition, higher institutions graduates and technicians are the most important sources of Gulf countries’ human capital. If the education institutions established well, graduates could compete around the globe through developing economies into digital economies with the right foundations to facilitate the economic activities and businesses. The current business model practiced should be refined to encounter digital economy foundations’ requirements. The current business model’s improvement to meet the COVID-19 implications most likely will contribute and complement economic value added to the economic progress and accomplish the anticipated digital economy if deliberate it well in a short period of time as the latter countries will catch up very fast to achieve their economic growth. SMEs are the backbone of the economies everywhere in the world; 90–99% of the companies in in most of the countries are SMEs that were not well classified define and are not existed in some countries. Further, SMEs are considered as the digital economy corner stone in transferring the technology and upgrading the local human capital skills through Foreign Direct Investment (FDI) spill over effects brought by the multinational companies to the host countries [1].

Furthermore, cyber laws should be familiarised to overwhelm the cyber complications allied with digital economy activities. Cyber-crimes may take place overseas, and in this respect, there is an urgent need for collaboration around the world to overcome cyber-crimes through smart partnerships. It should note that the conclusive currency of a digital economy is intellectual property rights (IPRs) implementation via the rule of law based on the World Trade Origination (WTO) agreements. IPRs includes copyrights, patents, trademarks, service marks and goods of geographical indication. It should be noted that IPRs are legal monopolies awarded to original owners of copyrights and patents to enable them to benefit from their discoveries and ensure the sustainable inventions and innovations [2].

Emergent digital economy master plan to address the policies and developing digital economy institutions to move to a digital economy is considered to be the first step. This study will be useful for digital technologies policy formulation as an underpinning of the digital economy development. In this background, an appraisal of the digital technologies and productivity growth contributions in each of advanced countries in general and in the East Asian countries specifically will afford guidelines for the policy-makers to articulate applicable national and international digital technologies policies. This study findings based on the study frameworks and models developed are expected to help formulating policies to stimulate digital technologies investment to clue in enlightening human capital and infrastructure needed to support active digital technologies usage. It is likely that it can capitalise the interaction within the countries and between other countries and make full use of the competitive advantages in of all countries to impressed its deficiencies. The countries will be capable of fast-tracking the association towards technology-savvy nations that has been attained by Japan, South Korea and China, among others [6].

According to United Nations (UN) [4], there is a need to discourse security concerns connected with digital technology applications, hence to warrant the accomplishment of the implementation of the digital technology applications. More precisely, the concerns that should to be addressed are to guarantee security and privacy of existing e-channels, such as automated teller machine (ATM) and electronic point of sale (EPOS) among others, and to resolve all network problems. Building individuals' and societies' consciousness and counselling the communities about the reimbursements and use of new digital technologies and digital services are required. Here should be rigorous promotions to teach the public, particularly directing the urban and rural populations; consequently, they are conscious of the digital economy concepts and scopes to build the knowledge of digital socialites that is vital on which a digital economy would be based. Moreover, Ahmed [2] presents an appropriate regulatory setting, concerning user guidelines, trusts, rights and protections, right integration and a smart partnership between telecommunications network operators and the economy sectors, suitable staff training and presenting client literateness for appropriate use, evolving reliable and drivable digital technology's structure and rigorous digital products and service design are crucial to implement digital economy applications. Besides, collaborations, cooperation and smart partnerships between private and public sectors within countries and between countries to construct digital economies are instantly required particularly the smart partnership within a country and between the countries as the digital economy is a universal phenomenon that connected the world economy.

Lastly, as [2, 3] show, the sustainability of higher economic growth will remain to be productivity-driven not input-driven as experienced by most of the countries. The input-driven caused the collapse of the Soviet Union in 1990s as a result of combining many countries and used their resources without technological progress to sustain the economic development and long-run economic growth. The productivity-driven that should sustain higher and long-run economic growth will be achieved through the enhancement of TFP as a technological progress that combined the three dimensions of sustainable development (economic development, environmental protection and social sustainable development via human capital development and digital technologies). Such amplification needs to strain the human capital quality, demand intensity, economic restructuring, capital structure, technical progress and environmental standards. In this respect, the green productivity through green TFP creates the sustainable development concept of progressing technologically, socially and environmentally that will relieve to realise the sustainable development dimensions required for long-run economic growth and to guarantee its sustainability. That is, it will maintain the privileges of the upcoming, as well as existing, generations for them to gain a better life span.

3. Literature review

Feyen et al. [9] address the important cybercrimes prevention via data protection and interoperability as addressed by [10]. The study suggested that cybercrimes become more important via cross-border spill overs of antitrust and data-governing ace decisions, as well as the potential to improve fintech, and the digital transformation of financial service will be through harmonisation of standards in areas of cybercrimes prevention, data protection and interoperability, among others. In this respect, collaboration and smart partnerships can help via regulatory consistency and peer learning within the countries and between the countries that will achieve the higher well-being of the entire population and around the globe.

Furthermore, [11] mentioned that the financial ecosystem digitisation will be centre to economic growth in overall and an enhancement in several economic activities with a certain effect on customer experiences. The study addresses the need of cybersecurity and cyber management resolutions accomplished of rapidly recognising threat circumstances, counting cyber-attacks on digitised services and products and counsel the users on the possible forthcoming threat.

Meanwhile, Sabău et al. [12] identifies the importance of corporate governance to increase the digitalisation process among companies. In this respect, corporate governance and social responsibility are required elements to develop digital economy and to achieve digital inclusion. The study findings can be used to improve the public governance, investors, companies, governments to highpoint good corporate governance role for increasing the overall well-being of the society within the digital economy. As well as to preserve transparency enlarged, in a digital ecosphere appears comparable an easy thing to do.

Smart partnerships are very important within and between the nations in this regard [13] appraise the convergence across the European Union (EU) 28 members in the digital economy arena grounded on the Digital Economy and Society Index (DESI) and its dimensions via the log t club convergence method. The study empirical finding found that during the study period (2015–2020), there was no inclusive convergence across EU 28 members in the digitalisation context.

Accordingly, [3, 14] explain that the methods used to measure productivity growth mostly ignore the pollutants that are produced by the production process as undesirable products and unpriced output. For instance, pollutant emissions produced as undesirable output in addition to the main output of production are omitted from the productivity accounting framework and other approach that estimated productivity growth. This chapter tries to incorporate green productivity methods by taking into account pollutant emissions into production functions as un-priced inputs. The pollutant emissions under consideration include carbon dioxide (CO_2) emissions (that measures air pollution), Biochemical Oxygen Demand (BOD) emissions (that measures organic water pollution) and their mixture in the formula of total pollutant emissions, that is, combined air and water pollutions' emissions. Though, other pollutants' emissions should be measured, such as noise pollution and all other types of pollutants' emissions. It should be mentioned that, in 2018, the Nobel Prize for Economic Sciences was awarded to William D. Nordhaus and Paul M. Romer for research undertaken in the 1970s. William D. Nordhaus was awarded the prize for his research that addressed negative externalities, such as pollutant emissions, whereas Paul M. Romer was awarded the prize for his research concerning the new factors of production inclusion in the production function such as digital technology in the form of ICT and human capital to achieving long-term economic growth through technical progress and green development that sustain long-run economic growth via what recently called digital economy. Moreover, Romer [15–19] emphasised how the economy can expand the boundaries, and thus the possibilities, of its future activities. In his focus on the fundamental challenges of climate change, Nordhaus [20–29] stressed the importance of the negative side, and thus the restrictions, of the endeavours in bringing about future prosperity.

Moreover, Ahmed's [14, 30, 31] studies indicated that the greatest apparent absence in the growth accounting models undertaken by preceding studies was found to be the exclusion of externalities, such as the pollutant emissions, which were generated by the manufacturing and other economic sectors. The mentioned studies intended to add to the accessible literature on the growth accounting and econometric approaches, in that these studies combined together both methods to calculate the total factor productivity (TFP) and TFP per unit of labour growth as residuals. This residual identified by Solow [32, 33] via internalising the pollutant emissions with the traditional factors of productions employed in conventional production functions. Accordingly, green TFP and green TFP per unit of labour growth became indicators of green productivity. That is taking into account economic development and environmental protection benefiting from the studies undertaking by [34–40]. Finally, [6] recalled that: 'It has been documented in the Solow [32, 33] empirical work on economic growth that after accounting for physical and human capital accumulation, something else accounts for the bulk of output growth in most countries. Together, physical and human capital accumulations are definitely critical for economic growth. The development becomes more complex with the role of knowledge in the economic growth procedure'.

As has been mentioned earlier, in many instances, digital technologies boosted growth, expanded opportunities and improved service delivery. Their aggregate impact has fallen short and is unevenly distributed. For digital technologies to benefit everyone everywhere requires closing the remaining digital divide, especially in Internet access. To develop a competitive edge in a digital economy would need a highly skilled labour force. Greatly skilled human capitals are the fuel to the digital economy engine of growth. Highly skilled workforces will offer the 'know-how' gained via learning by doing those energies into the production of innovative products that empower companies, businesses and countries to be competitive worldwide.

Thanks to COVID-19-positive economic impact that forced people to work from home to sustain economic activities that was not acceptable around the globe due to technophobia in the heart and minds of the decisions makers and governments' officials to accept online comprehensive activates. High involvement on online activities is allowed via the digital technologies' applications to run daily activities via digital governance. This study developed frameworks and models to be employed and empirically examined the impact of COVID-19 and the digital technology's role in sustaining the economic growth. Besides, the study offers recommendations and policy implications to transfer the economies into digital economies that would sustain economic development under any undesirable conditions, such as COVID-19 that triggered massive economic losses. In this respect, digital economic development is expected to diminish the economic fatalities related with forthcoming global pandemics.

The main objective of this research is to model and examine the digital economy's positive and negative externalities spill over effects on the sustainable economic growth through employing a mixed method approach, consisting of quantitative and qualitative analysis at macro and micro levels.

The study recommended foundations to transform public and private sectors into a digital economy to achieve the Sustainable Development Goals (SDGs) agenda and to overwhelm the COVID-19 and upcoming pandemics' negative externalities. It will likewise be used to moderate the COVID-19 and forthcoming pandemics' negative impact through enabling economic activities under disinclinations via using the proposed frameworks and models that modified productivity approaches to accommodate digital technologies' applications.

The study fills the gaps in growth theories through developing three different frameworks and econometric models, and internalising pollutants' emissions as private and unpriced inputs in the three models. Further, the green capital productivity model is the exclusive contributing model developed in this research; it has not been assumed and empirically examined in previous studies, with the exception of the studies undertaken by [2, 3, 5, 41].

The significant contribution of this study has modified the fundamental findings of Nobel Prize Laureates' research findings [29] to integrate innovation and climate change in the form of green productivity as well as existing studies in developing frameworks and models to measure digital economy indicators such as digital technology positive externalities and negative externalities such as cybersecurity shortcomings and negative externalities generated by pollutants' emissions. The role of these externalities on long-term sustainable economic growth has been ignored by several past studies undertaken in these areas. These three modified frameworks and models in a significant method articulate the technological progress issues and sustainable economic growth as one of the most important sustainable developments and long-run economic growth dimensions.

4. Methodology development process

This study employed digital economy's positive and negative externalities in unindustrialised study frameworks and models in this chapter. At both the macro and micro economic levels, this chapter anticipates to use a mixed approach of quantitative and qualitative analysis. In this subdivision, a parametric analysis based on a combined method of parametric analysis is developed. The method combines both growth accounting that is non-parametric approach and econometric that is parametric approach. This method was developed to be applied in two steps: the first step is an econometric approach to estimate the study parameters (explanatory variables coefficients), whereas the second step plugs these parameters into the models to calculate the productivity indicators. Three frameworks and models have been developed based on [1–4, 6, 30, 31, 42] modified extensive growth theory and intensive growth theory (labour productivity and capital productivity). The aforementioned mentioned studies modified and combined the production function and Solow's residual [32, 33] and refined by [43] to fill the gaps in both approaches that cast doubts on the results generated by both. The framework (**Figure 1**) is an extensive growth theory presentation of Model 1 that consists of the output (Gross Domestic Product [GDP]) as a function of capital, labour, digital technology and pollutant emissions for pollution are the explanatory variables based on their quantity. In addition, the framework presents TFP that combined the inputs quality contribution (explanatory variables) that indicated that technological progress to be transformed into sustainable digital economies.

This chapter suggests a digital productivity framework, a digital labour productivity framework and digital capital productivity framework (**Figures 1–3**) to be used at the country level. The frameworks will measure the' digital economy productivity implications via the collection of a primary data survey and the analysis of qualitative focus groups interviews with concerned experts. The qualitative approach will capture

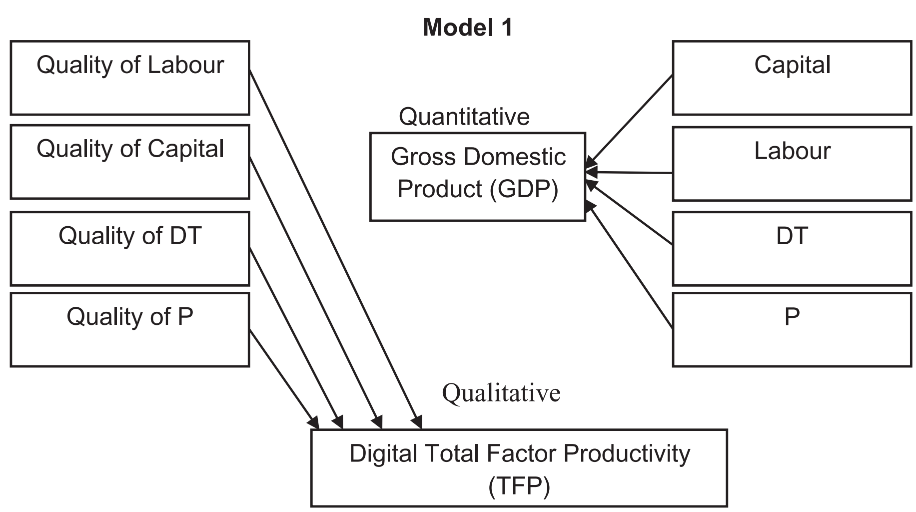

Figure 1.
Productivity framework, extensive growth theory. Source: Modified from [2].

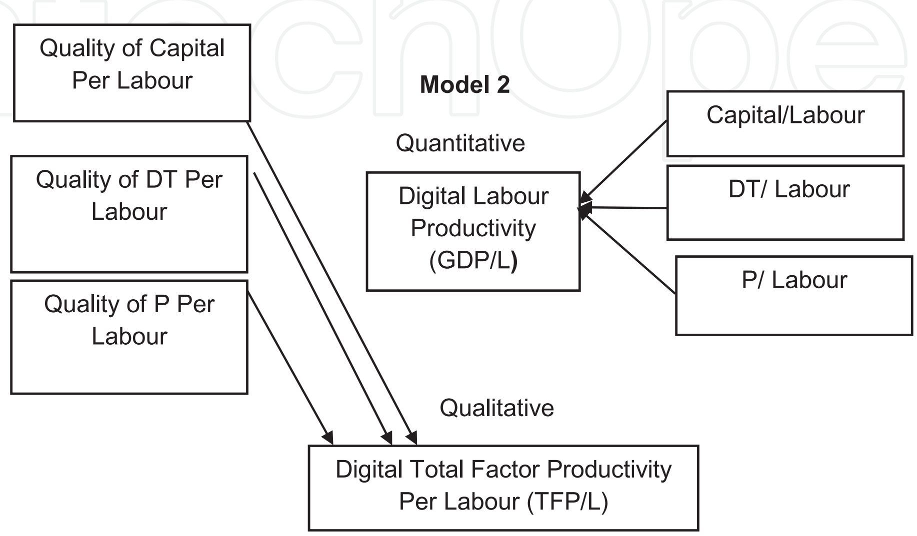

Figure 2.
Total factor productivity per worker framework, intensive growth theory. Source: Modified based on [2].

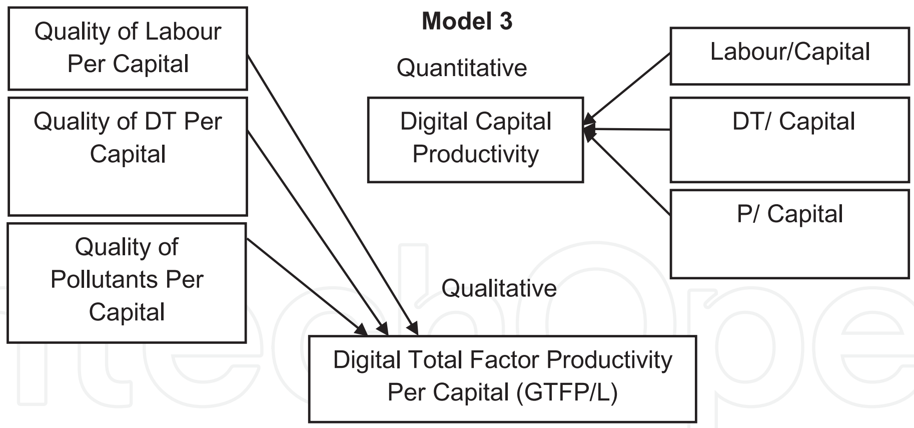

Figure 3.
Digital capital productivity framework, intensive growth theory. Source: Modified based on [2].

information and data that have not been published in the form of secondary data and information.

The production function for an economy can be categorised as follows:

$$\text{GDPt, i} = \text{F (Kt, i, Lt, i, DTt, i, Pt, i, Tt, i)} \tag{1}$$

where country i = 1, 2, … in Years t, output real GDP is a function of real fixed physical capital input K, labour input L, DT for digital technology that includes digital technologies' variables including cybersecurity variables, while P represents the pollutant emissions, and time T proxies for TFP as a technological progress of the digital economies and sustainable development indicator.

4.1 Extensive growth theory

This subsection offers the extensive growth theory based on GDP that is decomposed into physical capital, employment, digital technology (DT) and pollutants' emissions (P). The chapter tries to fill the gap found in [30] research via modifying this model into a parametric model and providing statistical analysis for it in the first step, as follows:

$$\Delta\text{lnGDPt, i} = a + \alpha.\Delta\text{lnKt, i} + \beta.\Delta\text{lnLt, i} + \lambda.\Delta\text{lnDTt, i} + \theta.\Delta\text{lnPt, i} + \varepsilon t, i \tag{2}$$

t = Number of years and i is number of countries.
where.
α is the output elasticity with respect to capital
β is the output elasticity with respect to labour
λ **is** the output elasticity with respect to digital technology
θ is the output elasticity with respect to pollutants' emissions
a is the intercept or constant of the model[1]
ε is the residual term[2]
ln is the logarithm to transform the variables

[1] The intercept term, as usual, gives the mean or average effect on dependent variables of all the variables excluded from the model.

[2] The residual term proxies for the total factor productivity growth that accounts for the technological progress of the economy through the quality of input terms.

Δ is the difference operator denoting proportionate change rate.

The intercept (a) in Eq. (2) has no place in the calculation of the productivity growth indicators based on the estimated results of Eq. (2) by succeeding a second step. The second step computes the progression rates of productivity indicators, transforming Eq. (2) as an extension of the basic growth accounting framework. The production function is indicated in the parametric form of the above equation as follows:

$$\Delta \text{lnTFPit} = \Delta \text{lnGDPit} \; \text{-}[\, \alpha.\Delta \text{lnKit} + \beta.\Delta \text{lnLit} + \lambda.\Delta \text{lnDTit} + \theta.\Delta \text{lnPt, i}] \tag{3}$$

Where the masses are assumed by the average value shares as follows:

$\Delta \text{lnGDPit}$ is the growth rate of output

$\alpha.\Delta \text{lnKit}$ is the contribution of the aggregate physicall capital

$\beta.\Delta \text{lnLit}$ is the contribution of the aggregate labour

$\lambda.\Delta \text{lnDTit}$ is the contribution of the digital technology

$\theta.\Delta \text{lnPit, i}$ is the contribution of the pollutants$'$emissions

$\Delta \text{lnTFPit}$ is the total factor productivity growth

The model decomposes the growth rate of GDP into the contributions of the rates of growth of the aggregate physical capital, labour, digital technology and pollutants' emissions, plus a residual term, typically referred to as the growth rate of TFP.

4.2 Intensive growth theory (labour productivity)

This subsection establishes an intensive growth theory framework (**Figure 2**) for Model 2, the labour productivity or output per labour (GDP)/labour as a function of capital per labour, digital technology per labour and pollutants' emissions per labour are the explanatory variables based on their quantity. Furthermore, the framework offers the total TFP per labour (TFP/L) that is expressed as the combined contribution of the quality of the explanatory variables.

This subsection demonstrates the decomposition of labour productivity into capital deepening, increased usage of digital technology per unit of labour and pollutants' emissions per unit of labour. Likewise, following [30, 31, 44–46], when constant returns $\beta = (1\text{-}\alpha\text{-}\ \lambda\,)$to scale is imposed, Eq. (2) becomes:

$$\begin{gathered} \ln GDPt, i = \text{a} + \alpha. \ln \text{Kt, i} + \lambda. \ln DTt, i + \theta. \ln Pt, i + (1 - \alpha - \lambda - \theta). \ln \text{Lt, i} + \varepsilon\text{t}, i \\ \text{t} = \text{Number of years} \end{gathered} \tag{4}$$

However, there are two options for dividing the variables by L:

1. Dividing the variables (data) by L before the analysis, in which the equation is given as: $\ln(\text{GDP/L})_\text{T} = \text{a} + \alpha \ln(\text{K/L})_\text{T} + \lambda \ln(\text{DT/L})_\text{T} + \theta. \ln(\text{P/L})_\text{T}$

   This will not be used in this study.

2. Dividing the variables by L during the analysis through programming the variables that will be used in this study, as follows

$$\begin{aligned} \ln(\text{GDP/L})_\text{T} = \text{a} &+ \alpha 1 \ln(\text{K/L})_\text{T} + \alpha 2 \left[\ln\ (\text{K/L})_\text{T}\right]^2 + \lambda 1 \ln(\text{DT/L})_\text{T} \\ &+ \lambda 2 \left[\ln\ (\text{DT/L})_\text{T}\right]^2 + \theta 1 \ln(\text{P/L})_\text{T} + \theta 2 \left[\ln\ (\text{P/L})_\text{T}\right]^2 \end{aligned}$$

The output elasticity is calculated with respect to capital per labour, digital technology per labour and pollutants' emissions per labour, i.e.$\alpha = \alpha 1 + \alpha 2$, $\lambda = \lambda 1 + \lambda 2$ and $\theta = \theta 1 + \theta 2$, respectively. Following [44, 30], the production function can be in the form:

$$\begin{aligned} &\Delta \ln (\mathrm{GDP/L})\mathrm{t,i} = \mathrm{a} + \alpha 1.\Delta \ln\ (\mathrm{K/L})\mathrm{t,i} + \alpha 2[\Delta \ln\ (\mathrm{K/L})\mathrm{t,i}]^2 + \lambda 1.\Delta \ln\ (\mathrm{DT/L})\mathrm{t,i} \\ &+\lambda 2[\Delta \ln\ (\mathrm{DT/L})\mathrm{t,i}]^2 + \theta 1.\Delta \ln\ (\mathrm{P/L})\mathrm{t,i} + \theta 2[\Delta \ln\ (\mathrm{P/L})\mathrm{t,i}]^2 + \varepsilon \mathrm{t}, i \\ &\mathrm{t} = Number\ of\ years \end{aligned} \tag{5}$$

It then, follows that:

$$\begin{aligned} &\Delta \ln (\mathrm{GDP/L})\mathrm{t,i}\ \text{is the digital labour productivity contribution} \\ &\overline{\alpha}.\Delta \ln \overline{(\mathrm{K/L})} = \alpha 1.\Delta \ln (\mathrm{K/L})\mathrm{t,i} + \alpha 2[\Delta \ln\ (\mathrm{K/L})\mathrm{t,i}]^2 \\ &\text{is the contribution of the capital deepening} \\ &\overline{\lambda}..\Delta \ln \overline{(\mathrm{DT/L})} = \lambda 1.\Delta \ln (\mathrm{DT/L})\mathrm{t,i} + \lambda 2[\Delta \ln\ (\mathrm{DT/L})\mathrm{t,i}]^2 \\ &\text{is the contribution of the digital technology per labour} \\ &\overline{\theta}..\Delta \ln \overline{(\mathrm{P/L})} = \theta 1.\Delta \ln (\mathrm{P/L})\mathrm{t,i} + \theta 2[\Delta \ln\ (\mathrm{P/L})\mathrm{t,i}]^2 \\ &\text{is the contribution of the pollutants}'\ \text{emissions per labour} \\ &\varepsilon \mathrm{t,i}\ \text{is the residual term that proxies for TFP per labour growth}\ (\Delta \ln (\mathrm{TFP/L})\mathrm{t,i}) \\ &\Delta\ \text{is the difference operator denoting proportionate change rate} \end{aligned}$$

As mentioned in extensive growth theory, the intercept (a) has no position in the calculation of the productivity growth rate indicators. Consequently, it develops:

$$\begin{aligned} &\Delta \ln (\mathrm{GDP/L})\mathrm{t,i} = \overline{\alpha}.\Delta \ln\ \overline{(\mathrm{K/L})}\mathrm{t,i} + \overline{\lambda}.\Delta \ln\ \overline{(\mathrm{DT/L})}\mathrm{t,i} + \overline{\theta}.\Delta \ln\ \overline{(\mathrm{P/L})}\mathrm{t}, \\ &\mathrm{i} + \Delta \ln (\mathrm{TFP/L})\mathrm{t,i} \end{aligned} \tag{6}$$

Where $\overline{\alpha}$, $\overline{\lambda}$ and $\overline{\theta}$ indicate the dividends of capital per labour, digital technology per labour, the pollutants' emissions per labour. Total factor productivity per labour [(TFP/L) is the TFP per labour] contribution as an indicator of digital productivity and sustainable long-run economic growth spill over effect.

Besides, to calculate the TFP per worker, and other productivity indicators contributions, Eq. (6) transforms:

$$\begin{aligned} &\Delta \ln (\mathrm{TFP/L})\mathrm{t,i} = \Delta \ln (\mathrm{GDP/L})\mathrm{t}, \\ &\mathrm{i} - \left[\overline{\alpha}.\Delta \ln\ \overline{(\mathrm{K/L})}\ \mathrm{t,i} + \overline{\lambda}.\Delta \ln\ \overline{(\mathrm{DT/L})}\ \mathrm{t,i} + \overline{\theta}.\Delta \ln\ \overline{(\mathrm{P/L})}\ \mathrm{ti}\right] \end{aligned} \tag{7}$$

Subsequently, Eq. (7) guides the decomposition of digital labour productivity growth into the contributions of capital per labour, increasing the production rate of digital technology per labour and the pollutants' emissions per worker production as a by-product or unpriced products besides the main products, alongside the combined contribution of the stated inputs qualities. This is articulated as digital TFP per labour contribution that is indicated as the digital technology spill over effect.

4.3 Intensive growth theory (capital productivity)

The digital capital productivity framework for Model 3 (**Figure 3**) is a demonstration of the digital capital productivity or output per capital (GDP/capital) as a function of labour per capital, digital technology per capital and the pollutants' emissions per capital, considered to be the explanatory variables based on their quantities. Furthermore, the framework presents the digital TFP per capital (TFP/K) as the combined contribution of the qualities of the inputs demonstrated above in the capital productivity function.

Henceforth, the digital capital productivity decomposes into labour per capital, digital technology per capital and the pollutants' emissions per capital, as presented in [1–6]. When constant returns to scale $[\alpha(1\text{-}\beta\text{-}\lambda-\eta)]$, has been imposed, Eq. (2) becomes:

$$\ln GDPt,\ i = \mathrm{a} + (1-\beta-\lambda-\delta).\ln \mathrm{Kt,i} + \beta\ \ln \mathrm{Lt,i} + \lambda.\ln DTt, i + \delta.\ln Pt,\ i + \varepsilon \mathrm{t}, i\mathrm{t} = \mathrm{N}umber\ of\ years \tag{8}$$

Accordingly, Eq. (8) has been transformed by dividing each term by K (capital input). The output elasticity was formerly calculated with respect to labour per capital, digital technology per capital and the pollutants' emissions per capital, i.e. $\beta = \beta 1 + \beta 2$, $\lambda = \lambda 1 + \lambda 2$, $\delta = \ \delta 1 + \delta 2$, correspondingly. Convening to [1, 2, 5, 6], the capital productivity production function can stand in the following formula:

$$\begin{aligned} &\Delta \ln (\mathrm{GDP/K})\mathrm{t,i} = \mathrm{a} + \beta 1 \Delta \ln\ (\mathrm{L/K})\mathrm{t,i} + \beta 2[\Delta \ln\ (\mathrm{L/K})\mathrm{t,i}]^2 + \lambda 1 \Delta \ln\ (\mathrm{DT/K})\mathrm{t,i} \\ &+\lambda 2[\Delta \ln\ (\mathrm{DT/K})\mathrm{t,i}]^2 + \delta \Delta \ln\ (\mathrm{P/K})\mathrm{t,i} + \delta \Delta \ln [\Delta \ln\ (\mathrm{P/K})\mathrm{t,i}]^2 \varepsilon \mathrm{t}, i \\ &\mathrm{t} = Number\ of\ years \end{aligned} \tag{9}$$

It couriers in the following terms:

$\Delta \ln (\mathrm{GDP/K})\mathrm{t,i}$ is the digital capital productivity contribution capital productivty
$\overline{\beta}\Delta \ln \overline{(\mathrm{L/K})} = \beta 1 \Delta \ln (\mathrm{L/K})\mathrm{t,i} + \beta 2[\Delta \ln (\mathrm{L/K})\mathrm{ti}]^2$
is the contribution of the labour per capital
$\overline{\lambda}\Delta \ln \overline{(\mathrm{DT/K})} = \lambda 1 \Delta \ln (\mathrm{DT/K})\mathrm{t,i} + \lambda 2[\Delta \ln (\mathrm{DT/K})\mathrm{ti}]^2$
is the contribution of the digital technology per capital
$\overline{\delta}\Delta \ln \overline{(\mathrm{P/K})} = \delta 1 \Delta \ln (\mathrm{P/K})\mathrm{t,i} + \delta 2[\Delta \ln (\mathrm{P/K})\mathrm{ti}]^2$
is the contribution of the pollutant emisssions per capital
$\varepsilon \mathrm{t,i}$ is the residual term that proxies for digital TFP per capital growth($\Delta \ln (\mathrm{TFP/K})\mathrm{t,i}$)
Δ is the difference operator denoting proportionate change rate.

It Following the output and labour productivity models' procedures, the intercept (a) has no value in the calculation of the productivity growth indicators as measuring other variables that are not considered in the models, subsequently it drives as follows:

$$\Delta \ln (\mathrm{GDP/K})\mathrm{t,i} = \overline{\beta}.\Delta \ln\ \overline{(\mathrm{L/K})}\mathrm{t,i} + \overline{\lambda}.\Delta \ln\ \overline{(\mathrm{DT/K})}\mathrm{t,i} + \overline{\delta}.\Delta \ln\ \overline{(\mathrm{P/K})}\mathrm{t,\ i} + \Delta \ln (\mathrm{TFP/K})\mathrm{t,i} \tag{10}$$

Where $\overline{\beta}$, $\overline{\lambda}$ and $\overline{\delta}$ indicate the portions of labour per capital, the digital technology per capital, the pollutants' emissions capital and (TFP/K), is the digital TFP per capital contribution as a digital technology spill over effect indicator to transform the countries, sectors firms understudy into sustainable digital economies.

Finally, to compute the average annual growth rate contribution of the TFP per capital, alongside other productivity indicators' contributions in the model, Eq. (10) converts into the followings:

$$\begin{aligned}&\Delta \ln (\mathrm{TFP/K})\mathrm{t,i} = \Delta \ln (\mathrm{GDP/K})\mathrm{t,}\\&\mathrm{i} - \left[\overline{\beta}.\Delta \ln\ \overline{(\mathrm{L/K})}\ \mathrm{t,i} + \overline{\lambda}.\Delta \ln\ \overline{(\mathrm{DT/K})}\ \mathrm{t,i} + \overline{\delta}.\Delta \ln\ \overline{(\mathrm{P/K})}\ \mathrm{ti}\right]\end{aligned} \tag{11}$$

The digital capital productivity growth decompresses into the labour per capital contribution, increasing production of the digital technology per capital and the pollutants' emissions per capital as a desirable output in the form of unpriced products. Besides, the digital TFP per capital contribution as combined input qualities as reaffirmed in Eq. (11).

5. Discussion

It has been stated by World Bank [10] that beyond pandemic periods, the statistical capacity to yield and commendably employ fundamental economic and social data is inadequate. Numerous lower economic states are incapable to precisely track public finances, report on external debt or screening their development goals. Without such data, the capability to grasp regimes accountable and track progress shortcomings, as well as data governance preparations to enable countless data use while protecting against misappropriation stays in their beginning. It should be recalled that the legal and regulatory frameworks for data are inadequate in lower-income countries, which all too frequently have gaps in critical safeguards as well as shortages of data-sharing measures. There, the data systems and infrastructure that enable interoperability and allow data to flow to more users are incomplete. In this respect, less than 20% of low- and middle-income countries have modern data infrastructure such as colocation data centres and direct access to cloud computing facilities in same countries calls Department of Statistics that collected data via annual survey among others. Even where promising data systems and governance frameworks exist, a lack of institutions with the requisite administrative capacity, decision-making autonomy and financial resources holds back their effective implementation and enforcement. To discourse these worries, the World Development Report 2021 requests for a new social contract for data to permit the usage and recycle of data to generate economic and social worth, encourages unbiased chances to benefit from data and raises inhabitants' confidence that they will not be abused by misappropriation data provided. Nevertheless, in looking for such a social contract, lower-income countries are otherwise frequently deprived since they lack the infrastructure and skills to capture data and turn them into value. It should be noted that the scales and organisations to contribute rightfully in universal data marketplaces and their governance and the institutional and regulatory frameworks to build trust in data organisations.

Thanks to the World Development Indicators (WDI) of the World Bank and International Monetary Fund (IMF) financial database system for providing free access to their databases that assisted many researchers, scholars to conduct research around the globe. Thanks to other organisations such as International Telecommunications Union (ITU) of the UN, among others, if they provide free access to their databases to help those who are in need to this data and are not able purchase it due to financial constraints to conduct research worldwide.

The proposed quantitative data for this research ranging from GDP, gross physical capital, human capital proxies, air, water and other pollutants' emissions proxies, human capital index, human development, CO_2 emissions, the level of well-being, etc. which do not include only material/economic aspects will be obtained from the World Development Indicators (WDIs) of the World Bank, financial data system of International Monetary Fund (IMF) and other data sources including individual countries and institutions.

While digital technology proxies will be obtained from International Telecommunications Union and other sources provided this data include cybersecurity data.

The fundamental element is that with appropriate public policies, technological progresses foster the well-being that is deliberated positive externalities of digital technologies that have designed the digital economy everywhere in the world. Nonetheless, there are negative externalities accompanying with this technology progress in the form of undesirable output alongside the desirable output. These negative externalities associated with digital technology progress comprising cybersecurity and the mismatch of human skills in augmenting the digital dividends created by the new factors of production significant contribution to the long-run sustainable economic growth. Besides its counterparts' negative externalities generated as undesirable output by pollutants' emissions that this study based the digital technologies negative externalities assumption on it.

This chapter develops the innovation and climate change integration with economic growth. The Sustainable Development Goals (SDGs) agenda to achieve sustainability issues will be empirically examined via this chapter models and frameworks to realise the long-term economic growth based on a digital economy transformation that will allow to technologically progress and environmentally and socially sustainable. This advancement is essential to sustain long-term economic growth, protect the environment and sustain social evolution through innovation and the spill over effects carried about by the implementation of the SDGs agenda.

It should be noted that the supreme momentous impact in terms of the methodology is that three positive and negative externalities productivity frameworks were established and exhibited how to measure the apprehension variables through primary data (questionnaire) and qualitative analysis (interview and case studies). Furthermore, for the studies that will employ secondary data, this chapter closed the gaps of existing productivity models through three modified models to estimate and calculate digital technologies positive and negative externalities alongside traditional productivity indicators' contributions to industries, firms, sectors and the economies in a combined econometric and the traditional growth accounting methods to estimate explanatory variables' coefficients that is disregarded by growth accounting studies. Whereas in a second step, productivity indicators are proposed to be calculated through plugging of the estimated explanatory variables' coefficients into the models to calculate the productivity indicators that were ignored in the econometric method. In doing so, the study contributes significantly via filling extensive growth theory (output) and intensive growth (labour productivity) gaps. Furthermore, the most significant contribution of this study is treating the digital technologies cybersecurity negative externalities spill over effects equivalent to the negative externalities generated by pollutants' emissions and developing capital productivity framework and model that were ignored in most of the studies with the exception of [1–4, 41] studies.

Moreover, these frameworks and models can be applied at the microeconomic level for sectors, companies and other business based on the available data. Besides, the proposed qualitative method to capture the information and data that cannot be captured via quantitative method, this they will be in form of interviews with the experts and case studies among other qualitative methods such as focus groups among others. The proposed three frameworks and models can be employed to analyse secondary data through econometric estimation and the calculation of productivity indicators for the secondary data at the Macro and micro levels. A questionnaire survey to collect the primary data can be designed and distributed based on this chapter proposed frameworks. Likewise, a qualitative approach can be conducted via interviews with experts to capture the data and information that could not be captured via a quantitative approach.

6. Conclusions and policy implications

The research ideas and output are expected to contribute to and fill the knowledge gaps in the form of modified models and frameworks that examine the digital economy and digital inclusion at the macro and micro levels; these aim to achieve digital transformation. The empirical findings will be generated via employing this chapter proposed models and frameworks can help to develop recommendations based on the empirical findings will be generated and policy implications that will be generated based on the most expected significant empirical findings to be used by policymakers, industry and academics. It could also be used by international organisations and other concerned institutions around the world as a podium to implement the SDGs to sustainable digital economies and businesses around the globe.

To ensure enhanced coherence, it needs to utilise these study frameworks and models to empirically examine the SDGs sustainability issues in general and digital technologies in particular. In doing so, they could achieve long-term economic growth based on a digital economy transformation that will allow them to be transformed into the digital technological base required to sustain long-term economic growth. They would also protect the environment through the innovation and spillier effect brought by the implementation of the SDGs agenda related to the digital inclusion in general and financial inclusion in particular. This study's outcomes will provide a digital economy framework and policy implications and recommendations to enhance cooperation, collaboration and smart partnership between and within the countries in the fields of knowledge transfer, technological progress, digital assets and the development of intellectual property. Adopting the suggested frameworks could help sustain long-term economic growth to overcome the impact of COVID-19 and possible future pandemics. Digital technology applications can facilitate the economic activities needed to fight hunger and achieve food security, provide good health and well-being, quality education, clean water and sanitation, affordable and clean energy, industry, innovation and infrastructure.

It will provide recommendations, policy implications and solutions to the problems facing in implementing the digital technology applications to transform their economies into digital economies and to implement the new technologies in the future to achieve the SDGs.

The aggregate economy, economic sectors, industries and companies will be provided with solutions and guidelines to implement digital technology applications to transform into digital economies. The proposed frameworks and models will be empirically examined in the economies, sectors and companies to provide practical solutions to sustain the economic development via the digital solutions needed to overcome the problems and lessons learned in the post-COVID-19 era and to develop policies to be implemented by public and private sectors to achieve sustainable development.

This study proposed ideas based on frameworks and models that will be useful for digital technology policy construction as a foundation for the establishment and growth of a digital economy based on digital economy level. In this setting, a contrast of digital technology's contributions to productivity growth would provide guidelines for policy-makers to frame suitable national digital transformation policies in line with the digital transformation programme. The findings from this study will likewise support the construction of a digital technology investment policy and help the development of the human capital and infrastructure needed to support the effective use of the digital technology, this should be supported by good governance, implementation of corporate social responsibility.

It should be noted that the countries can capitalise on their synergy within and between the countries to fully practice the competitive advantages to overhaul their digital assets' deficiencies. In that circumstance, the countries will be able to accelerate the movement towards a digital technology-savvy nation that is accomplished by the members of the Organisation for Economic Cooperation and Development (OECD), such as Europe, USA, Canada, Australia, Japan and South Korea and non-OECD countries such as China.

This study proposed that a digital transformation programme should be taken by countries to narrow the digital divide and dividends brought by digital technologies and to improve digital technology dividends. This would contribute to the transformation of digital economies and make a difference for the nations to enjoy high living standards and well-being, like their OECD counterparts. In addition, classifying the lagging concerning the adoption of digital technology and human capital development delivers a standard to improve cooperation and a smart partnership within and between countries. In this respect, the first phase to relocation to digital economies is an emerging digital economy master plan to identify the policies and strategies to develop digital economy flagships and pillars to improve the existing digital economy flagships and pillars for the countries such as Malaysia, among others, including refining and developing digital economy institutions that needed to facilitate knowledge economy activities and governed them. In this respect, the guidelines are provided for developing a digital economy blueprint and policy implications for digitising the whole economies in general and Small and Medium Enterprises (SMEs) and Micro level in particular. A framework for a digital transformation and developing digital economies should be produced to serve as a guideline for digital economy implementation.

Author details

Elsadig Musa Ahmed
Faculty of Business, Multimedia University, Melaka, Malaysia

*Address all correspondence to: elsadig1965@gmail.com

References

[1] Ahmed EM. COVID-19 implications on IsDB member countries sustainable digital economies. International Journal of Innovation and Knowledge Management in Middle East and North Africa (IJIKMMENA). 2020;**8**(1&2): 12-37

[2] Ahmed EM. Modelling information and communications technology cybersecurity externalities spillover effects on sustainable economic growth. Journal of the Knowledge Economy. 2021;**12**(1):412-430. DOI: 10.1007/s13132-020-00627-3

[3] Ahmed EM. Modelling green productivity spillover effects on sustainable development. World Journal of Science Technology and Sustainable Development. 2019;**17**(3):257-267. Available from: https://www.emerald.com/insight/content/doi/10.1108/WJSTSD-01-2020-0009/full/html

[4] United Nations (UN). Transforming our World: The 2030 Agenda for Sustainable Development. United Nations: United Nations General Assembly, New York; 2015. p. 2015

[5] Ahmed EM. Are bio-economy dimensions' new stream of the knowledge economy? World Journal of Science Technology and Sustainable Development. 2018;**15**(2):142-155. DOI: 10.1108/WJSTSD-06-2017-0014

[6] Ahmed EM. ICT and human capital spillover effects in achieving sustainable east Asian knowledge-based economies. The Journal of Knowledge Economy. 2017;**8**(3):1086-1112

[7] World Development Report. Digital Dividends. Washington DC, USA: The World Bank-International Bank for Reconstruction and Development; 2016

[8] Ahmed EM, Anwar A. Achieving Sudan's sustainable development via microfinance Mobile banking. In: Ali AES, Ali KM, Azrag MH, editors. Enhancing Financial Inclusion Through Islamic Finance. Vol. II. Switzerland AG: Palgrave MacMillan, Springer Nature; 2020. pp. 297-325

[9] Feyen E, Frost J, Gambacorta L, Natarajan H, Saal M. Fintech and the Digital Transformation of Financial Services: Implications for Market Structure and Public Policy. Basel, Switzerland: BIS Papers; 2021

[10] Romer PM. Increasing returns and long-run growth. Journal of Political Economy. 1986;**94**(5):1002-1037

[11] Romer PM. Growth based on increasing returns due to specialization. The American Economic Review, Chapters and Proceedings. 1987;**77**(2): 56-62

[12] World Bank. World Development Report 2021: Data for Better Lives. Washington DC, USA: The World Bank; 2021

[13] Badea L, Rangu CM, Scheau MC. Fintech–financial innovation facilitators. Acta Universitatis Danubius, OEconomica. 2021;**17**(3):301-316

[14] Sabău AI, Achimb MV, Safta LI. Does corporate governance may enhance the digitalization process? A panel data analysis. In: RSEP Conferences. 23rd RSEP International Economics, Finance & Business Conference—Virtual/Online; 25–26 November 2021; University of Washington Rome Center, Rome, Italy. BC Publishing; 2021. p. 287

[15] Shapova M, Varbanov T, Ovchinnikov E. Digital economy across

EU: Convergence or club convergence? In: 23rd RSEP International Economics, Finance & Business Conference—Virtual/Online 25–26 November 2021. Rome, Italy: University of Washington Rome Center; 2021. pp. 357-368. Available from: www.rsepconferences.com. Conference proceedings/full papers ISBN: 978-605-70583-5-5/December 2021

[16] Ahmed EM. Green TFP intensity impact on sustainable east Asian productivity growth. Economic Analysis and Policy. 2012;**42**(1):67-78

[17] Romer PM. Crazy explanations for the productivity slowdown. NBER Macroeconomics Annual. 1987;**2**:163-210

[18] Romer PM. Endogenous technological change. Journal of Political Economy. 1990;**98**(5):S71-S102

[19] Romer PM. Two strategies for economic development: Using ideas and producing ideas. In: Proceedings of the World Bank Annual Conference of Development Economics 1992. Washington, DC: World Bank; 1993

[20] Nordhaus WD. Resources as a constraint on growth. The American Economic Review. 1974;**64**(2):22-26

[21] Nordhaus WD. Can we control carbon dioxide? Vienna: IIASA Working Chapter; 1975. p. WP-75-063

[22] Nordhaus WD. Economic growth and climate: The carbon dioxide problem. The American Economic Review. 1977;**67**(1):341-346

[23] Nordhaus WD. Managing the Global Commons: The Economics of Climate Change. Cambridge, MA: MIT Press; 1994a

[24] Nordhaus WD. Expert opinion on climate change. American Scientist. 1994b;**82**(1):45-51

[25] Nordhaus WD. Integrated economic and climate modeling. In: Dixon PB, Jorgenson D, editors. Handbook of Computable General Equilibrium Modeling. Amsterdam: Elsevier; 2013. pp. 1069-1131

[26] Nordhaus WD. Estimates of the social cost of carbon: Concepts and results from the DICE-2013R model and alternative approaches. Journal of the Association of Environmental and Resource Economists. 2014;**1**(1–2):273-312

[27] Nordhaus WD. Projections and Uncertainties about Climate Change in an Era of Minimal Climate Policies, NBER Working Chapter 22933. Cambridge, MA: National Bureau of Economic Research; 2017

[28] Nordhaus WD. Evolution of modeling of the economics of global warming: Changes in the DICE model, 1992–2017. Climatic Change. 2018;**148**(4):623-640

[29] Nordhaus WD, Romer PM. Integrating Innovation and Climate with Economic Growth, Scientific Background on the Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 2018. Stockholm, Sweden: The Royal Swedish Academy of Sciences; 2018

[30] Ahmed EM. Carbon dioxide emissions, impact on Malaysia's manufacturing productivity growth. World Review of Science Technology and Sustainable Development. 2006;**3**(1):58-69

[31] Ahmed EM. The impact of biochemical oxygen demand emissions on Malaysia's manufacturing productivity growth. Global Economic Review. 2007;**36**(4):305-319

[32] Solow RM. The production function and the theory of capital. The Review of Economic Studies. 1955;**23**(2):101-108

[33] Solow RM. Technical change and the aggregate production function. The Review of Economics and Statistics. 1957;**39**(3):312-320

[34] Pittman RW. Multilateral productivity comparisons with undesirable output. Economic Journal. 1983;**93**:883-891

[35] Baumol WJ, Oates WE. The Theory of Environmental Policy. New York: Cambridge University Press; 1988

[36] Chaston K, Swinand G, Gollop F, Arontt R. A Welfare-Based Measure of Productivity Growth with Environmental Externalities. Department of Economics, USA: Boston College; 1997

[37] Gollop FM, Swinand GP. Total resource productivity: Accounting for changing environmental quality. In: Dean E, Harper M, Hulten C, editors. New Directions in Productivity Analysis. Conference on Research in Income and Wealth. Chicago, MI: University of Chicago Press; 2021

[38] Gollop FM, Swinand GP. From total factor to total resource productivity: An application to agriculture. American Journal of Agricultural Economics. 1998; **80**:577-583

[39] Gollop FM, Roberts MJ. Environmental regulations and productivity growth: The case of fossil fuelled electric power generation. Journal of Political Economy. 1983;**91**: 654-674

[40] Harchaoui T, Kabrelyan D, Smith R. Accounting for Greenhouse Gases in the Standard Productivity Framework Statistics. Canada: Micro-Economic Analysis Division; 2002

[41] Ahmed EM. Capital productivity determinants: East Asian perspectives. International Journal of Sustainable Economy. 2009;**1**(3):245-254

[42] Ahmed EM. Human capital and ICT per capita contribution to east Asian productivity growth. International Social Science Review. 2010;**85**(1-2):40-55

[43] Jorgenson DW, Gollop FM, Fraumenri B. Productivity and US Economic Growth. Amsterdam: North Holland; 1987

[44] Dollar D, Sokoloff K. Patterns of productivity growth in south Korean manufacturing industries 1963-1979. Journal of Development Economics. 1990;**33**(2):309-327

[45] Wong FC. Patterns of labour productivity growth and employment shift in the Singapore manufacturing industries. The Singapore Economic Review. 1993;**38**(2):231-251

[46] Felipe J. On the myth and mystery of Singapore's zero TFP. Asian Economic Journal. 2000;**14**(2):187-208

Chapter

For Better or for Worse: The Impact of Workplace Automation on Work Characteristics and Employee Well-Being

Maria C.W. Peeters and Judith Plomp

Abstract

This article examines the consequences of implementing an automation technology (i.e., Robotic Process Automation; RPA) for work characteristics and employee well-being. Based on the job demands-resources framework we examined to what extent the utilization of RPA was related to job resources (i.e., autonomy and task variety) and a job demand (i.e., information processing), and to what extent these work characteristics were related to work engagement and exhaustion. Data were collected among 420 employees working for a Dutch ministry where RPA was recently introduced. Structural equation modeling revealed that RPA use was negatively related to both autonomy and task variety, which formed a threat to employee work engagement. Contrary to our expectations, RPA use was unrelated to information processing and subsequent exhaustion. These findings put emphasis on the importance of designing new technologies with sufficient job resources to create and maintain a healthy and motivated workforce during and after implementing workplace automation.

Keywords: technological innovation, workplace automation, robotic process automation, work characteristics, employee well-being

1. Introduction

Technological innovations and work process automation play a key role in meeting the increased demands that organizations face in today's competitive and fast-changing market [1]. To become and remain efficient, automation and robotics offer many solutions for the potential optimization of work processes. Robotic Process Automation (RPA) is currently one of the most used tools in business process automation that stimulates higher organizational productivity [2]. RPA is a software robot that uses the interface of an already present computer system and mimics the actions of a human employee. RPA can automate work processes that are administrative, well-structured, and repetitive of nature [3–5]. Typical tasks that can be done by RPA entail, for example, processing incoming emails and orders, transferring data from one digital system to another, and searching for and communicating with potential new hires. Organizations greatly benefit from the implementation of RPA, mainly due to increased process speed and production growth, as well as error reduction [6].

However, although there are many advantages to the commissioning of RPA, it is estimated that between 30 and 50% of all RPA implementations fail [7]. This relatively high number of unsuccessful RPA implementations is in line with the general notion that digital transitions often do not result in desired outcomes, such as enhanced productivity and efficiency. A potential explanation for failing technological implementations is the lack of consideration for the employees who have to work with a new technology [8]. With this study we aim to gain more insight in this human-technology interaction [9] by investigating to what extent the implementation of an RPA technology impacts work characteristics and employee well-being.

In-depth knowledge on the consequences of digital transitions for the work characteristics and employee well-being is increasingly important, because both are to a large extent predictive of overall employee performance and organizational productivity [10, 11]. By studying this issue we contribute to the existing body of knowledge on workplace automation and information systems in two important ways. First, this study aims to address the research gap concerning the impact of workplace automation on individual work experiences. Whereas earlier research has mainly focused on the effects of technological innovations on employment and labor market composition, we argue that more understanding of the relationship between the implementation of an automation system and work characteristics, as well as well-being of those who have to work with these new technologies can contribute to the successful implementation of technological innovations. This can help organizations that want to innovate and invest in better designed jobs, as well as lead to better implementations of new technologies such that sustainable employee performance can be consolidated and organizational efficiency can be achieved. Second, we aim to contribute to the growing body of literature on workplace automation and the application of RPA technology [5, 6, 12, 13]. More specifically, we examine to what extent RPA influences the work experiences of employees and whether RPA technology results in the desired outcomes with regard to a decrease in job demands, an increase in job resources, and in turn enhanced employee well-being. In sum, with this research we want to achieve a better understanding of how employees experience working with RPA, so that such an innovation in the future actually contributes to what it is intended for and does not generate negative side effects. In the following sections, we will explain how RPA can influence work characteristics and how these work characteristics are related to employee well-being.

2. RPA and work characteristics

Work process automation changes the way work is performed and perceived by employees. For example, the use of robots that automate heavy manual labor can result in less physically straining job tasks for employees, while at the same time requires them to handle new machinery. Similarly, the use of chatbots can significantly decrease interpersonal interactions at work, but can potentially also result in employees to feel alienated from their original work role. Hence, the introduction of a new technology and workplace automation can have both simultaneously positive and negative influences on employees' work experiences.

The idea behind RPA technology is that administrative work processes become more streamlined and efficient, so that employees have to spend less time on performing repetitive work tasks [3]. Compared to traditional automation systems (e.g., BPM, CRM) RPA can automate many different work tasks, is easy to implement and use, and does not require modification of existing IT infrastructures [5]. As such, RPA is unique in a sense that it requires minimal human intervention, can be applied to a range of business applications, and is designed such that end users can make changes without the need to possess extensive programming skills. Although RPA does not automate and replace complete jobs, it does substantially change certain tasks and the way jobs are designed [9, 14]. Therefore, the implementation of RPA is likely to change the way employees (perceive their) work and thus can result in better or worse designed jobs, which likely has a profound impact on important outcomes related to employee work experiences and well-being [9].

From a work design perspective, the job demands-resources model states that all work characteristics can be divided into job demands and job resources [15]. Job demands, such as workload, time pressure, and role conflict, refer to all aspects of a job that require continuous cognitive or emotional effort and are related to physiological and/or psychological costs. Job resources are those aspects of a job that help employees cope with high job demands, attain work goals and performance, and stimulate professional growth. Examples of job resources are feedback, task variety, support, and autonomy [15]. In line with Demerouti [16] and Parker and Grote [9], we argue that during and after the implementation of a new technology and workplace automation both job demands and job resources are subject to substantial changes. A recent systematic literature review [17] on the impact of the implementation of technological innovations on core work characteristics, showed that the implementation of a new technology was associated with intensified job demands, including job complexity and workload. Additionally, the relationship between the implementation of a technological innovation and job resources was predominantly positive, especially with regard to autonomy and control. These findings suggest that although job demands tend to increase after the introduction of a new technology, job resources seem, at least to some extent, compensate for these increased demands. However, in finding an answer to the question which work characteristics are susceptible to change after the introduction of an RPA technology, it is important to take a closer look at the defining features of RPA.

Starting with job resources, as mentioned above, one of the main goals of RPA is to take over administrative and repetitive work tasks from employees [5]. This means that the use of RPA frees time that employees otherwise had to spend on monotonous tasks. Considering that RPA generates more time for other aspects of the job, this should allow employees to exert more control over their work structure and tasks. As such, we expect that RPA use relates to more autonomy at work for employees. This notion is also supported by a qualitative interview study of Engberg and Sördal [18], who found that the introduction of RPA enhanced the experienced freedom of employees to independently organize their work schedule and tasks.

Second, although RPA is useful in replacing structured and repetitive tasks, it is less suitable to take over complex work that requires more advanced problem-solving skills and abilities [3]. Taking into account that RPA technology releases employees from carrying out repetitive work duties, it simultaneously leaves more room to perform other and more challenging tasks. In line with this argumentation, several qualitative studies have shown that, overall, employees experienced that RPA enabled them to advance their skill set. In addition the introduction of RPA enabled them to devote time to their professional development and growth while performing new and challenging tasks [18, 19]. These findings suggest that RPA creates space for employees to focus on a variety of challenging work tasks. Therefore, we also expect that the use of RPA positively relates to task variety, which entails the extent to which employees experience variety in their job content and can perform a wide range of tasks that require different skills [20].

Turning to job demands, reference [21] indicates that RPA is able to take over and process up to 300% more information compared to human employees. This increase in productivity is due to the fact that RPA can complete a large range of administrative tasks in a fraction of the time compared to actual employees and can work throughout the night and weekend. Additionally, RPA is relatively easy to implement and configure, meaning that employees can use RPA, as well as make changes in how tasks are performed, without an extensive technical background [22]. This implies that employees are no longer bothered with continuously having to deal with processing and analyzing large amounts of information and are able to easily adjust the system during the implementation process based on the requirements and needs of their job. Information processing refers to the amount of data and information that employees are required to monitor and manage in their job [20, 23]. Considering that RPA takes over data and information processing tasks to a substantial extent, we propose that RPA completes a large range of administrative tasks in a fraction of the time compared to actual employees. Taken together, with regard to changes in job demands and job resources we formulate the following hypotheses:

Hypothesis 1:RPA use is positively related to (a) autonomy and (b) task variety.
Hypothesis 2:RPA use is negatively related to information processing.

3. Work characteristics and employee well-being

Employee well-being refers to a passive or active work-related affect and individual's evaluation of the quality of experiences at work [24]. In this study, we included work engagement and exhaustion as indicators of work-related well-being, considering that both are regarded as important factors in the operationalization of employee well-being [25, 26]. In relation to work-related well-being, the JD-R framework proposes two independent underlying processes [15]. First, a health impairment process, in which continued exposure to high job demands results in strain, burnout, and an overall decline in health-related outcomes. Second, a motivational process is proposed, in which access to sufficient job resources protects employees against high job demands and leads to motivation, work engagement, and increased productivity. Following these central assumptions, we argue that higher levels of autonomy and task variety associated with RPA use instigate the motivational process as proposed in the JD-R framework. To clarify, autonomy and task variety are key job resources, which consistently have been found to be predictive of work engagement and performance outcomes (for overviews see [27, 28]. Consequently, we propose that employees who can turn over their repetitive tasks to RPA are likely to experience more autonomy and task variety, and in turn feel more engaged. In addition, consistent exposure to high job demands, including workload and information processing, are linked to increased levels of exhaustion and burnout (e.g. [29]. With regard to information processing, we expect that employees who can transfer their administrative responsibilities to RPA and thus on a daily basis deal with substantially less repetitive job tasks, experience lower levels of information processing (see Hypothesis 2). In turn, lower levels of information processing are likely to relate to lower levels of exhaustion (i.e., a positive relationship). Therefore, we hypothesize the following:

Hypothesis 3:(a) Autonomy and (b) task variety are positively related to work engagement.
Hypothesis 4:RPA use is indirectly related to more work engagement through (a) autonomy and (b) task variety.
Hypothesis 5:Information processing is positively related to exhaustion.
Hypothesis 6:RPA use is indirectly related to less exhaustion through information processing.

4. Method

4.1 Sample and procedure

Data for this study was collected via an online questionnaire. We recruited data from employees within two large departments of a Dutch Ministry (N = 420). The response rate was 37.33%. In 2019 this Ministry introduced and implemented RPA in their organization. Employees working in the two departments typically hold office jobs, such as administrative workers, financial and legal experts, project managers and members, and HR representatives. We invited both employees who could turn over certain aspects of their work to RPA (i.e., RPA users, who make or control work processes and provide input for the RPA robot; N = 140) and employees whose work was not directly impacted by RPA (N = 280). In the questionnaire employees were asked whether their work was somehow impacted by the introduction of RPA and if so, in what way their work has changed and how they interacted with the robot. Based on these answers a distinction could be made between RPA users and non-RPA users. The group of RPA users consisted of employees from whom RPA took over one or several administrative and repetitive work tasks, such as scanning and filing emails and documents, extracting data, and generating (mass) emails. Additionally, this group also consisted of employees that made or controlled RPA work processes and output, as well as provided new input for the RPA robot. All employees received an email from the Ministry with information about the aim of the study, a link to the online questionnaire, and an explanation of the confidentiality was offered to all respondents. This study obtained approval of the Ethics Review Board.

In the total sample, 54.90% was male and the average age was 48.96 years (SD = 10.85). The mean job tenure was 14.61 years (SD = 11.22) and on average respondents worked for 33.48 hours a week (SD = 4.87). Most employees worked in jobs that required a Bachelor's Degree (48.10%) or an Associate Degree (12.10%). In terms of demographical variables (i.e., gender, age, weekly workhours, and contract type) RPA users did not differ significantly from non-RPA users. Additionally, we tested for differences between RPA users and non-RPA users on the study main variables by conducting independent samples t-tests in SPSS. **Table 1** shows the results

	RPA users		Non-RPA users		*t*-test
	M	SD	M	SD	
Autonomy	3.62	0.74	3.97	0.65	4.86**
Task variety	3.33	0.82	3.68	0.70	4.59**
Inform. Processing	3.83	0.65	4.02	0.67	2.82**
Work engagement	4.71	0.99	4.69	0.90	−0.22
Exhaustion	2.07	0.75	2.01	0.68	−1.15
*Note: n = 420. * p < 0.05, ** p < 0.01.*					

Table 1.
Results of t-tests comparing RPA users (N = 140) and non-RPA users (N = 280) on the study variables.

of these analyses. RPA users reported significantly lower levels of autonomy, task variety, and information processing compared to non-RPA users.

4.2 Measures

Frist, autonomy was measured with a Dutch translation of three items of the Work Design Questionnaire (WDQ; [20]). An example item of this scale is: "The job allows me to make a lot of decisions on my own". Cronbach's α was 0.80. Task variety was measured with two items of the WDQ [20]. One of these items is "The job involves a great deal of task variety". Information processing was measured with two items of the WDQ. An example of these items is: "The job requires me to monitor a great deal of information". Work engagement was measured with the three-item version of the Utrecht Work Engagement Scale [30]. An example item of this scale is: "At my work, I feel bursting with energy". Cronbach's α for this scale was 0.82. Exhaustion was measured with three items of the Burnout Assessment Tool (BAT [31]). One of the items is: "I feel mentally exhausted at work". Cronbach's α for this scale was 0.81.

4.3 Strategy of analysis

First, we evaluated the measurement model using confirmatory factor analysis (CFA). Latent variables (i.e., autonomy, task variety, information processing, work engagement, and exhaustion) were modeled with scale items. The following fit indices were used to evaluate model fit: the Comparative Fit Index (CFI), the Tucker-Lewis Index (TLI), and the root mean square error of approximation (RMSEA). With CFI and TLI values above 0.95, and RMSEA below 0.06, model fit is acceptable [32]. Second, we tested the proposed research model using structural equation (SEM) with the AMOS software package [33]. To assess the specific indirect effects of autonomy and task variety in the relationship between RPA use and work engagement, as well as the specific indirect effect of information processing in the relationship between RPA use and exhaustion, we applied the phantom model approach [34]. In addition, to test the robustness of our proposed research model, we tested an alternative model, that proposed a relationship between RPA use and work engagement, and in turn, autonomy and task variety. Additionally, this alternative model proposed an indirect relationship between RPA use, exhaustion, and information processing.

5. Results

5.1 Descriptive statistics

In **Table 2** the descriptive statistics, including the means, standard deviations, and correlations of the variables in this study can be found. Job level was the only demographic variable that correlated significantly with several of the outcome variables (i.e., autonomy, task variety, and information processing). Therefore, we controlled for job level in our further analyses.

5.2 Testing the hypotheses

The measurement model, including autonomy, task variety, information processing, work engagement, and exhaustion as latent variables, showed a very good fit to the data: χ^2 = 144.00, df = 55, CFI = 0.96, TLI = 0.94, RMSEA = 0.06. All factor loadings loaded significantly on their respective latent factor and ranged between 0.63 and 0.97.

In Hypothesis 1a and 1b we predicted that RPA use was positively related to (a) autonomy and (b) task variety. Contrary to our expectations, our analysis showed an opposite relationship, namely that RPA use was significantly and negatively related to both autonomy ($\beta = -0.19$, $p < 0.01$) and task variety ($\beta = -0.13$, $p < 0.05$), thereby not supporting Hypotheses 1a and 1b.

In Hypothesis 2, we predicted that RPA use would be negatively associated with information processing. Although this relationship was indeed negative, it was not significant ($\beta = -0.06$, $p = 0.17$), and thereby not in support of Hypothesis 2.

In line with Hypotheses 3a and 3b, we found that autonomy ($\beta = 0.13$, $p = 0.01$) and task variety ($\beta = 0.26$, $p < 0.05$) were as expected indeed positively and significantly related to work engagement, thereby confirming Hypothesis 3.

Turning to Hypotheses 4a and 4b and the indirect relationship between system use and work engagement through both autonomy and task variety, the data showed that this combined indirect effect was negative and significant (estimate = −0.06, $p < 0.02$ with a bias-corrected confidence interval ranging from −0.10 to −0.02). To assess the specific indirect effects of autonomy and task variety separately in the relationship between system use and work engagement, the phantom model approach was applied [34]. The specific indirect effect of autonomy in the relation between system use and work engagement was indeed negative and significant (estimate = −0.10, $p = 0.02$), thereby not in support of Hypothesis 4a. The specific indirect effect of task variety in the relation between system use and work engagement was also negative and significant (estimate = −0.06, $p = 0.02$). As such, Hypothesis 4b was also not confirmed.

In contrast to Hypothesis 5, we found no significant relationship between information processing and exhaustion, ($\beta = 0.08$, $p = 0.17$). As such, Hypothesis 5 was not supported by the data.

Hypothesis 6, in which an indirect effect of information processing in the relationship between RPA use and exhaustion was hypothesized, was not supported by the data (estimate = −0.01, $p = 0.16$ with a bias-corrected confidence interval ranging from −0.02 to 0.00). As such, Hypothesis 6 was not confirmed.

Overall, the proposed structural model showed a good fit to the data: χ^2 = 210.235, df = 78, CFI = 0.94, TLI = 0.92, RMSEA = 0.06. **Figure 1** shows a schematic representation of all study's results.

	Mean	SD	1	2	3	4	5	6	7	8
1. Age	48.96	10.85	—							
2. Job level	2.72	0.68	−0.01	—						
3. System use	0.33	0.47	−0.08	−0.25**	—					
4. Autonomy	3.85	0.70	0.03	0.34**	−0.24**	—				
5. Task variety	3.56	0.76	−0.05	0.48**	−0.23**	0.47**	—			
6. Information processing	3.96	0.67	0.07	0.37**	−0.14**	0.36**	0.36**	—		
7. Work engagement	4.70	0.92	0.05	0.05	0.01	0.28**	0.32**	−0.14***	—	
8. Exhaustion	2.04	0.71	−0.04	−0.01	0.06	−0.14**	−0.13**	0.09	−0.27**	—

*Note: n = 420. * p < 0.05, ** p < 0.01.*

Table 2.
Descriptive statistics and inter-correlations of the study variables N = 420.

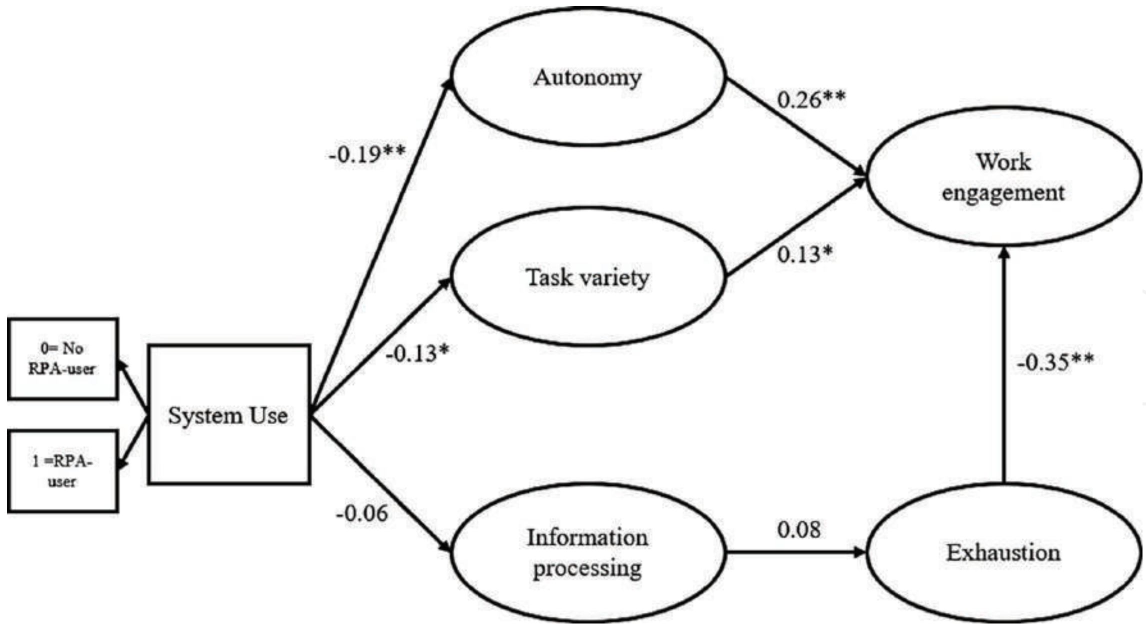

Figure 1.
*Overview of results of structural equation modeling. Note: n = 420. * p < 0.05, ** p < 0.01.*

Last, we tested a plausible alternative model, in which system use was related to autonomy and task variety, through work engagement. Additionally, in this alternative model we proposed that system use was indirectly related to information processing through exhaustion. The alternative model showed a lower overall fit with the data (χ^2 = 248.549 df = 80, CFI = 0.92, TLI = 0.90, RMSEA = 0.07). After comparison of the two models, the proposed research model yielded a significantly better fit ($\Delta\chi^2$ = 38.314, Δdf = 2, p < 0.01).

6. Discussion

To gain a better understanding of the impact of workplace automation on the quality of work and employee well-being, we examined to what extent the introduction of RPA relates to work characteristics and subsequent work-related employee well-being. We drew on the JD-R framework [15] to argue for a positive relationship between RPA use (vs. non-use) and the job resources autonomy and task variety, and in turn work engagement. Additionally, we proposed a negative association between RPA use and information processing and subsequently exhaustion. Contrary to our expectations, the results showed that RPA use was negatively related to both autonomy and task variety, which in turn were positively related to work engagement. Moreover, the indirect effects of both autonomy and task variety were negative in the relationship between RPA use and work engagement. These results indicate that the introduction of a workplace automation, and more specifically the use of RPA, is at the expense of work engagement for employees who have to deal with this new technology through a decrease in job resources. Furthermore, we found no significant relationship between RPA use and information processing and in turn exhaustion, suggesting that job demands were not significantly affected by the introduction of a new workplace technology.

Unexpectedly and remarkably, the findings of this study demonstrate that working with RPA as a new technology is associated with lower levels of both autonomy and task variety. This is a worrying finding in itself, especially because autonomy and task variety are important predictors of work engagement, as also underlined by the results of this study. Moreover, many studies have demonstrated that a lack of job resources, including autonomy and task variety, is also associated with other negative work outcomes such as burnout, turnover intentions, lower levels of learning behaviors, as well as a decrease in motivation, proactivity, and performance [35–37]. This further underlines that it is very important to conserve job resources when introducing a new work process automation.

A possible explanation for the negative association between RPA use and autonomy and task variety - and thus the opposite intended effect of RPA - could lie in the ongoing implementation process of a workplace automation [9]. In this case, RPA was relatively recently introduced within the organization, meaning that the system was still in continuous adjustment to the specific demands of the organization and employees. Although RPA takes over well-structured and repetitive work tasks, the provided output still needs to be regularly checked by human employees. Therefore, it could be that employees working with RPA were still spending considerable time to examine and correct potential system mistakes and updating the robot to certain tasks and needs [38]. Considering that employees needed to search, report, and adjust RPA system errors, this could lead to a decreased sense of autonomy and control. Additionally, because this also requires a different set of work skills, room to engage in new and challenging tasks could be limited. Moreover, employees who had to work with RPA could not freely choose whether RPA took over certain work tasks they previously performed themselves. It could be the case that this lack of individual influence on the use of RPA resulted in a decreased feeling of control. As such, because employees were required to use and learn RPA and did not have a final say in whether RPA was implemented in their work or not, their autonomy may be threatened and thus reduced.

Taken together, the present study findings implicate that after the implementation of a work process automation technology, employee engagement, and thus well-being, is at risk due to a significant decrease in core job resources for RPA users. Additionally, the results of this study showed that RPA use is not related at all to information processing. A possible explanation for this finding may be that information processing simultaneously increases and decreases for RPA users, thereby canceling out any effects. More specifically, it could be that while RPA use relates to less administrative information that has to be analyzed and processed, employees do have to process more information associated with learning to work and getting familiar with RPA, as well as controlling and adjusting RPA processes. In that case, it would be useful to distinguish between different types of information processing related to a digital transition. For instance, information processing associated with the eventual effects of a new technology on individuals work content (and thus an expected decrease in simple and monotonous work tasks), and information processing related to the implementation process and learning a new technology.

Alternatively, other job demands than information processing could be taken into account when examining the impact of RPA on work characteristics. For instance, workload and role conflict could be potential interesting factors in light of the implementation of RPA, considering that the job content is likely to change due to the implementation of a new work process automation technology. Additionally, in the initial phase after a digital transition a new system requires new routines and knowledge, which is likely to have an impact on employees' workload [39].

Last, we did not found the expected positive relationship between information processing and exhaustion. Exhaustion is often regarded as a more distal outcome compared to work engagement, because employee exhaustion only develops after repeated exposure of (high) job demands [40]. Due to the cross-sectional design of this study that also was conducted only two months after the implementation of RPA, it could be that the health impairment processes, as proposed by the JD-R framework, had not been set in motion yet.

6.1 Theoretical contributions

A first important contribution of the current study is that it demonstrates that the relationship between the implementation of technological innovations at work and employee well-being via work characteristics is not straightforward. Our results show that, although RPA is often introduced with the intention to lessen the burden on employees concerning monotonous, repetitive work tasks, this goal is not necessarily achieved. Based on the present study, it seems that job demands do not decrease for those employees that work with the new technology. More importantly and also contrary to our expectations, the use of a new system at work was related to lower instead of higher levels of autonomy and task variety, meaning that job resources of system users seem to decrease after implementation of a work process automation. Thus, our findings demonstrated that the introduction of a new technology did not lower demands. In fact, it even generated less resources in that it created less space for employees to take control over their work and engage in challenging and a wider variety of tasks. Taken together, these findings provide support for the existence of a technology paradox, in that the potential of a new workplace technology does not necessarily results in desired organizational and individual outcomes. Specifically, the implementation of a work process automation should not be at the expense of employee job resources.

Second, the present study contributes to the emerging literature on RPA [5, 6] and offers more insight into workplace automation, and specifically the implementation of RPA, on employee experiences. Whereas earlier studies on the impact of workplace automation and RPA showed overall positive associations with job resources [18, 41, 42], the results of this study present a different picture. Our findings suggest that automation does not always result in a desired reduction of demands, and more importantly, that it poses a potential treat to well-being via a decrease in job resources. To the best of our knowledge this is one of the first papers that focusses on both job resources and a job demand following the implementation of a workplace automation. To gain a deeper understanding of the complex human-technology interaction, future research should place emphasis on changes in both challenging and hindering demands following a digital transition, as well as on job resources that can help employees cope and perform with automation and RPA.

6.2 Limitations and future research

This study has several limitations. First, due to the cross-sectional study design, we cannot draw conclusions about the causal relationships between RPA use, the examined job resources and demand, and work engagement and exhaustion. Although we carefully followed the core premises by the JD-R model [15], it could be the case that some proposed relationships are reciprocal. For instance, it might be that employees who experience high levels of work engagement also perceive more job resources in their work [43]. Earlier studies (e.g. [44, 45] indeed found that job resources and work engagement influence each other in both directions, suggesting a gain cycle in which the presence of job resources and work engagement reinforce each other reciprocally. These findings further underline the importance of more longitudinal research to investigate such bidirectional relationships in a digital transition context. Additionally, when investigating the influence of a technological implementation on employees' job quality and work experiences, future research could apply a longitudinal study design, in which users and non-users are compared at several measurement points, including pre- and post-implementation. Since employees included in the present study were not randomly assigned to use RPA, the selection of employees to use RPA could be correlated with their perceptions of task variety and job automation. For instance, some employees are more capable and can handle more task variety, so they may be more likely to be selected to use RPA. Thus, it is a challenge to determine the causal effect. Therefore, a within-group pre-post design would have been better and is recommended for future studies.

In addition, the use of self-reports could lead to common method bias [46]. However, additional to the good fit of the measurement model, we conducted Harman's single-factor test, which demonstrated that variance in the data was not due to a single underlying factor and thus indicating that common method bias was not a problem in this study. Moreover, it can be argued that constructs reflecting individual states, such as work engagement and exhaustion, as well as perceived work characteristics, can best be evaluated by the individual actor, and are not necessarily suitable to cross-validate with other-ratings.

Finally, in this study we focused on (only) three specific work characteristics that were likely to be influenced by the introduction and use of RPA, namely autonomy, task variety, and information processing. The choice of these work characteristics was based on earlier qualitative research findings on the impact of RPA on job resources [18]. Moreover, we reasoned that the implementation of RPA lessens the amount of information that needs to be processed by human employees, as well as generates more control and room for other challenging tasks. Considering that we found no relationship between RPA use and information processing, it would be particularly interesting to uncover if and how other job demands of system users are affected by the implementation of a workplace automation. For instance, future research could further differentiate between challenging and hindering job demands, were job hindrances (e.g., job insecurity, role conflict, and constraints) are associated with exhaustion and job challenges (e.g., workload and cognitive demands) with engagement [47]. It could be that the implementation of new technologies at work simultaneously incite hinderances and challenges for employees. More insight into how workplace automation affects these specific job demands could contribute to a better implementation of new technologies and optimize adaption among employees who have to work with these technologies [9]. Similarly, it would be relevant to examine what and how job resources can help employees to achieve their goals and stay motivated during the introduction of a new technology [16]. In sum, it is of key importance to design jobs in such a way that a digital transition involves both challenging and realizable job demands, as well as sufficient job resources to stimulate employee performance and well-being. A human-centered approach to workplace automation and job design with particular consideration for employee work experiences is of key importance in reducing the technology-paradox and optimizing the full potential of technology [8].

6.3 Practical implications

The present study connects to a broader debate on the quality of work in the rapid-changing contemporary world of work [48, 49]. Both employees and managers benefit greatly from a healthy and motivating work environment, especially in times of digital transition and widespread automation within organizations. The findings of this study provide further insight into how technological innovations relate to employee well-being through work characteristics and underline the importance of stimulating autonomy and task variety in order to safeguard employee motivation after introducing a workplace automation.

Facilitating a work environment in which employees have access to sufficient job resources that help them deal and work with technological advancements, as well as enabling good performance, is one of the most important implications for practice. Based on the results of this study and in line with the recommendations of reference [16], organizations and HR practitioners should take responsibility during and after the implementation of new technologies. One of the focal points should be to (re) design jobs in such a way that technological innovations turn into a resource itself by closely paying attention to the needs and concerns of users. Carefully identifying how job demands may change after a digital transition can also help organizations to offer appropriate job resources for employees to cope with changes in their job demands. For instance, access to sufficient training and education can help employees to become acquainted and more proficient in using a new technology, and thereby also reducing workload, anxiety, and job insecurity [50]. Additionally, providing feedback and support from the organization and managers are two main resources for employees that help them deal with the negative consequences of job demands [51]. Furthermore, another way to successfully gain and maintain well-being and motivation during a digital transition, is by facilitating employee job crafting [52] which refers to an individual proactive strategy to seek out relevant job resources that can help employees during technological change. Managers and organizations play a key role in creating a work environment in which employees feel encouraged to engage in job crafting and proactively seek out resources they need to adjust and perform [53].

In sum, during and following the implementation of a technological innovation, organizations and managers should be aware of changes in job demands and needs from employees, as well as focus on providing adequate resources for employees to cope with these demands and to stimulate optimal performance with a new technology.

7. Conclusion

The current study demonstrates that the introduction of a workplace automation system may have a profound negative impact on employee job resources. More specifically, the findings indicate that use of an automation system relates to lower levels of autonomy and variation in work tasks, forming a serious threat to the work engagement of employees who have to work with the new system. As such, this study shows that organizations should take a close look at and take into account potentially affected job resources due to the implementation of a workplace automation. Importantly, focusing on stimulating relevant job resources, such as autonomy and task variety, during and after digital transitions is necessary to maintain and promote employee well-being and motivation.

Acknowledgements

This research was funded by a grant from A + O fonds Rijk, an independent Dutch Foundation for innovation and research within the Dutch Government.

Author details

Maria C.W. Peeters[1,2]* and Judith Plomp[1]

1 Department of Social, Health and Organizational Psychology, Utrecht University, Utrecht, The Netherlands

2 Eindhoven University of Technology, Human Performance Management Group, Eindhoven, The Netherlands

*Address all correspondence to: m.peeters@uu.nl

References

[1] Schilling MA, Shankar R. Strategic Management of Technological Innovation. Chennai, India: McGraw-Hill Education; 2019

[2] Miers D, Kerremans M, Ray S, Tornbohm C. Gartner Magic quadrant for robotic process automation software. Market Research Report, no. G00379618. 2019.

[3] Asatiani A, Penttinen E. Turning robotic process automation into commercial success–Case Opus Capita. Journal of Information Technology Teaching Cases. 2016;**2**:67-74

[4] Kroll C, Bujak A, Darius V, Enders W, Esser M. Robotic process automation-robots conquer business processes in back offices. Capgemini Consulting. 2016:1-48

[5] Van der Aalst WMP, Bichler M, Heinzl A. Robotic process automation. Business and Information Systems Engineering. 2018;**60**:269-272

[6] Aguirre S, Rodriguez A. Automation of a business process using robotic process automation (RPA): A case study. In: Figueroa-García JC, López-Santana ER, Villa-Ramírez JL, Ferro-Escobar R, editors. Applied Computer Sciences in Engineering. Vol. 742. Cham: Springer International Publishing; 2017. pp. 65-71

[7] Herm LV, Janiesch C, Helm A, Imgrund F, Fuchs K, Hofmann A, et al. A Consolidated Framework for Implementing Robotic Process Automation Projects. In: Fahland D, Ghidini C, Becker J, Dumas M, editors. Business Process Management. Cham: Springer International Publishing; 2020. pp. 471-488

[8] Peeters MCW. Sustainable work performance in times of digitalization: From paradox to potency. Gedrag en Organisatie. 2020;**33**:163-183

[9] Parker SK, Grote G. Automation, algorithms, and beyond: Why work design matters more than ever in a digital world. Applied Psychology: An International Review. 2020;**69**:1-45

[10] Gayathiri R, Ramakrishnan L, Babatunde SA, Banerjee A, Islam MZ. Quality of work life–Linkage with job satisfaction and performance. International Journal of Business and Management Invention. 2013;**2**:1-8

[11] Warr P, Nielsen K. Wellbeing and work performance. In: Diener E, Oishi S, Tay L, editors. Handbook of Well-being. Salt Lake City: DEF Publishers; 2018

[12] Hofmann P, Samp C, Urbach N. Robotic process automation. Electronic Markets. 2020;**30**:99-106

[13] Madakam S, Holmukhe RM, Jaiswal DK. The future digital work force: Robotic process automation (RPA). Journal of Information Systems and Technology Management. 2019;**16**:1-17

[14] Osmundsen K, Iden J, Bygstad B. Organizing robotic process automation: balancing loose and tight coupling. Hawaii: Proceedings of the 52nd Hawaii International Conference on System Sciences; January 2019

[15] Bakker AB, Demerouti E. Job demands–resources theory: taking stock and looking forward. Journal of Occupational Health Psychology. 2017;**22**:273-285

[16] Demerouti E. Turn digitalization and automation to a job resource. Applied

Psychology: An International Review. 2020:1-6

[17] Plomp J, Peeters MCW. The impact of technological innovations on the quality of work and wellbeing: A systematic literature review. Gedrag and Organisatie. 2020;**33**:348-375

[18] Engberg S, Sördal T. Robotic Process Automation-Robotic Process Automation and its Effects on Job Characteristics [thesis]. Lund, Sweden: Lund University; 2019

[19] Johansson B, Engberg S, Lindgren I, Sordal T. Impacts of RPA on employees skill variety. Paper presentation at the Conference of the Association for Information Systems (AMCIS). August 2020

[20] Morgeson FP, Humphrey SE. The Work Design Questionnaire (WDQ): developing and validating a comprehensive measure for assessing job design and the nature of work. Journal of Applied Psychology. 2006;**91**:1321-1339

[21] Lamberton C, Brigo D, Hoy D. Impact of Robotics. RPA and AI on insurance industry, challenges and opportunities. Journal of Financial Perspectives. 2016;**4**:1-13

[22] Noppen P, Beerepoot I, van de Weerd I, Jonker M, Reijers HA. How to Keep RPA Maintainable? In: Fahland D, Ghidini C, Becker J, Dumas M, editors. Business Process Management. Cham: Springer International Publishing; 2020. pp. 453-470

[23] Daft RL, Macintosh NB. A tentative exploration into the amount and equivocality of information processing in organizational work units. Administrative Science Quarterly. 1981;**26**:207-224

[24] Warr P. The measurement of well-being and other aspects of mental health. Journal of Occupational Psychology. 1990;**63**:193-210

[25] Martínez-Iñigo D, Totterdell P, Alcover CM, Holman D. Emotional labour and emotional exhaustion: Interpersonal and intrapersonal mechanisms. Work and Stress. 2007;**21**:30-47

[26] Schaufeli WB, Taris TW, Van Rhenen W. Workaholism, burnout, and work engagement: Three of a kind or three different kinds of employee well-being? Applied Psychology. 2008;**57**:173-203

[27] Halbesleben JRB. A meta-analysis of work engagement: Relationships with burnout, demands, resources and consequences. In: Bakker AB, Leiter MP, editors. Work Engagement: A Handbook of Essential Theory and Research. New York: Psychology Press; 2010. pp. 102-117

[28] Schaufeli WB. Work engagement: What do we know and where do we go? Romanian Journal of Applied Psychology. 2012;**14**:3-10

[29] Bakker AB, Demerouti E, Verbeke W. Using the job demands-resources model to predict burnout and performance. Human Resource Management. 2004;**43**:83-104

[30] Schaufeli WB, Shimazu A, Hakanen J, Salanova M, De Witte H. An ultra-short measure for work engagement: The UWES-3 validation across five countries. European Journal of Psychological Assessment. 2019;**35**:577-591

[31] Schaufeli WB, De Witte H, Desart S. Manual of Burnout Assessment Tool (BAT). Leuven, Belgium: KU Leuven; 2019

[32] Hu LT, Bentler PM. Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. Structural Equation Modeling: A Multidisciplinary Journal. 1999;**6**:1-55

[33] Arbuckle JL. Amos for Windows. Analysis of Moment Structures, Version 6.0. Spring House, PA: AMOS Development Corporation; 2005

[34] Macho S, Ledermann T. Estimating, testing, and comparing specific effects in structural equation models: The phantom model approach. Psychological Methods. 2011;**16**:34-43

[35] Bakker AB, Demerouti E, Euwema MC. Job resources buffer the impact of job demands on burnout. Journal of Occupational Health Psychology. 2005;**10**:170-180

[36] Parker SK, Morgeson FP, Johns G. One hundred years of work design research: Looking back and looking forward. Journal of Applied Psychology. 2017;**102**:403-420

[37] Schaufeli WB, Bakker AB. Job demands, job resources, and their relationship with burnout and engagement: A multi-sample study. Journal of Organizational Behavior. 2004;**25**:293-315

[38] Montero JC, Ramirez AJ, Enríquez JG. Towards a method for automated testing in robotic process automation project. In: Proceedings of the 14th International Workshop on Automation of Software Test (AST). Piscataway, New Jersey, US: IEEE Press; May 2019. pp. 24-47

[39] Lundh M, Rydstedt LW. A static organization in a dynamic context: A qualitative study of changes in working conditions for Swedish engine officers. Applied Ergonomics. 2016;**55**:1-7

[40] Crawford ER, LePine JA, Rich BL. Linking job demands and resources to employee engagement and burnout: A theoretical extension and meta-analytic test. Journal of Applied Psychology. 2010;**95**:834-848

[41] Morris MG, Venkatesh V. Job characteristics and job satisfaction: Understanding the role of enterprise resource planning system implementation. MIS Quarterly. 2010;**34**:143-161

[42] Venkatesh V, Bala H, Sykes TA. Impacts of information and communication technology implementations on employees' jobs in service organizations in India: A multi-method longitudinal field study. Production and Operations Management. 2010;**19**:591-613

[43] Taris TW, Kompier MA. Cause and effect: Optimizing the designs of longitudinal studies in occupational health psychology. Work & Stress. 2014;**28**:1-8

[44] Schaufeli WB, Bakker AB, Van Rhenen W. How changes in job demands and resources predict burnout, work engagement, and sickness absenteeism. Journal of Organizational Behavior. 2009;**30**:893-917

[45] Xanthopoulou D, Bakker AB, Demerouti E, Schaufeli WB. Reciprocal relationships between job resources, personal resources, and work engagement. Journal of Vocational Behavior. 2009;**74**:235-244

[46] Podsakoff PM, MacKenzie SB, Lee JY, Podsakoff NP. Common method biases in behavioral research:

A critical review of the literature and recommended remedies. Journal of Applied Psychology. 2003;**88**:879-903

[47] Van den Broeck A, De Cuyper N, De Witte H, Vansteenkiste M. Not all job demands are equal: Differentiating job hindrances and job challenges in the Job Demands–Resources model. European Journal of Work and Organizational Psychology. 2010;**19**:735-759

[48] Adamson M, Roper I. Good' jobs and 'bad' jobs: Contemplating job quality in different contexts. Work Employment and Society. 2019;**33**:551-559

[49] Cazes S, Hijzen A, Saint-Martin A. Measuring and Assessing Job Quality: The OECD Job Quality Framework. Paris: OECD Social, Employment and Migration Working Papers 174; 2015

[50] De Witte H, Vander Elst T, De Cuyper N. Job insecurity, Health and Well-being. In: Vuori J, Blonk R, Price RH, editors. Sustainable Working Lives. Dordrecht, NL: Springer; 2015

[51] Xanthopoulou D, Bakker AB, Dollard MF, Demerouti E, Schaufeli WB, Taris TW, et al. When do job demands particularly predict burnout? The moderating role of job resources. Journal of Managerial Psychology. 2007;**22**:766-785

[52] Tims M, Bakker AB. Job crafting: Towards a new model of individual job redesign. SA Journal of Industrial Psychology. 2010;**36**:1-9

[53] Wang H, Demerouti E, Bakker AB. A review of job crafting research: The role of leader behaviors in cultivating successful job crafters. In: Parker SK, Bindl UK, editors. Proactivity at work: Making things happen in organizations. New York, USA: Routledge; 2016. pp. 77-104

Chapter

Digital Transformation in the Construction Sector: From BIM to Digital Twin

Bruno Daniotti, Alberto Pavan, Cecilia Bolognesi, Claudio Mirarchi and Martina Signorini

Abstract

In the next years, perhaps more than ever before, a technological revolution will transform the construction sector in all its aspects, greatly affecting services, production, and supplies. With BIM, and even more considering the Digital Twin topic, the innovation of tools has entailed a methodological innovation for the whole sector, owing to virtual reality simulations and actual dynamic real-time monitoring. This research, starting from an integrated analysis between the current research trends and some relevant national and European projects about the digitalization of construction sector, aims at providing a systematic analysis of some of the pillars that are guiding this phenomenon. In detail, the state of the art, activities, and trends of standardization and platform development in construction sector are considered and intersected to provide a clear background towards the future trends in the sector.

Keywords: BIM, digital twin, digital platforms, standardization, process management, construction

1. Introduction

In the next years, perhaps more than ever before, a technological revolution will transform the construction sector in all its single aspects, greatly affecting services, production, and supplies. Freehand drawing, drafting machines or CAD have represented innovative tools in graphic representations. In such cases, the evolution of tools for the productivity of the sector has improved and quickened the design, but not more than that. With Building Information Modeling (BIM), and even more considering the Digital Twin (DT) topic, the innovation of tools has entailed a methodological innovation for the whole sector. Around BIM and DT several technologies and topics needs to be analyzed including virtual reality simulations, dynamic real-time monitoring and controlling, data driven decisions, etc. Nowadays, several drivers can be identified in the evolution of both the research and the industrial applications. Hence the need to provide a systematic analysis that can provide a clear background useful for future research works. Among these drivers the standardization activities and the development of digital platforms for the construction sector represent key points for the understanding of the ongoing research and development in the digitalization of the construction sector. The work here presented has been developed starting from an integrated analysis between the current research trends and some relevant national and European projects about the digitalization of construction sector and considering a perspective view that comprehend the history and evolution of the BIM topic and its implications.

This research aims at providing a systematic analysis of these two pillars considering the intersection of both the research trends and the results obtained from the development of some key national and European projects. The results here proposed can inform future research paving the way for the development of new works around these two key drivers of the digital transformation in the construction sector.

Following these directions, this chapter is organized as follows. Section 2 reports a brief analysis of the main evolution points that shaped the change from CAD to BIM. Section 3 proposes an analysis of the standardization framework analyzing the existing works and the ongoing and future activities. Section 4 reports a presentation of some of the main projects that have been developed in the context of the development of digital platforms for the construction sector. Finally, Section 5 reports the conclusions of the chapter.

2. BIM: from CAD to BIM

2.1 The first steps

In the last two decades the work of designers has radically changed not only in relation to conceptual differences in the representation of the project [1], more and more oriented to 3D development as a model from which to derive two-dimensional drawings of plans, sections and elevations, but also in relation to the technical instrumentation offered by the software and hardware capabilities related to the representation and simulation of the project, with inevitable repercussions on the professionalism and responsibility of individual actors [2].

On the one hand, the ability to represent the project as classically occurred in the past has remained the same for centuries, delegating to the designer the realization skills of his own project, with responsibility for all parts of its development and the obligation to represent and describe every single piece of information destined to its best realization; on the other hand, the step change that occurred with the digital design processes was first slight with the introduction of the first two-dimensional CAD, then more and more involving with the transition to BIM [3].

The transition from manual drawing to CAD [4] takes place as for BIM starting from the mechanical and precisely automotive industries; the need for absolute precision in the design for production is required by the simulations related to the efficiency of vehicles as well as the hypothesis of making the house a machine for living is becoming more and more possible.

In a traditional design workflow, the designer generally worked on his single area of expertise and from a preliminary architectural content descended the structural and plant choices unless required by a state of necessity. The subordination of actions in the development of the project was very clear and the roles as well. With the advent of CAD and the use of different layers this position of absolute dominance over the project begins to waver, if only for the possibility of greater flexibility in the construction of variants compared to previous workflows. Coordination becomes part of the design routine, at least above a certain size, and a process of modernization of the workflows takes place. Coordination has very specific goals: smoothing out conflicts, introducing compatible variants, correcting layers. There remains a vast waste of forces and time to correct different layers, sections, up to a better coordination between the windows of the model space but still in two-dimensional and limited scope. The discordances between those who work in architecture and those who work in engineering remain also when we try to visualize the project: for an architect it's about evaluating the space and the perspective views or anyway the 3D sketches are the most used means; for an engineer the most adequate representation concerns plans and construction details.

In the early days of the BIM revolution [5], the first calculation applications linked to CAD tools, some first library of materials and objects, offered as blocks, mainly linked to price lists, came forward.

When BIM arrives, the revolution is disruptive; the designer's point of view changes from the setting, working primarily from the 3D model. The sub-units of the model are objects, parametric, informed, and offer rapid possibilities in their transformation, in the modeling of the whole [6]. The preliminary phase of the project already brings in itself more information than necessary, having the single objects parameters defined; some argue that this definition from the first phases of the project of the objects risks binding the less experienced to the design. Nevertheless, the obtained model results the only true DB of all the information on the project, through which we can build the base documentation and not only.

In addition, the parametric model combines the expectations of two worlds: the expectations of architects, who want to visualize the project at 1 m from the ground, and of engineers, who want to visualize what is in the project, such as in the walls or floors, finds a point of contact [7].

2.2 BIM model definition and introduction of a disruptive process

Once the backroom battles that accused BIM of deadening the creative process of designers have died down, process integration comes into its own. Geometric information alone does not allow the representation of the project necessary for the BIM process in its entirety, and therefore BIM proposes an object-based representation. In the case of construction, this translates into a representative schema modeled around the project entities and their mutual relationships.

In the definition of the floor object, for example, the geometry constitutes only one of the different properties of this building element; a room consisting of floors and walls, in addition to the geometric data will contain information such as connected walls and adjacent spaces. We speak not only of model set-up but of "building representation", considering the specific domain of information integrated in the objects.

As the structural principles of object modeling are reshaped, metrics are introduced to measure the actual application of BIM within production facilities; as the level of maturity of BIM adoption increases, so do the levels. Level 0 represents the initial form of the introduction process; generally, people still work in two-dimensional mode, with 2D drawings enriched by data without shared standards. We are in traditional procedures, prodromes of a real BIM and far from an object-based structure. In level 1 standardized structures and formats are introduced, certainly in the design phase there is a 3D phase enriched by 2D documents with design information; however the collaborative phase is still remote and federated models are not yet in progress so the strengths of BIM are not yet used. At Level 2, we are already thinking in a fully collaborative environment: all parties are using 3D CAD models, and collaboration comes in the form of how information is exchanged between the various parties through common file formats that allow anyone to create a investigable federated model. So, we are in a 3D environment with attachments where the starting disciplines are still on separate models that can be assembled. At level 3, sharing and collaboration between disciplines is total. There is a single design model allocated in an IFC-compliant repository referred to in the following lines. At Level 3, the design team has overall control over design and construction, and design optimization is achieved. In Level 3, we talk about a fully open process and data integration enabled for standards-compliant "web services." (**Figure 1**)

2.3 Federated models and shared environments

The need to deal with a common language, to share procedures and basic documents, to use interoperable and sharable software, a choice reinforced using BIM within the Public Administrations, together with the need to have reference figures for certain categories of work in the design flow, to be able to build environments of data sharing determine at first a disruption in the organization of work [8]. In BIM the information flows related to the project are integrated; there is a shift from a "document-centric" approach, to an innovative "data-centric" approach, with attention paid to the entire life cycle of the work; the BIM model therefore immediately guarantees the complex management of the building and distributed over time starting from the design, planning for the realization, estimation, up to the realization and management of the work.

The big step forward is about the ability to work synchronously on the same model as the key element; each project is modeled in relation to a number of models focused on specific disciplines. The models are associated with a federated model, a centralized repository of information for the entire project. In a typical construction project, the federated model may consist of the architectural model, the structural model, and other specialized models containing all the relevant information provided by the building owner, architect, structural engineer, mechanical engineer, plumbing

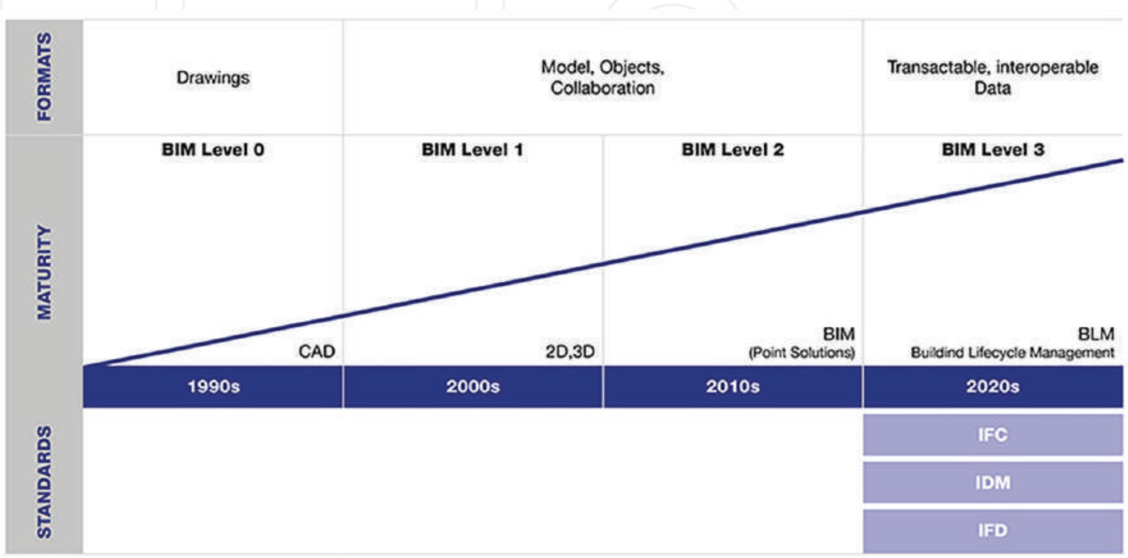

Figure 1.
Levels of insight into the use of BIM, from level 0 to level 3 objective, BSI PAS 1192–2.

engineer, and contractors. It is easy to understand how the possibility of cooperation between the different types of design and the consequent management of conflicts can be resolved through platforms, but not only; shared work imposes the sharing of procedures and requires a shared environment, favoring the construction of digital environments where information can be transmitted.

The sharing environment is CDE, in Italy, better known as Common Data Environment [9] abroad: it is an environment of organized collection and sharing of data related to models and digital works, referring to a single work or a single complex of works. The professional figure who deals with the management of the Data Sharing Environment and the information dynamics based on the introduction, exchange, management and storage of data is the CDE Manager. The Data Sharing Environment Manager is a figure who is in charge of the data sharing environment implemented by the organization to which they belong.

2.4 BIM dimension and new professionalisms

For the intrinsic properties of the models in BIM environment they lend themselves to simulation processes even complex enough; we can consider them as prodromal to the development of Digital Twins. To explain their natural inclination to the complex management of the built environment, a scale of dimensional values, from one to seven, has been coined to describe the intrinsic characteristics within the workflow; after the second and third dimensions of BIM, graphic representation of the work in 2D, function of the plan, or 3D, function of space, the fourth dimension 4D is introduced to simulate the work or its elements as a function of time, as well as space; the fifth dimension 5D [10] as a function of economic value; the sixth 6D as a function of simulating the work for management, maintenance and eventual disposal; the seventh 7D as a simulation of the work as a function of economic, environmental and energy sustainability of the intervention (**Figure 2**).

For the management of the whole process new roles are needed and different degrees of specialization are introduced, keeping the focus of the activity linked to the management of the model even if informed; also the UNI 11337–7 [11] standard

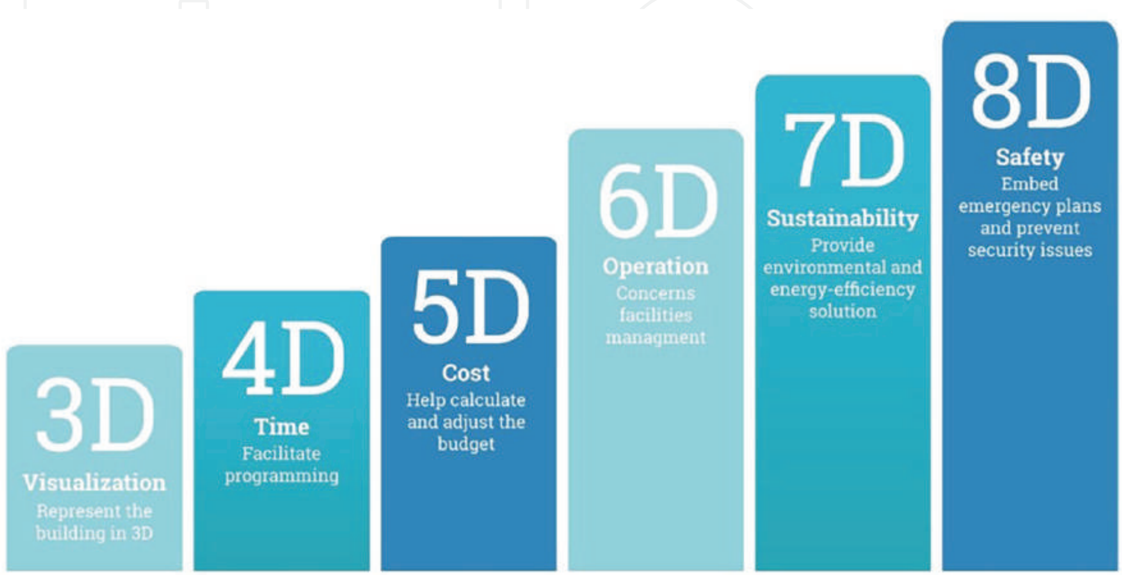

Figure 2.
BIM "3D-7D" graph [10].

identifies roles, knowledge and skills associated to the professional activities involved in the BIM information flow, aggregating the roles foreseen by previous British standards in the following four roles. The BIM manager is considered for the general supervision and coordination of the projects from the information point of view. This is the person who defines the BIM instructions and the way in which the digitization process impacts the organization and the work tools. The BIM Coordinator operates at the level of the single order, in agreement with the top management of the organization and on the indication of the BIM Manager. The BIM Specialist is the advanced operator of management and information modeling and usually acts within the single orders for authoring activities through digitization procedures and object modeling and management.

Generally, he follows the elaboration of the model and also interfaces with the CDE Manager. The BIM specialist must know the software for the realization of a BIM project, according to his own disciplinary competence (architectural, structural, plant engineering, road, hydraulic). He must understand and use the technical and operational documentation for the production of drawings and models (standards and procedures); he/she must "model the information" for the graphic and non-graphic models, interfacing with the supervision and coordination of the BIM Coordinator or the BIM Manager of the company or of the design group in order to elaborate the graphic models and the related objects and their libraries; he/she must extract data from the models, from the drawings and from the objects; he/she must modify the models and the objects derived from the coordination between models and from the project revisions. Its intervention is part of the digital workflow enhanced by the ability to analyze the contents of the information specification and the information management plan having full capacity to verify the information model, and to validate its consistency.

2.5 Interoperability standards and ongoing evolutions

The progressive transition to BIM has created an inevitable proliferation of software products related to information modeling [12] in which the model can find full expression of its geometry and related information. However, the coordinated work between different teams, as well as forcing the sharing of data in a common environment, imposes the solution of problems related to communication between software. The software is proprietary, with problems of communication between each other such as to require an open format whose purpose lies in neutrality towards commercial brands of software to share sets of projects and assets through standards of communication and data exchange. The attempt to standardize data transmission through the use of an open format has decades of history (**Figure 3**).

Over the years, the evolution of the data schema has added multiple degrees of complexity to its hierarchical structure based on the entity-relationship model, to provide a data transposition that preserves more and more information and the consequent relationships. Currently the IFC standard can standardize and codify different components of the BIM model: the recognition of the object in an automatic way, the information on characteristics and attributes, the relationships with other objects, all this to transmit the information model keeping the logic and the geometric-documental information connected to it. However, the IFC attempts to enclose in a predefined logical scheme a context, such as the construction sector, which is represented by a greater degree of complexity than is currently possible to unravel by computer and this particular points it is that one that renders still more important the geometric definition of the model like first interface with the consumer destined to the understanding of the model.

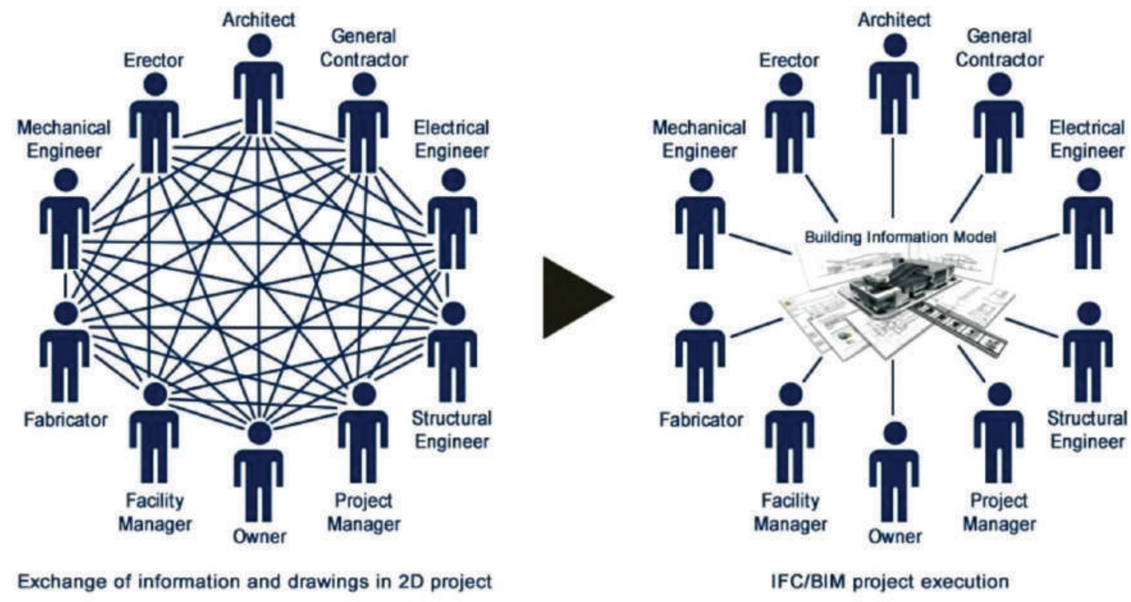

Figure 3.
Interoperability [12].

3. BIM standardization: UNI, CEN TC442, ISO TC59 SC17, buildingSMART

The evolution over time of Building Information Modeling can be traced back to three fundamental aspects:

- technological evolution;
- legislative developments;
- evolution of technical regulations.

The technological evolution can be traced back to the transition from CAD (Computer Aided Design) software systems also dedicated to the construction sector (from the early 80s) to Object-Oriented programming systems of the AEC (Architecture Engineering Construction) domain, also known as BIM Authoring software (starting from the late 80s and with considerable development since the late 90s—**Figure 4**).

The legislative evolution (laws, mandatory rules), especially in the European panorama, can be traced back to the strategy of relaunching the construction sector of the British government after the systemic crisis of 2007/2008 and the related PAS (2011–2013) which they achieved (**Figure 5**): the obligation of government BIM public procurement above 5 million pounds in 2016 in the UK; the introduction of BIM in voluntary form in the European Procurement Directive of 2014: the consequent transposition of BIM in the contract codes of the EU member states (by 2016) and, for example in Italy, the introduction of mandatory BIM from 2019 to 2025 (complex works greater than or equal to 100 million–2019; each works over 1 million euros–2025).

The regulatory evolution at the level of the practices and standards presents three fundamental moments, corresponding to the production of three reference documents (**Figure 6**): the PAS 1192–2 UK (2013), the BIMForum LOD Specifications USA (2013) the BIM Project Execution Planning–of the Pennsylvania University, USA (2010).

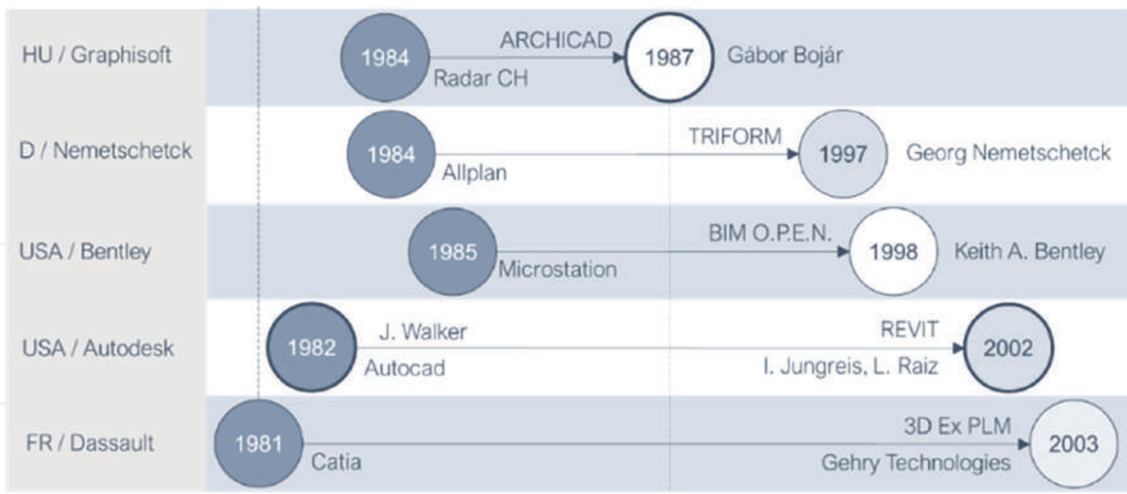

Figure 4.
Tools evolution to BIM (example).

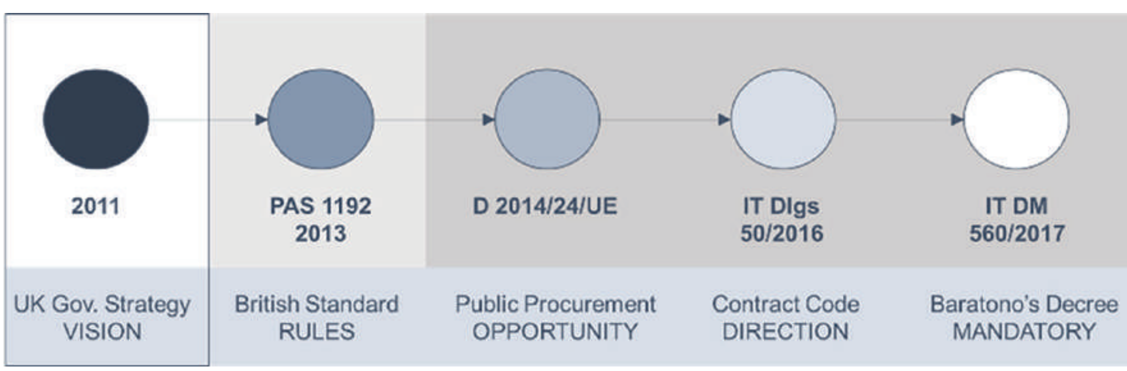

Figure 5.
Laws evolutions to BIM (EU).

Figure 6.
Main technical specifications and reference practices for BIM.

These constitute, on the one hand, the arrival points of the first works and standards on BIM (ISO STEP 10303; ISO 16739—IFC), on the other hand, the principle of all voluntary technical regulations now in use (**Figure** 7): worldwide at ISO level, in Europe at CEN level and in each individual state (e.g., Italy, Great Britain and United States of America) at UNI, BSI, ANSI levels among others.

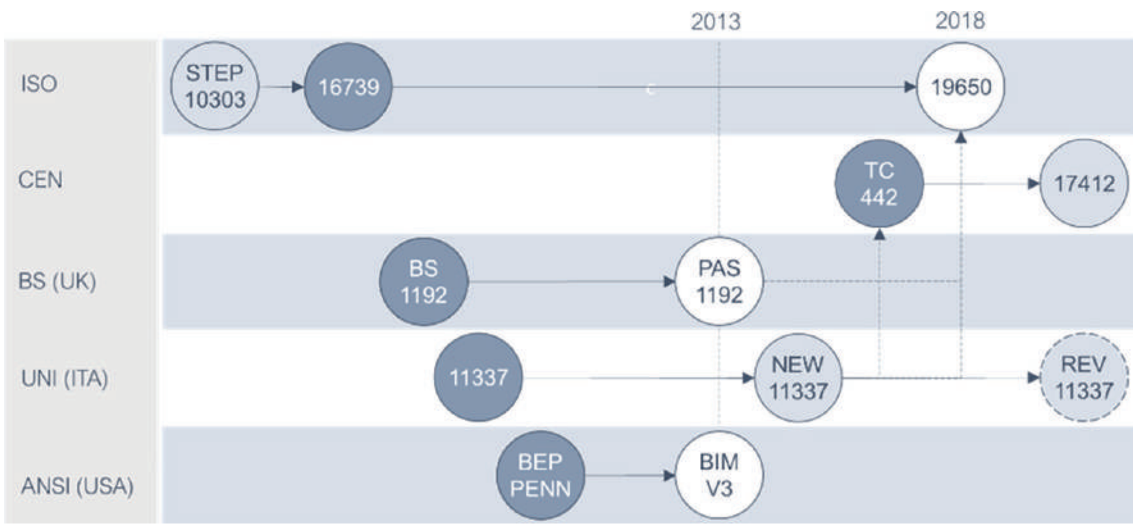

Figure 7.
BIM standard evolution in the world.

The voluntary technical standards are non-mandatory regulatory references that the market adopts to define a workspace–market–within whose boundaries all the actors concerned recognize common principles, shared, with which to operate to protect everyone and the market itself. The standardization body that operates internationally is the International Organization for Standardization (ISO), and its standards take the acronym: ISO. The standardization body that operates at European level (and some added states including Great Britain) is CEN, and its standards take the acronym: EN. CEN is part of ISO. For BIM there is an agreement called "Vienna Agreement" for which (from 2017) each ISO standard automatically becomes a CEN standard (without specific further adoptions). The ISO standards on BIM, after 2017, are therefore ISO EN standards. Finally, each state has its own national standardization body (for Italy the UNI, for Great Britain the BSI, for the USA the ANSI, etc.). They draw up the national rules valid in the specific territory in the national language. For the EU countries the EN standards are automatically adopted even at national level, therefore, in the BIM panorama, the ISO and CEN standards are for example: in Italy UNI EN ISO, and in Great Britain BS EN ISO (**Figure 8**).

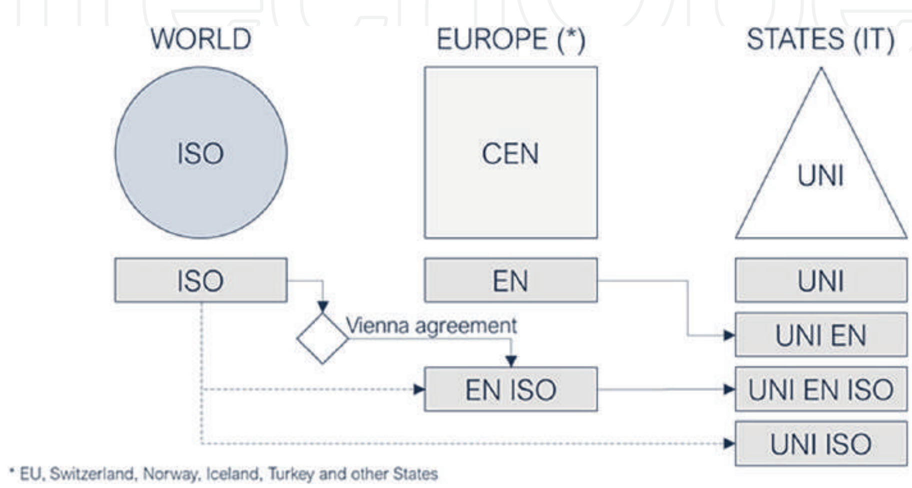

Figure 8.
Standard body structure in the world.

Analyzing the three normative levels (national, CEN and ISO) we see that BIM, although not yet so widespread and prevalent in the construction sector (compared for example to CAD), enjoys a large panorama of reference standards that actually allow a conscious and regulated use in every market, as illustrated in the following **Figure 9**.

With the publication of the first part of the package of standard ISO 19650: 2018 (Information Management—IM) the basic regulatory framework of BIM assume a picture like the one presented in **Figure 10**. Although the last born, ISO 19650 (in its various parts) becomes the reference standard, applicable in all markets. In Europe, it applies together with the subsequent CEN standards (of which, the first, is on the definition of the Level of Information Need: EN 17412:2021).

Nowadays, only Italy and Great Britain have decided to apply the faculty, provided for in ISO 19650, to insert national annexes to facilitate local markets in its application. Other states are considering adopting their own annexes (Spain, France, Germany, Morocco, etc.).

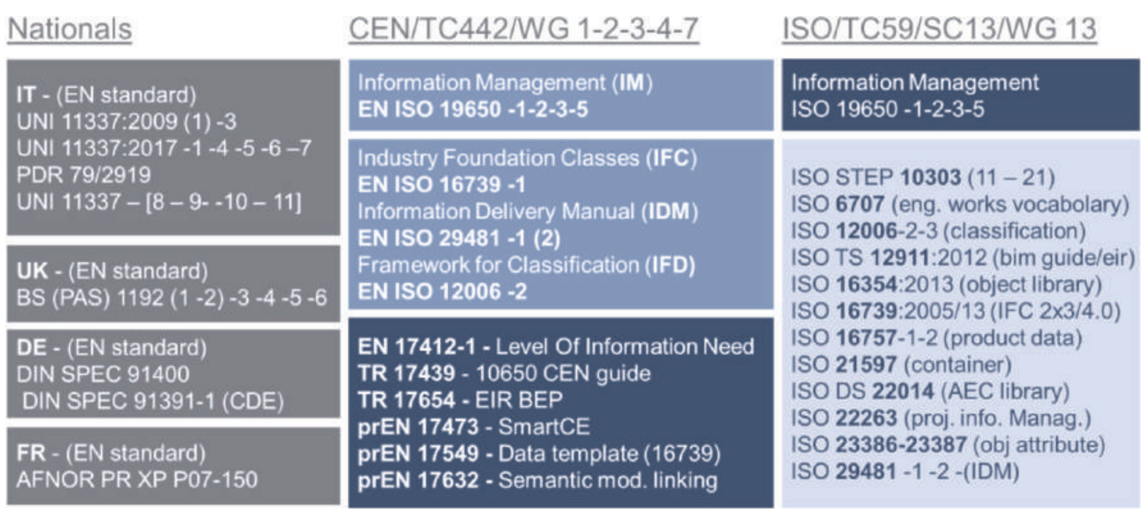

Figure 9.
Map of BIM standards in the world.

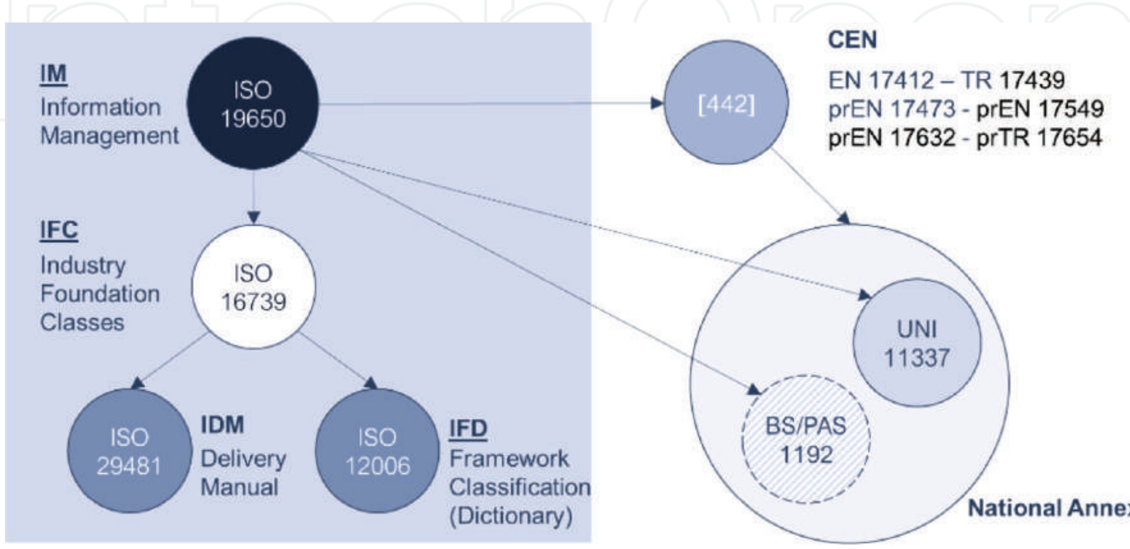

Figure 10.
BIM standard basic relationship.

In particular, while Italy has adopted the path of attaching the entire international package to national standards UNI11337, as a separate package, Great Britain has chosen to withdraw its standards and practices of group 1192 as the fundamental principles of these are assumed in ISO 19650 and insert the remaining parts not transposed at the bottom of the UK national version of ISO 19650 part 2 (in these regulatory annexes). For this reason, it should always be remembered that BS EN ISO 19650-2 (**Figure 11**) has a different conformation from the original version, which does not include annexes.

The Italian decision to keep in force the entire package of UNI 11337 standards is justified by the need to verticalize on the Italian market not only the ISO 19650 but all the most important ISO and CEN standards. In addition to stimulating the writing of other parts or standards necessary not only in the Italian market but also in the international or European scene (**Figure 12**).

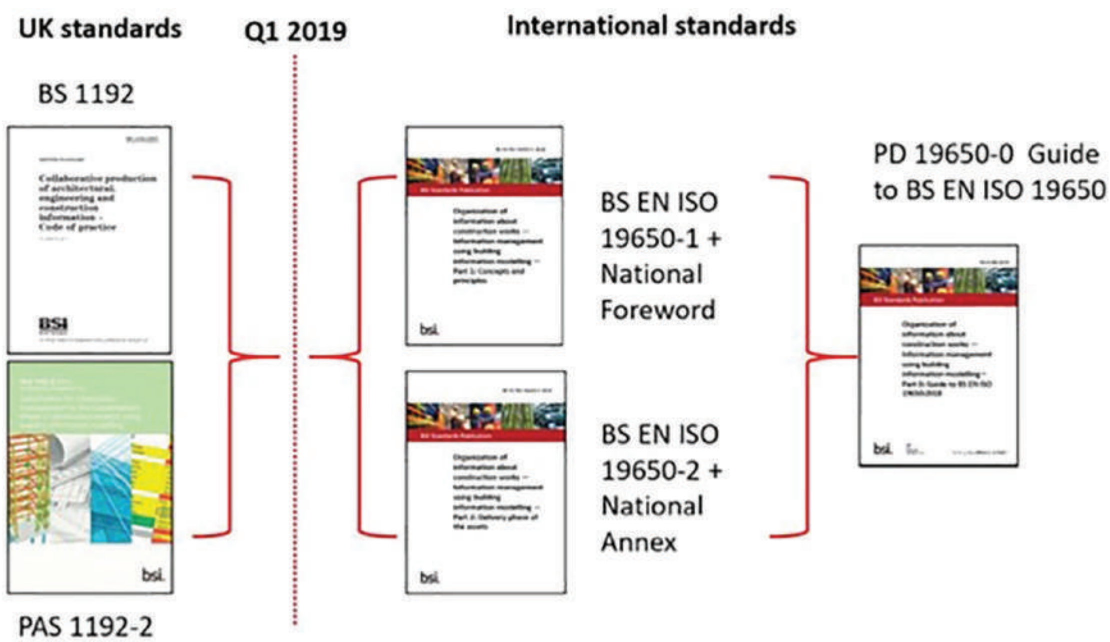

Figure 11.
ISO 19650 vs. BS EN ISO 19650.

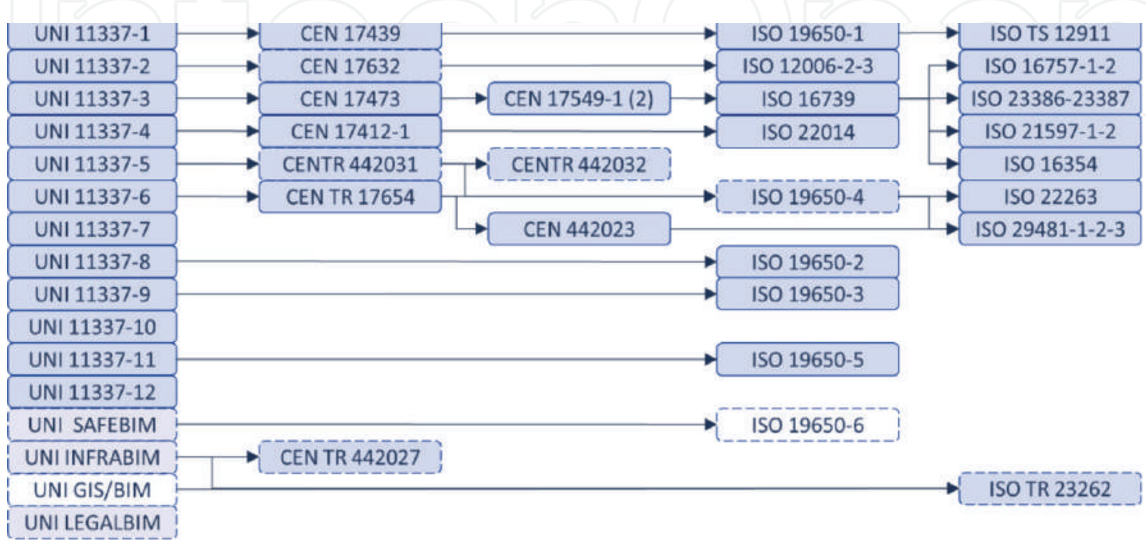

Figure 12.
Standard BIM map relationship.

For example, part 7 of the UNI 11337 (2017) is currently being studied at CEN 442 for the definition of BIM roles and figures at European level, in order to clarify the confusion currently present between BIM professionals, such as between these and those of Project Management (BIM Manager vs. Project Manager; **Figure 13**).

The BIM figures of UNI 11337–7:2017, are:

- **Common data environment manager (CDE manager):** the common data environment manager (CDE manager) is a figure who deals with the data sharing environment implemented by the organization to which it belongs or contractually provided for a specific order by another entity.

- **Manager of digitized processes (BIM manager):** The manager of digitized processes (BIM manager) is a figure that relates mainly to the level of the organization, as regards the digitization of the processes put in place by the same, possibly having the supervision or general coordination of the portfolio of orders in progress. Delegated by the top management of the organization, he defines the BIM instructions and the way in which the digitization process impacts on the organization and on the work tools.

- **Coordinator of the order information flows (BIM coordinator):** The coordinator of the order information flows (BIM coordinator) operates at the level of the individual order, in agreement with the top management of the organization and on the recommendation of the manager of the digitized processes.

- **Advanced operator of management and information modeling (BIM specialist):** The advanced operator of management and information modeling (BIM specialist) usually acts within the individual orders, collaborating in a stable or occasional manner with a specific organization.

An outline of BIM standards cannot fail to end without a quick mention of the IFC (Industry Foundation Classes) standard for open language and OpenBIM. IFC is curated and implemented worldwide by BuildingSmart International and is regulated by the ISO 16739 standard. IFC is both a data model (with definition of standard classes and relationships) and an open schema for generating exchange files in non-proprietary format (**Figure 14**). Non-proprietary formats guarantee the integrity and readability of data over time, which is extremely important, for example, in public procurement.

LEVEL	PM	BIM Management		
	ISO 21500	USA	UK	UNI
Organization	Proposal Manager	Information Manager	//	BIM Manager
Job order	Project Manager	BIM Manager	Information Manager	//
			Task Inform. Manager	
	PM Staff (Communication)	BIM Coordinator	Interface Manager	BIM Coordinator
		BIM Specialist	Information originator	BIM Specialist
		//	//	CDE Manager

Figure 13.
BIM figure and roles.

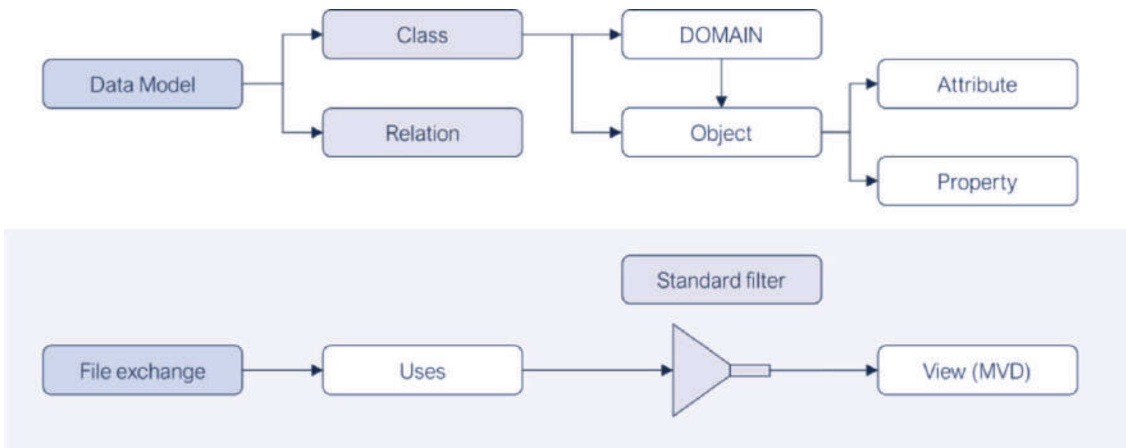

Figure 14.
BuildingSmart ISO 16739–IFC.

4. BIM-based platforms for building process management and research developments towards digital twin

The entire building process must deal with an ineffective information exchange between actors due to a data exchange still mainly based on paper-based transmission system, a variety of classification systems as well as on a use of disparate criteria and practices and a consistent number of stakeholders involved such as architects, engineers, services, and contractors from the design to operation phase. Each stakeholder possesses different set of skills, standards and tools, and thus the communication and the information exchange are characterized by a high level of complexity, as well as the knowledge and process management are often time-consuming [13].

The relevance of BIM in the Architecture, Engineering, Construction, and Operation (AECO) sector is worldwide recognized. Its implementation benefits the construction project reducing and avoiding errors, speeding up the process, improving the communication among the involved actors [14]. It integrates multidisciplinary data to create a digital representation of an asset throughout its life cycle from planning and design to construction and commissioning. BIM-based platforms such as INNOVance and BIMReL help in this direction enhancing data and information exchange along the building lifecycle.

The first BIM-based platform for the construction sector in the Italian context is INNOVance. It aims at collecting, processing and sharing data and supporting involved stakeholders by creating a unique code for the products, services, activities and resources used, a standardized datasheet and a web portal that allows users to use the information at every stage of construction [15].

BIMReL is an interoperable open-source BIM library for construction products that allows to associate all the technical information of the products to the BIM objects present in it. It supports the management of information throughout the entire life cycle of a building, based on the definition of information and technological needs. The added value lies in providing standardized datasheets conforming to UNI 11337–3 [13].

With the need to monitor and control assets all through their lifecycle and with IoT introduction and Artificial Intelligence (AI) diffusion, the birth and the growing affirmation of the Digital Twin has become more and more important [16].

The DT can be defined as “a realistic digital representation of assets, processes, or systems in the built or natural environment” [17] where data are synchronized from the physical to the digital [18], therefore it is seen as a technology that enables the physical and virtual space to communicate [19].

DT presents a new approach in the AEC sector: it is not only a building visual representation, but the latter can be enhanced with real-time data to diagnose the asset state and with the integration of statistic, probabilistic or AI models to allow predictive skills [20–22]. DT can be used for the following applications: real time monitoring, simulation, diagnosis, and performance prediction [16, 23–25].

BIM and DT are still mainly applied on new buildings, even though a growing consideration for the renovation requires their use and advantages.

In fact, since AECO sector and especially buildings are the cause of serious issues to the environment such as high level of energy consumption and CO_2 emissions, in recent times more attention is being paid to renovation phase [26–28].

Hence, the practice of renovating and re-using buildings needs to be stimulated. Nevertheless, improving the quality of renovations, reducing the time of building construction phase, minimizing the impact on tenants, and guaranteeing that cost/benefits targets are accomplished are typical barriers that need to be faced and overcome [29, 30].

Digitalisation becomes an instrument towards the construction sector to enhance the renovation process. Digital solutions can be adopted to manage information and data in a more ordered structure, with a consequent reduction of time and building waste and, an increased productivity and performance [31].

4.1 BIM in renovation context: The BIM4EEB project

To improve the building process efficiency towards the main renovation barriers, Europe is responsible for various initiatives for the promotion and dissemination of digital tools through policies (e.g., 'Renovation Wave' [28], funding (e.g., InvestEU [27]) and regulations (e.g., EU-level regulatory framework for the creation of the Single Market for Data for better data quality and data management [31]).

Also, it is responsible for several research projects aiming at exploiting digitals tools to make the renovation process more efficient and improve the performance of the building with attention to the sustainability aspect. The waste of time and the consequent waste of money caused by inefficiency is limited and reduced with the digitalisation that results in using resources more efficiently and responsibly.

In this respect, regarding technologies such as BIM and DT aiming at improving the building information management and communication there are different H2020 projects. Among these projects aimed at developing BIM-based tools for an efficient retrofitting [32], BIM4EEB can be mentioned.

The ongoing European project BIM4EEB, namely BIM based fast toolkit for Efficient rEnovation of residential Buildings, has the main goal to develop a BIM-based toolkit for improving renovation of existing residential buildings. The research activity developed within the project involves the use of IoT in residential buildings, the development of a platform for the share of information among the involved stakeholders and different kind of BIM-based tools implemented.

The BIM-based toolkit has been developed for different areas of renovation, such as: fast mapping of existing buildings, building information management, energy simulation of renovation scenarios, fast-track construction management, etc.

BIM-based tools are connected and can be accessed by the BIM management system (BIMMS), a platform where all the activities of the building process can be managed and the interested parties can exchange data from different sources.

BIM4EEB toolkit is characterized by the following tools, as showed in **Figure 15**:

- BIM Management System
- BIMplanner is a fast-tracking tool for renovation operations
- BIMeaser is a BIM assisted Energy refurbishment assessment tool
- AUTERAS and BIMcpd are tools to support decision-making and energy refurbishment assessment
- BIM4Occupants is a human machine interface tool
- Fast mapping toolkit is a tool for reducing the survey time

As part of the project, testing and validation of the developed toolkit are planned at three demonstration sites identified in existing residential buildings and located in different environmental contexts: Mediterranean (Italy), continental climate (Poland) and northern countries (Finland).

A social housing building owned by ALER has been selected for the Italian demonstration site and it is located in Monza (Lombardy). The building, dating back to

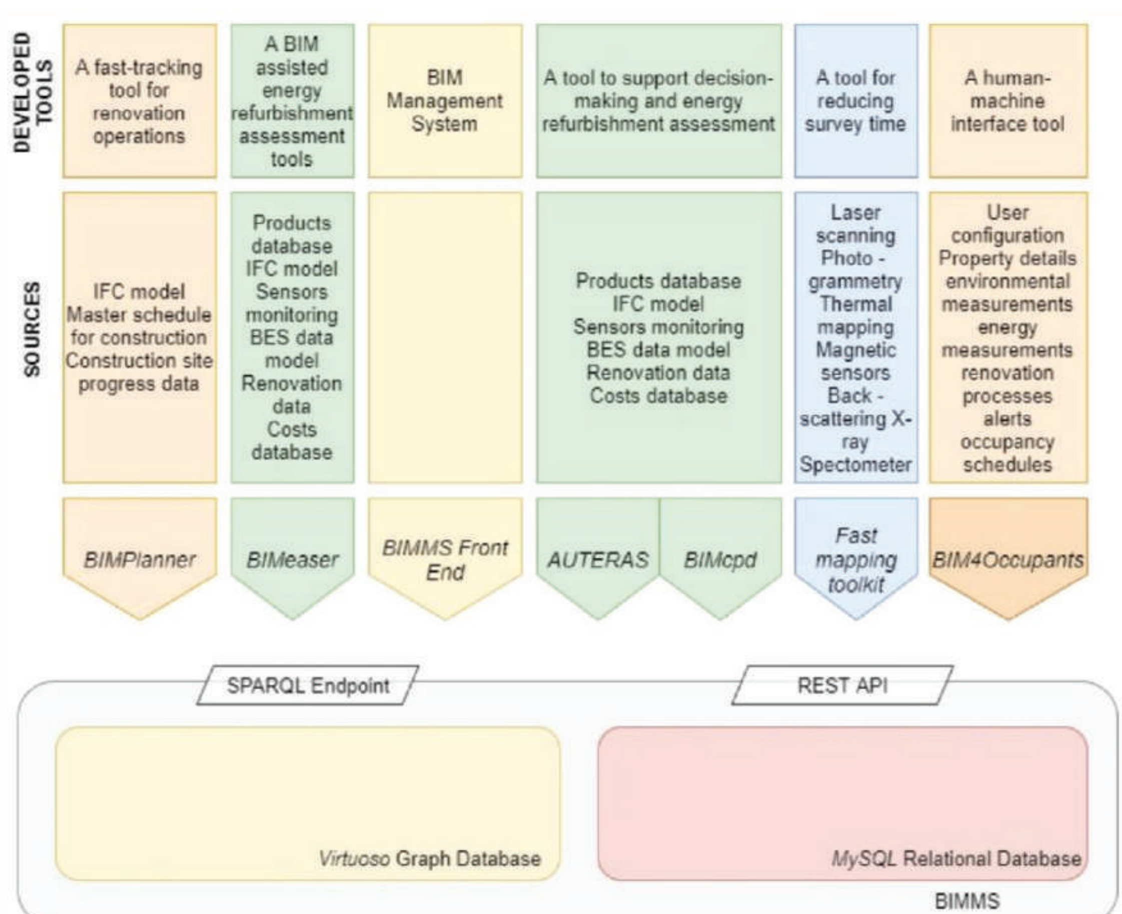

Figure 15.
BIM4EEB toolkit Daniotti et al. [33].

the 60s, presented a significant need for renovation measures. Hence, it has been subjected to two main renovation interventions such as the replacement of windows and the application of external thermal insulation.

The Poland demonstration site is placed in Chorzow, a town in the southern Poland, and it was built at the beginning of 1900.

The Finnish demonstration site instead is located in the city of Tampere.

The expected results of the project are the following:

- a time reduction by at least 20% compared to traditional methods,
- a cost reduction by 15%,
- a net primary energy use reduction by 10% for a residential apartment,
- working days reduction from 3 to 1.5 required for a deep energy audit.

The project, lasting 3 years, is now at its conclusion. The last part of the project consists in the demonstration of the BIM-toolkit feasibility to the previously mentioned case studies. In this regard, the achievement of the project is assessed by using Key Performance Indicators (KPIs) such as Renovation Process KPIs, Energy Performance KPIs, Human Comfort KPIs, Economic Performance KPIs, Social Related KPIs, Environmental and Safety KPIs evaluating objectives and stakeholders' requirements fulfillment.

4.2 Building information modeling adapted to efficient renovation: H2020 projects

Belonging to the topic "Building information modelling adapted to efficient renovation", in addition to BIM4EEB project, there are other Horizon 2020 projects: BIM4REN (BIM-Based Tools for Fast & Efficient Renovation) [34], BIM-SPEED (Harmonized Building Information Speedway for Energy-Efficient Renovation) [35], BIMERR (BIM-based holistic tools for Energy- driven Renovation of existing Residences) [36], ENCORE (ENergy Aware BIM Cloud Platform in a COst-Effective Building REnovation Context) [37]. Also SPHERE project (Service Platform to Host and SharE REsidential Data) [38], part of "ICT enabled, sustainable and affordable residential building construction, design to end of life" topic, is considered among BIM4EEB sister projects (**Table 1**).

All these projects have in common the study and development of solutions for a more efficient building renovation by using BIM. The main objectives are reduction of renovation working time of at least 15–20% compared to current practices; acceleration of the market uptake across Europe, by speeding-up industrial exploitation, among constructing/renovations companies with a target of 50% of their renovation business based on BIM; creation of best practice examples for the construction retrofitting sector with benefits for the operators and associated stakeholders.

If on the one hand BIM4EEB, BIM4REN, BIM-SPEED, BIMERR and ENCORE are all characterized by the development of BIM tools, on the other hand SPHERE project aims at improving the energy design, construction, performance, and management of building with the development of a BIM-based Digital Twin platform based on Platform as a Service (PaaS) approaching the concept of Digital Twin.

Programme	Topic	Project
Technologies enabling energy-efficient systems and energy-efficient buildings with a low environmental impact	LC-EEB-02-2018 Building information modeling adapted to efficient renovation (European Commission, Building information modeling adapted to efficient renovation (RIA), 2018)	BIM4EEB
		BIM4REN
		BIM-SPEED
		BIMERR
		ENCORE
	LC-EEB-06-2018-2020 ICT enabled, sustainable and affordable residential building construction, design to end of life	SPHERE

Table 1.
EU projects promoting digitalization in the built environment.

SPHERE is a Horizon2020 project that has developed a Digital twin environment based on Platform as a Service. The project aims at enhancing the performance and management of buildings, reducing construction costs and the environmental impact, starting from the design and construction phase but including also manufacturing and operational phase. It enables the integration of large-scale data, information and knowledge, and it facilitates decision making and the collaboration among involved users. SPHERE exploits the concept of Digital Twin for predictive and interrogative purposes. For the first the Digital Twin will be used for the prediction of future performance of the building, for the latter the Digital Twin will be investigated to get information about the current and past status [39].

5. Discussion and conclusions

This chapter proposes an overview of the main drivers that are guiding the digital revolution in the construction sector. The intrinsic changes that the entire construction value chain is experiencing are generating and will generate important impacts not only on construction but on the entire society and the people that will live in buildings and use infrastructure. Nowadays, the Digital Twin topic represents a key element of both research and practice innovation with enormous potential impacts considering the possibility to continuous monitoring buildings and infrastructure and the integration of controlling systems. This evolution will produce impacts on several scales, from the practical development of assets with a better quality up to the operation and maintenance with the possibility of creating data driven decision systems.

To provide a comprehensive overview on this area three main points are reported in the chapter. First, the movement from CAD to BIM is clarified to highlight the main key points that are driving the creation of digital simulation (information models) of buildings and infrastructures. Then a detailed description of the standardization context is provided. To clarify how standards are shaping the BIM context and will impact on its integration at the different levels (international, European, national) the standardization principles are presented and linked to the evolution that the standards have experienced in the last years shaping the BIM panorama. Finally, the so called "platformization" concept is proposed with the presentation of some key national (considering Italy) and European projects that have been developed or are under development and will shape the creation of the future platforms for the construction sector (DigiPLACE, BIM4EEB, INNOVance, BIMRel, Sister projects, SPHERE).

Platforms and standards represent two main axes of the digital transformation of the construction sector and are strictly intersected providing the backbone to enable the future of the digital constructions. Nevertheless, platform development is still an open research and industry topic that needs to be clarified and disseminate in the construction sectors considering the different levels that characterize it (European, national, regional, etc.). This dimension should be considering according to the standardization works that needs to be distributed in these different levels to guarantee, on the one hand a sufficient generalization for common topics, and on the other hand detailed focal points integrated in the national/local context to guarantee a practical applicability from the interested stakeholders. Researchers and industry stakeholders can start from the results here presented to have a clear picture of the standardization and platform development driver. Future research should work to integrate other trends and key topics in this picture to create a shared map of the drivers for a digital evolution of the construction sector.

Acknowledgements

The work detailed in this manuscript was carried out within the BIM4EEB project. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 820660.

Author details

Bruno Daniotti, Alberto Pavan, Cecilia Bolognesi, Claudio Mirarchi*
and Martina Signorini
ABC Department, Politecnico di Milano, Milan, Italy

*Address all correspondence to: claudio.mirarchi@polimi.it

References

[1] Scheer D. The Death of Drawing. Architecture in the Age of Simulation. 1st ed. New York: Imprint Routledge; 2014. p. 258. DOI: 10.4324/9781315813950

[2] Bernstein PG, Pittman JH. Barriers to the adoption of building information modeling in the building industry. In: Autodesk Building Solutions Whitepaper. San Rafael, CA: Autodesk Inc.; 2005

[3] Carmona J, Irwin K. BIM: Who, what, how and why. Building Operating Management. 2009. Available from: http://www.facilitiesnet.com/software/article/BIM-Who-What-How-and-Why–7546 [Accessed: August 21, 2009]

[4] Azhar S. Building information Modeling (BIM): Trends, benefits, risks and challenges for the AEC. Leadership and Management in Engineering. 2011;**11**(3):241-252. DOI: 10.1061/(ASCE)LM.1943-5630.0000127

[5] Pavan A, Giani M, Mirarchi C. BIM: metodi e strumenti Progettare, costruire e gestire nell'era digitale. 1st ed. Milan: Tecniche Nuove; 2017. p. 328

[6] Osello A. Il futuro del disegno con il BIM per ingegneri e architetti. 1st ed. Palermo: Dario Falccovio Editore; 2012. p. 324

[7] Dimyadi P, Parsanezhad J. Effective facility management and operations via a BIM-based integrated information system. In: CIB Facility Management Conference: CIB W070, W111 & W118: 21-23 May 2014. Copenhagen, Denmark; 2014. DOI: 10.13140/2122989764

[8] Ashworth S, Carbonari G, Stravoravdis S. How Facility Management Can Use Buidling Information Modelling (BIM) to Improve the Decision Making Process. Technische Universität Wien Published; 2015. pp. 55-69. DOI: 10.34749/JFM20152120

[9] Pavan A, Rota A, Mirarchi C, Romano A. I capitolati informativi con metodologia BIM. 1st ed. Milan: Tecniche Nuove; 2021. p. 232

[10] Charef R, Alaka H, Emmitt S. Beyond the third dimension of BIM: A systematic review of literature and assessment of professional views. Journal of Building Engineering. 2018;**19**:242-257. DOI: 10.1016/j.jobe.2018.04.028

[11] Mirarchi C, Spagnolo SL, Daniotti B, Pavan A. Structuring general information specifications for contracts in accordance with the UNI 11337:2017 standard. Digital Transformation of the Design, Construction and Management Processes of the Built Environment. 2019:103-112. DOI: 10.1007/9783030335700-0_10

[12] Borin P, Zanchetta C. IFC–Processi e modelli digitali openBIM per l'ambiente costruito. 1nd ed. Vol. 194. Palermo: Milan: Maggioli Editore; 2020

[13] Lupica Spagnolo S, Amosso G, Pavan A, Daniotti B. In: Daniotti B, Gianinetto M, Della Torre S, editors. BIMReL: The Interoperable BIM Library for Construction Products Data Sharing, in Digital Transformation of the Design, Construction and Management Processes of the Built Environment. Cham: Springer; 2020. pp. 37-47

[14] Build up, Digitalization in the construction industry. 2019. Available from: https://www.buildup.eu/en/news/overview-digitalisation-construction-industry

[15] Lupica Spagnolo S. Information integration for asset and maintenance

management. In: Integrating Information in Built Environments. From Concept to Practice. Routledge: Taylor& Francis Group; 2017. pp. 133-149

[16] Boje C, Guerriero A, Kubicki S, Rezgui Y. Towards a semantic construction digital twin: Directions for future research. Automation in Construction. 2020;**114**:103179

[17] Centre of Digital Built Britain. The Gemini Principles. 2018

[18] Batty M. Digital twins. Environment and Planning B: Urban Analytics and City Science. 2018;**45**:817-820

[19] El Jazzar M, Piskernik M, Nassereddine H. Digital twin in construction: An empirical analysis. In: EG-ICE 2020 Workshop on Intelligent Computing in Engineering, Proceedings. 2020. pp. 501-510

[20] Camposano JC, Smolander K, Ruippo T. Seven metaphors to understand digital twins of built assets. IEEE Access. 2021;**9**:27167-27181

[21] Mathupriya S, Saira Banu S, Sridhar S, Arthi B. Digital twin technology on IoT, industries & other smart environments: A survey. Materials Today: Proceedings. In press

[22] Sacks R, Brilakis I, Pikas E, Xie HS, Girolami M. Construction with digital twin information systems. Data-Centric Engineering. 2020;**1**:e14

[23] Errandonea I, Beltrán S, Arrizabalaga S. Digital twin for maintenance: A literature review. Computers in Industry. 2020;**123**:103316

[24] Fuller A, Fan Z, Day C, Barlow C. Digital twin: Enabling technologies, challenges and open research. IEEE Access. 2020;**8**:108952-108971

[25] Jafari MA, Zaidan E, Ghofrani A, Mahani K, Farzan F. Improving building energy footprint and asset performance using digital twin technology. IFAC-PapersOnLine. 2020;**53**(3):386-391

[26] European Commission, Renovation Wave: Doubling the Renovation Rate to Cut Emissions, Boost Recovery and Reduce Energy Poverty, 2020.

[27] BPIE. The European renovation wave: From words to action. 2020

[28] European Commission, A Renovation Wave for Europe–greening our buildings, creating jobs, improving lives. 2020

[29] IET and NTU. Scaling Up Retrofit 2050. 2018

[30] S. D'Oca, A. Ferrante, C. Ferrer, R. Pernetti, A. Gralka, R. Sebastian, P. o. t. Veld, Technical, Financial, and Social Barriers and Challenges in Deep Building Renovation: Integration of Lessons Learned from the H2020 Cluster Projects. Buildings, MDPI, Switzerland; 2018. pp. 1-25

[31] ECSO, Digitalisation in the Construction Sector. 2021

[32] European Commission. Building information modelling adapted to efficient renovation (RIA). 2018

[33] Daniotti B, Bolognesi CM, Spagnolo SL, Pavan A, Signorini M, Ciuffreda S, et al. An Interoperable BIM-Based Toolkit for Efficient Renovation in Buildings. Buildings, MDPI, Switzerland; 2021. pp. 1-16

[34] Building Information Modelling based tools & technologies for fast and efficient RENovation of residential buildings|BIM4REN Project. 2018. 1-9

[35] Harmonised Building Information Speedway for Energy-Efficient

Renovation|BIM-SPEED Project. 2018. 1-8

[36] BIM-based holistic tools for Energy driven Renovation of existing Residences|BIMERR

[37] ENergy aware BIM Cloud Platform in a COst-effective Building REnovation Context|ENCORE Project. 2019. 1-6

[38] Service Platform to Host and SharE REsidential data|SPHERE Project. 2018. 1-9

[39] Alonso R, Borras M, Koppelaar RHEM, Lodigiani A, Loscos E, Yöntem E. SPHERE: BIM digital twin platform. Proceedings. 2019;**20**:9

Chapter

New Approaches to Innovation Management in the Context of Digital Transformation

Zhanna Mingaleva and Vladimir Postnikov

Abstract

The previous decade is rightfully called the era of digital transformation. The purpose of the study is to assess the impact of global trends on innovation activity, as well as to identify new factors influencing innovation models. A conceptual approach to the analysis of the evolution of innovation models based on the transformation of information and communication technologies for innovation based on the bibliographic analysis and integration of existing concepts and theories of innovation, digitalization and sustainable development is created. With the help of the factor method, the analysis of the main innovation models is carried out and a promising innovation model is determined. It is found out that digital technologies are the technological basis of the modern model of the innovation ecosystem. The result of the research is the author's classification of modern factors of innovation activity that determine the directions and types of implemented innovations, as well as the role of innovation in society. The peculiarity of the study is that it has a conceptual nature, does not use the collection of empirical data, but is based on the integration of previously developed concepts and theories.

Keywords: digital transformation, model of closed innovations, model of open innovations, the innovation ecosystem model, innovation management

1. Introduction

From the end of the twentieth century, digital technologies are actively penetrating into all spheres of society. Scientists and researchers started talking about the transition to a new model of functioning based on digital technologies - Society 5.0 and Industry 4.0 [1–5]. At the same time, the influence of digital transformation is felt by many countries, as well as all sectors and industries of the economy and types of enterprises.

The impact of digital technologies has also been experienced by the key process of technological business development - the innovation process [6–8]. The use of modern supercomputers, robotic complexes, VR technologies, etc. in science, research, and production has led to significant changes in the system of organization of innovation activities. Digital technologies accelerate the flow of information, reduce the cost of obtaining and exchanging information, and provide a basis for applying the open innovation model. And in turn, innovations also affect the digital economy [9].

For the sustainable implementation of innovations, and their successful and effective participation in global transformation processes, it is necessary to take into account the influence of the main trends that take place in the economy and society. Including the widespread dissemination of the concept of sustainable development. The first attempts to analyze the relationship between industry 4.0, society 5.0, and sustainable development goals are made in the modern scientific literature [10–14].

However, the rapid development of digital technologies comes into conflict with the applied models and methods of innovation management. Moreover, a contradiction between the level of development of digital infrastructure and the effectiveness of innovation management methods already exists in a number of countries and regions. This requires a revision of a number of conceptual approaches.

The presented work is aimed at reducing the gap in the theoretical literature on the analysis of the evolution of innovation models, identifying modern factors of innovation activity, identifying promising areas and types of innovation, and assessing the complex role of innovation in the economy and society.

The structure of the work is formed in accordance with the goal and the objectives of the research.

Section 2 contains a bibliographic description of the available literature, concepts, and theories on the relationship between innovation models and the information and digital technological basis for innovation, as well as a list of the main factors influencing innovation. Section 3 contains a description of the methodological approaches to the research and the basic limitations of the study. The main results of the study are reflected in Section 4. This section also contains some controversial issues and research results that require further discussion and empirical verification. In conclusion, the main conclusions and further directions of research are presented.

The discussion of the hypothesis will make it possible to identify and evaluate new factors of innovation activity in the conditions of digitalization of the economy and create a theoretical basis for the formation of a new approach to innovation management that corresponds (adequate) to modern trends in the development of society.

2. Theoretical

2.1 Models of innovation in innovation theories

Schumpeter is rightfully considered to be the founder of innovation theory [15]. The mechanisms of creating new knowledge and innovations always influenced human life, especially during critical moments of economic development [16–19]. At the same time, innovations and the innovation process have the function of ensuring the competitiveness of the company by creating new products, new technologies for manufacturing new products, or new methods of organizing activities. Success in the competitive struggle is ensured by legal protection of innovations, which gave an advantage over other companies by providing a monopoly right to produce a specific product or possess a specific production technology, organization of activities, provision of services, etc.

At the same time, strict legal regulation of monopoly rights to innovation (discovery, new product, new technology, etc.) was the basis for a special approach to the organization of innovation activity, called the concept of "closed" innovation. We will not dwell on the characteristics of the closed innovation model in detail. But we would like to pay attention to only 2 points that are directly related to the topic of this study.

The first concerns the main characteristics and factors of innovation. On the basis of previous studies, the following success factors for innovation activity can be identified in the model of "closed" innovations [20–29]. They are:

- internal R&D and technological capabilities (investment in research and development, acquisition of capital assets, etc.),
- close cooperation with universities, research centers,
- availability of strong public funding,
- specific industry and production characteristics of the company, including such as energy intensity, material intensity, human capital, the absorption capacity of the industry market to adopt a new product, the size of the company, etc.,
- technical norms and standards defining the characteristics of a new product or new technology,
- the level and strength of competition in international markets,
- cooperation with other private firms (private co-financing of individual research projects)
- access to external knowledge (primarily in terms of checking innovation for patent protection), etc.

The main results of various studies show that internal R&D, acquisition of fixed assets, and technical regulations, are the main drivers of "closed" innovation. Large firms were more successful in introducing various innovations, including radical ones.

The second is the main information technology basis of innovation, which made it possible to achieve success. Computers, including supercomputers, were the information-technological and technical basis for the implementation of innovations within the framework of this model, the presence of which ensured advantage (winning) in research activities and competition [30–34].

However, it was the development of the information technology and technical basis for innovation that simultaneously became the reason for changing the innovation model, the basis for the transition to the open innovation model. Changes in the level of implementation of information and communication technologies in various processes of society's life became the key points of transition from one model to another. Digital transformation has had a big impact on innovation.

The transition from the closed innovation model to the open innovation model is provoked by the massive introduction of information and computer technologies into the communication environment of society and business management. Computers became not only a powerful means of processing large amounts of data but also a means of everyday communication for ordinary people, as well as a tool for promoting products in markets [35–38]. At the same time, strict legal support of monopoly rights to innovation was partially preserved in the open innovation model but led to certain transformations in the system of innovation diffusion and transfer.

As for the main factors for the success of innovation in the model of "open" innovations, the factors listed above are added to such factors as the active development of network interaction between companies and the regional community, other subjects of society, the emergence and accounting for side effects from other innovations, taking into account external effects from own innovations, more active consideration of environmental norms and standards, the emergence of requirements for social responsibility, ethics and morality [39–42]. Also, in the model of "open" innovation, the role and importance of the factor of access to external knowledge have significantly increased, (external knowledge became the main source of information for scientific and research activities), as well as the role of interaction with other companies, including private ones [43].

The next major step in changing the applied model of organizing innovation activity is the emergence of an innovation ecosystem and a model that describes it. The transition to the innovation ecosystem model is based on the strengthening of the processes of digitalization of society and the economy, which began with the mass digitization of various elements, data, and processes [44–50]. As a result, such characteristics of the information and communication environment as the openness of information, the speed and ability to transfer information in the external environment, the social effect, and significance of information have become the most important factors in the management of innovation activity.

Thus, there is a clear and direct connection between the information and digital technological basis for the implementation of innovation activities and the innovation model used by companies. Digital technologies become the technological basis of the modern model of the innovation ecosystem.

However, the emergence and formation of a modern innovation management system, built on the basis of the innovation ecosystem model, is also under the influence of another global trend - the increasing application (in society and economy) of the requirements of sustainable development and climate safety of human activities.

2.2 Sustainable development as a global factor in the transformation of innovation models

The second global trend in the development of modern society, which is influenced by the transformation of the innovation model, is the concept of sustainable development and climate security of society [51–53]. The widespread adoption of the provisions of this concept and its implementation in the practice of state regulation and corporate governance changed the role and importance of companies in modern business and economy and led to the formation of an environmental assessment of innovations [54–56]. To assess the socio-environmental consequences of business activities, more and more diverse social and environmental indicators are used, and the quality of innovation activity is assessed through the statistics of "green" innovations of all types and through the concept of sustainable innovation [57–61]. Moreover, in recent years, the provisions of the concept and ESG regulation and the assessment of ESG factors in the framework of business processes and innovation activities have been widely applied.

Without dwelling in detail on the characteristics of each of the types of innovations used today in the practical activities of various companies and organizations [62], it is important to highlight the changes in emphasis on the characteristics of innovations implemented in the innovation ecosystem model. These are, first of all, environmental or "green" innovations that ensure the achievement of sustainable development goals, elimination of climate consequences, and ensuring environmental safety [6–67]. In turn, the development of green innovations involves the formation of a new system of innovation management. The main factors of the innovation model are also changing. In the system of "green" innovations and in the innovation ecosystem model, new factors of influence appeared, such as the applied business model and value proposition as part of the company's innovation policy, consideration and use of ESG factors in innovation activities, and the application of ESG regulation, more comprehensive consideration of the long-term consequences of innovation for nature and society, the focus of innovation on meeting environmental norms and standards, social responsibility, ethics and morality in the framework of innovation [68–79]. The importance of such factors as the openness of information, the speed and possibilities of information transfer in the external environment, the social effect, and the significance of information, which appeared in the open innovation model, increased also.

So, an analysis of global trends occurring in the society of the XXI century showed that in modern conditions digitalization and sustainability became the two inextricably linked trends and fundamental factors that have a significant impact on innovation. It is these two trends that underlie the formation and development of the modern model of innovation.

In this regard, an important theoretical and practical question that arises is the problem of identifying and assessing the significance of new factors influencing the implementation of innovation activities within the framework of a new innovation model that corresponds (adequately) to modern trends in the development of society.

Within the framework of this scientific problem, the following hypothesis was formulated.

Hypothesis 1: *digitalization of the economy and the implementation of sustainable development goals make changes to the innovation management model, leading to the emergence of new factors influencing innovation.*

The results of the study will expand scientific knowledge about the factors and models of innovation in modern conditions, supplementing the theoretical base with an analysis of the evolutionary development of innovation models. Also, the results of the study will add literature on the impact of digitalization on specific processes in the economy and society - innovation and on the mutual influence of digitalization processes, sustainable development, and innovation.

3. Methodological note

The presented work is conceptual in nature and is based on the integration of concepts and theories previously developed by world science [80–85]. The study is based on a thorough review of the literature on the evolution of innovation models, on other conceptual ideas in the field of the development of innovation theory, on the integration of various points of view and analysis, which were combined to develop a conceptual framework and build an analytical model [3, 86–89].

The bibliographic base of the study is Web of Science, Scopus, Springer, and Google Scholar. The search was conducted on the following keywords: the AND model AND of “closed” innovations; innovation AND eco-system; the “open” innovation AND model; digital AND transformation AND of AND innovation AND activity; innovations AND in AND industry AND 4.0.; sustainable AND innovation; green AND innovation; sustainable innovation AND digital platforms.

The selection was carried out according to the following criteria: TITLE-ABS-KEY. An extended set of criteria was used, since checking only by the TITLE criterion did not give the required result in a number of cases. For example, checking by the search criteria “TITLE-ABS-KEY (digital AND transformation AND of AND innovation AND activity) AND PUBYEAR > 2009” in the Scopus system returned 470 articles, while checking only by TITLE (digital AND transformation AND of AND innovation AND activity) AND PUBYEAR >2009″ published only 1 article.

Similarly, checking with the search criteria “TITLE-ABS-KEY (innovations AND in AND industry AND 4.0) AND PUBYEAR > 2009” in the Scopus system returned 470 articles, while checking only with TITLE (innovations AND in AND industry AND 4.0) AND PUBYEAR >2009″ showed no publications with that title at all.

The literature review has a clear goal - to identify the main changes taking place in the implementation of innovative activities under the influence of digitalization processes and the implementation of sustainable development goals and to identify new factors influencing innovative activities in modern conditions.

For this purpose, scientific articles and books on the following topics were collected and analyzed: (1) the model of “closed” innovations; (2) the “open” innovation model; (3) the innovation ecosystem; (4) sustainable innovation; (5) green innovation; (6) factors of innovative activity; (7) digitalization and digital transformation of innovation activity; (8) innovations in Industry 4.0.

In total, 1659 different publications for the period 2010–2021 and January–February 2022 were studied.

Bibliographic analysis made it possible to develop a factorial model for the evolution of innovative systems based on their digital transformation. This work is strictly conceptual and does not involve the collection of empirical data. Future empirical studies carried out will make it possible to verify the reliability and accuracy of the proposed theoretical model. Also, in the process of future verification of the proposed theoretical model, it is possible to determine the quantitative values of the strength of influence of individual factors and their groups.

At the same time, in order to preserve the freedom of choice of scientific papers used for analysis, it was decided not to conduct a systematic review of the literature, similar to reviews in other conceptual studies, for example, describing Digital Platform Ecosystems for Sustainable Innovation [90–92].

4. Research results

4.1 Factor model of the innovation ecosystem

Currently, in the theory of innovation, there are three integrated models which characterize the organization of the innovation process in different information and communication basis and principles. Such as the *closed innovation model (CIM); open innovation model (OIM) and the innovation ecosystem model (IEM)*.

Over the past two decades, these models have been affected by two global trends: digitalization and the expansion of the scope of the sustainable development goals. The influence of these two global trends on the peculiarities of innovation activity at the present stage of development is manifested in turn through a set of factors underlying innovation management and the applied model of innovation activity [93–96]. **Table 1** demonstrates a list of factors affecting innovation activity in general, divided into 3 main innovation models: the closed innovation model (CIM); the open innovation model (OIM) and the innovation ecosystem model (IEM).

The list of factors and the author's assessment of their significance is compiled using the method of bibliographic analysis of scientific literature devoted to the study of factors of construction and implementation of innovative activities, as well as the method of comparative analysis of innovative models of various types [7, 97–102]. Modern factors (factors of the innovation ecosystem) are identified by the authors independently in the process of studying the issues of the formation of the digital economy and the creation of national innovation ecosystems [34, 103–106]. Also, to identify these factors, the results and conclusions of scientific research on the transformation of the open innovation model in the conditions of creating Society 5.0 were used [3, 107–109].

The factors are divided into 4 groups depending on their participation in innovation activities and depending on environmental conditions.

The order of factors in groups is given based on their importance in the closed innovation model - the list of factors is built as their importance decreases in this model. This order is chosen from the point of view of the historical context of the analysis since it is the first historical model of closed innovations and the analysis of the order of model construction and their transformation begins from the consideration of these factors. At the same time, it allows you to trace the change in the importance of particular factors in social development, as well as the transition of society to the new operating model based on digital technology – Society 5.0 and Industry 4.0.

Not going into detail on the features of the transformation of the model of closed innovation to the open innovation model, let us pay attention to the creation and development of innovation ecosystems, which mostly reflects the trends, requirements, and features of digital transformation.

Table 1 makes it possible to come to the conclusion that in the innovation ecosystem model, the influence and impact on the effectiveness of innovation activities are increased from all factors except the factor of internal R&D. However, this decrease is rather nominal and reflects not the absolute decrease in the value of the factor, but its relative importance compared to other factors, especially new ones.

Moreover, several factors have appeared in the innovation ecosystem model that is not typical of traditional models of closed and open innovations. The emergence of these factors was caused by the influence of digital technologies and modern computer and information and communication technologies, which radically changed approaches to understanding the fundamentals of the functioning of society, business, and innovation.

Further, we would like to focus in more detail on the characteristics of each specific factor in order to understand their role in the process of digital transformation of innovation activity.

Analyzing the directions and power of changes in the role and influence of factors, first of all, it is necessary to assess the impact of such a group of factors as "*Innovative resources*". These traditionally include investments in research and development (R&D), cooperation with public and private organizations, acquisition of capital assets and external knowledge. We also include such factors as side effects from other

Influencing factors	CIM	OIM	IEM
Innovation Resources			
Internal R&D and technological capabilities (investment in research and development, acquisition of capital assets)	+++	++	++
Cooperation with government organizations (state funding)	+++	+++	++
Cooperation with private organizations (private co-financing)	++	+++	+++
Access to external knowledge	+	++	+++
Network interaction (with universities, scientific centers, other subjects of society, etc.)	+	++	+++
Side effects from other innovations	—	++	+++
Industrial and market conditions			
Specific characteristics of the firm, including such as energy intensity, material intensity, human capital, absorptive capacity, industry affiliation, firm size, etc.	+++	++	++
Technical norms and standards	++	+++	+++
The level and strength of competition in international markets	++	+++	++
Environmental regulations and standards	+	++	+++
Applicable business model and value proposition	—	—	+++
ESG factors and ESG regulation	—	—	+++
Social and public factors			
Presence of external effects from own innovations	—	++	+++
Social responsibility, ethics, and morality	—	++	+++
Long-term consequences of innovation	—	+	++
Information and communication environment			
The speed and possibilities of information transfer in the external environment	—	+	+++
Openness of information	—	+	+++
Social effect and significance of information	—	+	+++

Source: compiled by the authors.Abbreviations: CIM - closed innovation model; OIM - open innovation model; IEM - the innovation ecosystem model.

Table 1.
The main factors of innovation activity in different innovation models.

innovations and networking in this group, since a side effect from another innovation can become a source (resource) of basic knowledge and ideas for new developments, and networking is the basis and a powerful resource for search and innovation activities. At the same time, it should be noted that the last two factors appeared only at the stage of the open innovation model and were developed and recognized in the innovation ecosystem model.

The first of these factors is a complex and multi-element factor of the level of development and scale of the company's internal R&D and its technological capabilities [110–115]. This complex factor is described by such indicators as investments in research and development (their volume, structure, sources), acquisition volumes, acquisition of capital assets, and qualitative indicators of R&D directions and structures. In the conditions of the closed innovation model, this factor was key to the effectiveness of the company's innovation activity. However, in the models of open innovation and innovation ecosystem, its role is decreasing, since now companies can attract R&D resources and technological capabilities of other companies based on the formation of external links within one or more innovative projects or within the framework of long-term scientific and technical cooperation with various private firms, science-based and market-based partners [116–119]. Such opportunities for external interaction have expanded especially strongly in the process of digital transformation.

The analysis of changes in the influence of the factor of cooperation with state organizations on public financing issues shows that under the conditions of applying the innovation ecosystem model, this factor acquires a specific orientation [120–124]. Thus, the directions of state support for research in the EU countries are currently focused on solving environmental problems and are largely associated with "green" innovations. Financing of non-"green" innovations has moved to the sphere of cooperation between private firms.

At the same time, the high importance of factors of internal investment in research activities, specialized equipment purchase, access to external knowledge, the development of cooperation with suppliers and universities was noted both in earlier studies in this area and in modern works devoted to stimulating various kinds of innovations and above all "green" innovations. Modern researchers have noted that these factors are more important for enterprises in the implementation of environmental innovation than other innovations [68, 125–127].

The following three factors of the given group (Access to external knowledge, Networking (with educational institutions, etc.), and the Side effects of other innovations) had no importance and influence in the framework of the model of closed innovation.

In the closed innovation model, access to external knowledge is of some importance, but it refers, first of all, to the analysis of patent information and data on scientific and technological research conducted by competitors concerning the development of new products and technologies, as well as their improvement. Innovations obtained by corporate research centers and laboratories are actively protected by means of patent law, and the dissemination of innovations to the external environment is carried out on the basis of licenses, patents, franchisees and other instruments for the transfer of property rights [112, 128].

In the open innovation model, based on the exchange of knowledge between different firms and their involvement in solving a single complex task, the role of the factor of access to external knowledge increased significantly [129–131].

As for the innovation ecosystem model, its functioning is impossible without broad and free access to external knowledge.

The factor of network interaction between various subjects of society in the model of the innovation ecosystem has acquired a special scope and significance [56, 116, 132–136]. If in the closed innovation model such interaction existed mainly between manufacturing firms and research centers and universities, then as the open innovation model and the innovation ecosystem model expanded, such networks began to cover an increasing number of economic entities and society as a whole, including not only business partners but competitors also. Modern research proved that companies involved in innovative cooperation with other firms of their industry affiliation and industry market are more actively developing and implementing "green" innovations.

Finally, as for the impact of side effects from other innovations, as can be seen from **Table 1** in the closed innovation model, this factor did not matter, since innovation activity had an internal basis and an internal orientation. In the open innovation model and the innovation ecosystem model, this influence appeared and intensified due to the openness of both models and the inevitable dependence on external phenomena and processes [119, 137–141].

The group of factors "*Industry and market conditions*" is also quite important and traditional for all models. Within the framework of the innovation ecosystem model, it includes six factors, four of which strongly influenced upon innovation activity in the closed innovation model and continue to play an important role in modern conditions.

As in the group of innovative resources, the first of the factors of the group "Industry and market conditions" is complex and multi-element. These are specific characteristics of the company, including such as energy intensity, material intensity, human capital, absorption capacity, industry affiliation, size of the company, etc. [142–144]. In the closed innovation model, all these characteristics were crucial for choosing the object of innovation activity, the mechanism of its implementation, directions of development, etc. In the models of open innovation and innovation ecosystem, these characteristics begin to lose their significance, as the transition of innovations between industries and activities becomes easier, more active, and broader. Nevertheless, the industry affiliation of companies, as well as the structure and national jurisdiction of capital are significant factors in the innovation ecosystem model in terms of the types of innovations being implemented. Thus, modern research proved that in the case of networking based on innovative cooperation within the same industry and market, the greatest effect is obtained when interacting between foreign companies. However, the positive effect of cooperation with competitors in the field of innovation is achieved by organizing a network between local firms, as well as between competing companies in the service sector.

The second traditional factor of this group – "technological norms and standards" has become increasingly important recently [9, 145–149]. This is determined by the fact that increasing the uniformity of products in accordance with international norms and standards makes it possible to ensure sales on global markets without additional adaptation of technical documentation and products to the national legislation of various countries. At the same time, technological norms and standards play a more important role in open innovation and ecosystem models than in closed innovation models, when the focus was primarily on internal corporate and national norms and technical standards.

Similarly, the influence of the third factor of this group ("the level and strength of competition in international markets") is also manifested. It becomes the most significant in the open innovation model. However, in the conditions of digitalization of production and the "erasing" national borders of many production processes, this factor loses part of its influence on innovation activity [150–152].

The factor "Applied business model and value proposition" is new in relation to the models of closed and open innovations [50, 153–160]. The transformation of many classical business models in all spheres of activity, which occurred under the influence of the widespread use of digital technologies and the general digitalization of production and business, means a reorientation of business to a value model of supply. Innovation activity, as one of the key business processes of the company, starts to focus on the value model of supply. At the same time, the influence of the factor of the applied business model within the framework of the innovation ecosystem model will be more pronounced in relation to local companies. This is determined by the fact that it is local firms that are more focused on creating value propositions for a specific end-user of a specific region (territory, city). Modern digital technologies make it possible to take into account the interests of the local community more specifically and to develop and promote new values more specifically, especially within the framework of product and process innovations.

Two more factors from the "Industry and market conditions" group - the factors "Environmental norms and standards" and "ESG factors and ESG regulation" are closely interrelated and are also the result of current trends [161–166]. At the same time, digitalization of all processes of environmental control, monitoring of the environmental situation, the possibility of rapid response to various events in society and nature, increasing the openness and transparency of corporate governance based on information and communication technologies, provide a technical and technological basis for the influence of these factors, which will increase over time.

The next group of factors *"Social and public factors"* concerns the assessment of the social consequences of innovation, the manifestation of externalities from innovation [138, 167, 168]. At the same time, the external effects factor includes only that part of the external effects that create our own innovations (external effects from other people's innovations are taken into account in the group of "innovative resources", which was already noted earlier). It is the presence of external effects and their significance for society as a whole that is becoming an increasingly important indicator of the social expediency of innovation. And in the model of the innovation ecosystem, this becomes a key factor in the implementation of a particular innovation. At the same time, the digital environment creates particularly favorable conditions for the widespread scaling of these effects (both positive and negative). This, accordingly, increases the importance of ethics, morality, and social responsibility of business for innovation [96, 169, 170].

In this group of factors, the factor of long-term consequences of innovations is also singled out as an independent one [140, 168]. In the digital society and the digital economy, the importance of this factor is increasing.

As for the last group of factors *"Information and communication environment"*, it is also new and specific primarily for the stage of digital transformation of activities. The widespread use of digital technologies has significantly increased the role and status of information and knowledge in the innovation system [101, 171–175]. At the same time, it is necessary to clearly distinguish the concept and factor of "external knowledge" and "information in general". In this case, external knowledge includes specialized scientific and technical knowledge (information) related to the specific activities of the company. This factor was singled out as an independent one in the group of "innovative resources" and analyzed in sufficient detail in this paper. The development of external knowledge and information is closely related to the innovation decision-making system.

As for information in general, as well as its characteristics such as openness of information, speed, and possibilities of information transmission in the external environment, various types of effects from the dissemination of information (economic, social, socio-political, etc.) in Society 5.0, in Industry 4.0, in the model of the innovation ecosystem become more significant. At the same time, it should be noted that in both cases, the information and communication environment and the level of digitalization of society and the economy are the key basis for increasing the importance of these factors [176–178].

4.2 Difficulties in the development of innovation models based on digital transformation

The emergence and wide distribution of innovation ecosystems at various levels confirm the conclusion that the digital environment is an important development factor and a condition that affects innovation.

However, the active introduction of the innovation ecosystem into the business model and its further development faces a number of fundamental issues related to the role of innovation as a competitive tool.

However, with the development and improvement of computer and digital technologies, the key factors of innovation activity are also changing, including the procedure for determining the copyright holder of innovation and the mechanism of protecting property rights. Thus, participation in the creation of an innovation and its practical application "erodes" the individual nature of rights, making legal protection and protection of rights more difficult and complex. Moreover, in recent years, there has been a broad discussion in the scientific community and society about who is the creator and copyright holder of the intellectual property rights in the case of participation in the creation of artificial intelligence. This is closely related to addressing the ethical issues of intellectual property protection [179, 180].

Artificial intelligence – a supercomputer with the help of which new knowledge is obtained - is beginning to be interpreted as a special subject of scientific and research activity, and not as a tool for obtaining new information and data about phenomena and processes. In the twentieth century, computers and computing technologies are perceived as a tool /technical means by which scientific research is facilitated, scientific results are obtained more accurately and quickly. However, with the development of digital technologies and the creation of self-learning and self-developing systems, ideas about protecting the intellectual property rights of a robot/artificial intelligence as an equal creator of intellectual property with human researchers began to spread. This can lead to a significant transformation of such an element of innovation activity

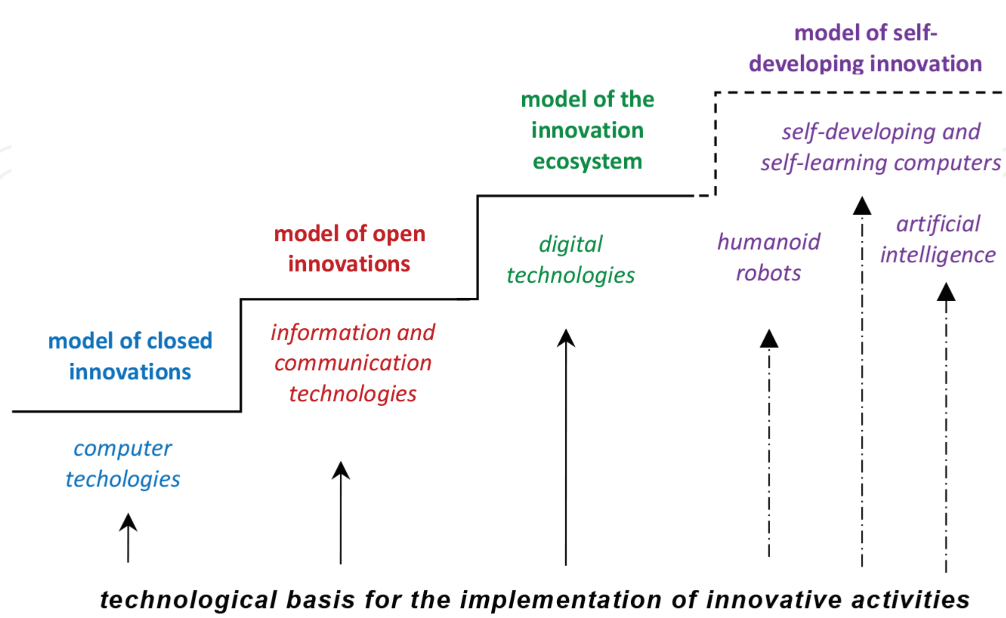

Figure 1.
Evolution of innovation models and their information and digital basis. Source: Compiled by the authors.

as the mechanism for determining the right holder of innovation and the mechanism for protecting property rights, and, accordingly, change the model of innovation activity itself.

Based on different studies in the field of forecasting the directions of development of information and digital technologies, it can be assumed that a new model of innovation will be formed in the future, which will be based on robots, artificial intelligence, and self-developing computer systems [181–185]. Conventionally, such a new model of innovation can be called a model of "self-developing" innovation.

The stages of transformation of models of innovation activity, including a new model, the characteristics of the information and digital basis of their existence, as well as their relationship are shown in **Figure 1**.

The diagram of the evolution of innovation models presented in **Figure 1** is the author's development and requires further research both of a theoretical nature and empirical verification in order to clarify the basic parameters of the model.

5. Conclusions

In general, summing up the characteristics of the process of evolution of innovation activity models under the influence of digital transformation, the following can be distinguished.

Digitalization has had a significant impact on the process of creating innovations and implementing innovative activities and has also led to the transformation of the innovation model. To date, the evolution of innovation activity models has gone through three stages - from the closed innovation model through the open innovation model to the innovation ecosystem model. However, it should be noted that all three models continue to be actively used in business, and the choice of model primarily depends on the specifics of the products (including market features), the industry specifics of the company, its size, capital structure, form of ownership, etc.

The second important trend that has influenced the transformation of the innovation model is the broad implementation of the provisions of the concept of sustainable development and climate security. However, in the modern world, sustainability can be ensured only based on universal consideration of all factors that affect the life of society, and not only on the specific conditions of doing business. That is why, within the framework of the modern model of the innovation ecosystem, greening factors and ESG factors have appeared and gained significant influence, the transition to the use of which in the regulation of activities has become a necessary element of any business.

It should be noted that the use of computer technology has posed a number of unexpected questions to society regarding intellectual property rights. The process of intellectualization of labor (i.e., an increase in the share of intellectual labor in human economic and economic activity), on the one hand, and the increasing use of a modern computer, information and communication, and digital technologies, on the other hand, naturally lead to a change in the model of innovation management and organization of innovation activities on a new technological basis.

Acknowledgements

The work is carried out based on the task on fulfilment of government contractual work in the field of scientific activities as a part of base portion of the state task of the Ministry of Education and Science of the Russian Federation to Perm National Research Polytechnic University (topic # FSNM-2020-0026). This research was partially supported by the Ministry of Education and Science of the Russian Federation to Perm National Research Polytechnic University as part of the development of the Technology Transfer Center (topic # 075-15-2021-1378).

Conflict of interest

The authors declare no conflict of interest.

Author details

Zhanna Mingaleva[1]* and Vladimir Postnikov[2]

1 Faculty of Humanities, Center for Research on Sustainable Development and Innovation Processes, Department of Economics and Industrial Management, Perm National Research Polytechnic University, Perm, Russia

2 Faculty of Humanities, Department of Economics and Industrial Management, Perm National Research Polytechnic University, Perm, Russia

*Address all correspondence to: mingal1@pstu.ru

References

[1] Bordeleau F-E, Mosconi E, de Santa-Eulalia LA. Business intelligence and analytics value creation in industry 4.0: A multiple case study in manufacturing medium enterprises. Production Planning & Control. 2020;**31**(2-3):173-185. DOI: 10.1080/09537287.2019.1631458

[2] Chen M, Sinha A, Hu K, Shah MI. Impact of technological innovation on energy efficiency in industry 4.0 era: Moderation of shadow economy in sustainable development. Technological Forecasting and Social Change. 2021;**164**:120521. DOI: 10.1016/j.techfore.2020.120521

[3] De Felice F, Travaglioni M, Petrillo A. Innovation trajectories for a society 5.0. Data. 2021;**6**(11):115. DOI: 10.3390/data6110115

[4] Ramírez-Montoya MS, Castillo-Martínez IM, Sanabria-Zepeda JC, Miranda J. Complex thinking in the framework of education 4.0 and open innovation—A systematic literature. Review Journal of Open Innovation: Technology, Market, and Complexity. 2022;**8**:4. DOI: 10.3390/joitmc8010004

[5] Żywiolek J, Rosak-Szyrocka J, Molenda M. Satisfaction with the implementation of industry 4.0 among manufacturing companies in Poland. European Research Studies Journal. 2021;**24**(3):469-479. DOI: 10.35808/ersj/2366

[6] Cusumano MA, Gawer A, Yoffie DB. The Business of Platforms: Strategy in the Age of Digital Competition, Innovation, and Power. New York: Harper Collins; 2019

[7] Ludbrook F, Michalikova KF, Musova Z, Suler P. Business models for sustainable innovation in industry 4.0: Smart manufacturing processes, digitalization of production systems, and data-driven decision making. Journal of Self-Governance and Management Economics. 2019;**7**:21-26. DOI: 10.22381/JSME7320193

[8] Yoo Y, Boland RJ, Lyytinen K, Majchrzak A. Organizing for innovation in the digitized world. Organization Science, INFORMS. 2012;**23**(5):1398-1408. DOI: 10.1287/orsc.1120.0771

[9] Teece DJ. Profiting from innovation in the digital economy: Enabling technologies, standards, and licensing models in the wireless world. Research Policy. 2018;**47**(8):1367-1387. DOI: 10.1016/j.respol.2017.01.015

[10] Ejsmont K, Gladysz B, Kluczek A. Impact of industry 4.0 on sustainability - bibliometric literature review. Sustainability. 2020;**12**(14J):5650. DOI: 10.3390/su12145650

[11] Birkel H, Müller JM. Potentials of industry 4.0 for supply chain management within the triple bottom line of sustainability – A systematic literature review. Journal of Cleaner Production. 2021;**289**:125612. DOI: 10.1016/j.jclepro.2020.125612

[12] Beltrami M, Orzes G, Sarkis J, Sartor M. Industry 4.0 and sustainability: Towards conceptualization and theory. Journal of Cleaner Production. 2021;**312**:127733. DOI: 10.1016/j.jclepro.2021.127733

[13] Piccarozzi M, Silvestri C, Aquilani B. Is this a new story of the 'two giants'? A systematic literature review of the relationship between industry 4.0, sustainability and its pillars. Technological Forecasting and Social

Change. 2022;**177**:121511. DOI: 10.1016/j.techfore.2022.121511

[14] Zengin Y, Naktiyok S, Kaygın E, Kavak O, Topçuoğlu E. An investigation upon industry 4.0 and society 5.0 within the context of sustainable development goals. Sustainability. 2021;**13**(5):2682. DOI: 10.3390/su13052682

[15] Schumpeter J. The Theory of Economic Development. Cambridge: Harvard University Press; 1934

[16] Ahn S. Competition, innovation and productivity growth: A review of theory and evidence. OECD Economics Department Working Papers. 17 January 2002;**317**:1-77. DOI: 10.2139/ssrn.318059

[17] Fagerberg J, Fosaas M, Sapprasert K. Innovation: Exploring the knowledge base. Research Policy. 2012;**41**(7):1132-1153. DOI: 10.1016/j.respol.2012.03.008

[18] Mingaleva Z, Deputatova L, Akatov N, Starkov Y, Mitrofanova E. Application of HADI-cycle for providing sustainability of processes of knowledge and innovation. Entrepreneurship and Sustainability Issues. 2019;**7**(2):1628-1640. DOI: 10.9770/jesi.2019.7.2(58)

[19] Mingaleva Z, Deputatova L, Starkov Y. Management of Organizational Knowledge as a basis for the competitiveness of Enterprises in the Digital Economy. Integrated science in digital age. ICIS 2019. Lecture Notes in Networks and Systems. 2020;**78**:203-212. DOI: 10.1007/978-3-030-22493-6_18

[20] Acharya R, Ziesemer T. A closed economy model of horizontal and vertical product differentiation: The case of innovation in biotechnology: A correction. Economics of Innovation and New Technology. 1997;**5**(1):91-92. DOI: 10.1080/10438599700000009

[21] Almirall E, Casadesus-Masanell R. Open versus closed innovation: A model of discovery and divergence. Academy of Management Review. 2010;**35**(1):27-47. DOI: 10.5465/AMR.2010.45577790

[22] Barge-Gil A. Open, semi-open and closed innovators: Towards an explanation of degree of openness. Industry and Innovation. 2010;**17**(6):577-607. DOI: 10.1080/13662716.2010.530839

[23] Felin T, Zenger TR. Closed or open innovation? Problem solving and the governance choice. Research Policy. 2014;**43**(5):914-925. DOI: 10.1016/j.respol.2013.09.006

[24] Parmentola A, Simoni M, Tutore I. Fast and furious: How the open vs closed dilemma affects the technology diffusion dynamic. Management Decision. 2018;**56**(4):867-890. DOI: 10.1108/MD-01-2017-0071

[25] Regenfelder M, Slowak AP, Santacreu A. Closed-loop innovation for mobile electronics - the business model innovation approach of the sustainably SMART project. Electronics Goes Green. 2016;**(EGG). 2016**:1-6. DOI: 10.1109/EGG.2016.7829847

[26] Ettlie JE, Pavlou PA T-b. New product development partnerships. Decision Sciences. 2006;**37**(2):117-147. DOI: 10.1111/j.1540-5915.2006.00119.x

[27] Malerba F. Sectoral systems of innovation and production. Research Policy. 2002;**31**:247-264

[28] Mingaleva Z, Bykova E, Plotnikova E. Potential of the network concept for an assessment of organizational structure. Procedia-Social and Behavioral Sciences. 2013;**81**:126-130. DOI: 10.1016/j.sbspro.2013.06.400

[29] Greenfield A. Radical Technologies: The Design of Everyday Life. London: Verso Books; 2017. p. 349

[30] Rojas MA, Saldanha TJ, Khuntia J, Kathuria A & Boh WF. Overcoming Deficiencies for Innovation in SMEs: IT for Closed Innovation versus IT for Open Innovation. International Conference on Information Systems, ICIS 2020 - Making Digital Inclusive: Blending the Local and the Global. Association for Information Systems (AIS), India. 2021. arr.no.167844

[31] Bardhan I, Krishnan V, Lin S. Business value of information technology: Testing the interaction effect of IT and R & D on Tobin's Q. Information Systems Research. 2013;**24**(4):1147-1161. DOI: 10.1287/isre.2013.0481

[32] Cainelli G, De Marchi V, Grandinetti R. Do knowledge-intensive business services innovate differently? Economics of Innovation and New Technology. 2020;**29**(1):48-65. DOI: 10.1080/10438599.2019.1585639

[33] Choi B. The role of firm size and IT capabilities in open and closed innovation. Asia Pacific Journal of Information Systems. 2019;**29**(4):690-716. DOI: 10.14329/apjis.2019.29.4.690

[34] Li C, Jiang Y, Fang P. Innovation in advanced manufacturing driven by supercomputing. Procedia CIRP. 2019;**83**:584-589

[35] Boudreau K. Does "Opening" a Platform Enhance Innovative Performance? Panel Data Evidence on Handheld Computers Working Paper. Boston, and HEC, Paris: Massachusetts Institute of Technology; 2006

[36] Christensen CM, Verlinden M, Westerman G. Disruption, disintegration and the dissipation of differentiability. Industrial and Corporate Change. 2002;**11**(5):955-993. DOI: 10.1093/icc/11.5.955

[37] Kesidou E, Narasimhan R, Ozusaglam S, Wong CY. Dynamic openness for network-enabled product and process innovation: A panel-data analysis. International Journal of Operations and Production Management. 2022;**42**(3):257-279. DOI: 10.1108/IJOPM-06-2021-0380

[38] Chesbrough H. The logic of open innovation: Managing intellectual property. California Management Review. 2003;**45**(3):33-58. DOI: 10.1177/000812560304500301

[39] Chesbrough HW. Open Innovation: The New Imperative for Creating and Profiting from Technology. Boston, MA: Harvard Business School Publishing; 2003

[40] Chesbrough HW, Vanhaverbeke W, West J. Open Innovation: Researching a New Paradigm. Oxford: Oxford University Press; 2006

[41] Saebi T, Foss NJ. Business models for open innovation: Matching heterogeneous open innovation strategies with business model dimensions. European Management Journal. 2015;**33**(3):201-213. DOI: 10.1016/j.emj.2014.11.002

[42] Bröring S, Herzog P. Organising new business development: Open innovation at Degussa. European Journal of Innovation Management. 2008;**11**(3):330-348. DOI: 10.1108/14601060810888991

[43] Boh WF, Huang C-J, Wu A. Investor experience and innovation performance: The mediating role of external cooperation. Strategic Management Journal. 2020;**41**(1):124-151. DOI: 10.1002/smj.30891

[44] Calabrese M, Sala AL, Fuller RP, Laudando A. Digital platform ecosystems

for sustainable innovation: Toward a new meta-organizational model? Administrative Sciences. 2021;**11**(4):119. DOI: 10.3390/admsci11040119

[45] Granstrand O, Holgersson M. Innovation ecosystems: A conceptual review and a new definition. Technovation. 2020;**90-91**:102098. DOI: 10.1016/j.technovation.2019.102098

[46] Helfat CE, Raubitschek RS. Dynamic and integrative capabilities for profiting from innovation in digital platform-based ecosystems. Research Policy. 2018;**47**(8):1391-1399. DOI: 10.1016/j.respol.2018.01.019

[47] Jackson DJ. What Is an Innovation Ecosystem? (2011). Available from: https://erc-assoc.org/sites/default/files/topics/policy_studies/DJackson_Innovation% 20Ecosystem_03-15-11.pdf (Accessed: January 7, 2022)

[48] Jacobides M, Cennamo C, Gawer A. Towards a theory of ecosystems. Strategic Management Journal. 2018;**39**:2255-2276. DOI: 10.1002/smj.2904

[49] Mingaleva Z, Mirskikh I. The problems of digital economy development in Russia. Advances in Intelligent Systems and Computing. 2019;**850**:48-55. DOI: 10.1007/978-3-030-02351-5_7

[50] Smorodinskaya N, Russell M, Katukov D, Still K. Innovation ecosystems vs. innovation systems in terms of collaboration and co-creation of value. In: 50th Hawaii International Conference on System Sciences. AIS Electronic Library (AISeL), Village, HI, USA; January 4-7, 2017

[51] Abdelkafi N, Täuscher K. Business models for sustainability from a system dynamics perspective. Organization & Environment. 2016;**29**:74-96. DOI: 10.1177/1086026615592930

[52] Colglazier W. Sustainable development agenda: 2030. Science. 2015;**349**:1048-1050. DOI: 10.1126/science.aad2333

[53] Hall J, Vredenburg H. The challenges of sustainable development innovation. MIT Sloan Management Review. 2003;**45**:61-68

[54] Brunnermeier S, Cohen M. Determinants of environmental innovation in US manufacturing industries. Journal of Environmental Economics and Management. 2003;**45**:278-293

[55] Jaffe AB, Palmer K. Environmental regulation and innovation: A panel data study. The Review of Economics and Statistics. 1997;**79**:610-619

[56] Kirschten U. Sustainable innovation networks: Conceptual framework and institutionalization. Progress in Industrial Ecology, An International Journal. 2005;**2**(1):132-147. DOI: 10.1504/PIE.2005.006781

[57] Boons F, Lüdeke-Freund F. Business models for sustainable innovation: State of the art and steps towards a research agenda. Journal of Cleaner Production. 2013;**45**:9-19. DOI: 10.1016/j.jclepro.2012.07.007

[58] Cillo V, Messeni Petruzzelli A, Ardito L, Del Giudice M. Understanding sustainable innovation: A systematic literature review. Corporate Social Responsibility and Environmental Management. 2019;**26**:1012-1025. DOI: 10.1002/csr.1783

[59] Godin B, Gaglio G. How does innovation sustain 'sustainable innovation'? In: Handbook of Sustainable Innovation. Cheltenham: Edward Elgar Publishing; 2019

[60] Schaltegger S, Wagner M. Sustainable entrepreneurship and sustainability innovation: Categories and interactions. Business Strategy and the Environment. 2011;**20**:222-237. DOI: 10.1002/bse.682

[61] Schaltegger S, Lüdeke-Freund F, Hansen EG. Business models for sustainability: A co-evolutionary analysis of sustainable entrepreneurship, innovation, and transformation. Organization & Environment. 2016;**29**:264-289. DOI: 10.1177/1086026616633272

[62] OECD/Eurostat. Oslo Manual. 2018: Guidelines for collecting, reporting and using data on innovation, 4th Edition, The Measurement of Scientific, Technological and Innovation Activities, OECD Publishing, Paris/Eurostat, Luxembourg. 2018. doi:10.1787/9789264304604-en (Accessed: January 14, 2022)

[63] Adams R, Jeanrenaud S, Bessant J, Denyer D, Overy P. Sustainability-oriented innovation: A systematic review. International Journal of Management Reviews. 2016;**18**(2):180-205. DOI: 10.1111/ijmr.12068

[64] Carrillo-Hermosilla J, del Río P, Könnölä T. Diversity of eco-innovations: Reflections from selected case studies. Journal of Cleaner Production. 2010;**18**:1073-1083. DOI: 10.1016/j.jclepro.2010.02.014

[65] Bossle MB, Dutra De Barcellos M, Vieira LM, Sauvée L. The drivers for adoption of eco-innovation. Journal of Cleaner Production. 2016;**113**:861-872. DOI: 10.1016/j.jclepro.2015.11.033

[66] Mingaleva Z, Shpak N. Possibilities of solar energy application in Russian cities. Thermal Science. 2015;**19**(2):S457-S466. DOI: 10.2298/TSCI150330087M

[67] Ramkumar S, Mueller M, Pyka A, Squazzoni F. Diffusion of eco-innovation through inter-firm network targeting: An agent-based model. Journal of Cleaner Production. 2022;**335**:130298. DOI: 10.1016/j.jclepro.2021.130298

[68] Bofinger Y, Heyden KJ, Rock B. Corporate social responsibility and market efficiency: Evidence from ESG and misvaluation measures. Journal of Banking and Finance. 2022;**134**:106322

[69] Chen L, Zhang L, Huang J, Xiao H, Zhou Z. Social responsibility portfolio optimization incorporating ESG criteria. Journal of Management Science and Engineering. 2021;**6**(1):75-85

[70] Chouaibi Y, Zouari G. The effect of corporate social responsibility practices on real earnings management: Evidence from a European ESG data. International Journal of Disclosure and Governance. 2022;**19**(1):11-30

[71] Diaye MA, Ho SH, Oueghlissi R. ESG performance and economic growth: A panel co-integration analysis. Empirica. 2022;**49**(1):99-122

[72] Ferrero-Ferrero I, Fernández-Izquierdo MÁ, Muñoz-Torres MJ. Can board diversity enhance the integration of ESG aspects in management system? Lecture Notes in Business Information Processing. 2013;**145**:1-9

[73] Giese G, Lee L-E, Melas D, Nagy Z, Nishikawa L. Consistent ESG integration through ESG benchmarks. Journal of Index Investing. 2019;**10**:24-42

[74] Kaiser L. ESG integration: Value, growth and momentum. Journal of Asset Management. 2020;**21**(1):32-51

[75] Karwowski M, Raulinajtys-Grzybek M. The application of corporate social responsibility (CSR) actions

for mitigation of environmental, social, corporate governance (ESG) and reputational risk in integrated reports. Corporate Social Responsibility and Environmental Management. 2021;**28**(4):1270-1284

[76] Mingaleva Z. Ethical principles in consulting. Procedia-Social and Behavioral Sciences. 2013;**84**:1740-1744. DOI: 10.1016/j.sbspro.2013.07.024

[77] Parfitt C. ESG integration treats ethics as risk, but whose ethics and whose risk? Responsible Investment in the Context of Precarity and risk-shifting. Critical Sociology. 2020;**46**(4-5):573-587

[78] van Duuren E, Plantinga A, Scholtens B. ESG integration and the investment management process: Fundamental investing reinvented. Journal of Business Ethics. 2016;**138**(3):525-533

[79] Zaccone MC, Pedrini M. ESG factor integration into private equity. Sustainability (Switzerland). 2020;**12**(14) 5725:1-15

[80] Docherty M. Primer on 'open innovation': Principles and practice. Vision. 2006;**30**(2):13-17

[81] Gassmann O, Enkel E, Chesbrough H. The future of open innovation. Research-Technology Management. 2010;**40**:213-221. DOI: 10.1111/j.1467-9310.2010.00605.x

[82] Hajrizi E, Nagy K. Transformative research driven innovation - the artistry of innovation management in the age of spiritual machines. In: GBRS2018 International Conference, St. John's University, Roma, Italy, 13-15 June 2018. 2018

[83] Lopes APVBV, de Carvalho MM. Evolution of the open innovation paradigm: Towards a contingent conceptual model. Technological Forecasting and Social Change. 2018;**132**(C):284-298. DOI: 10.1016/j.techfore.2018.02.014

[84] Marullo C, Ahn JM, Martelli I. Open for innovation: An improved measurement approach using item response theory. Technovation. 2022;**109**:102338. DOI: 10.1016/j.technovation.2021.102338

[85] Oh D-S, Phillips F, Park S, Lee E. Innovation ecosystems: A critical examination. Technovation. 2016;**54**:1-6. DOI: 10.1016/j.technovation.2016.02.004

[86] Fulmer SI. Editor's comments: The craft of writing theory articles—Variety and similarity. Academi of Management Review. 2012;**37**:327-331. DOI: 10.5465/amr.2012.0026

[87] Gilson LL, Goldberg CB. Editors' comment: So, what is a conceptual paper? Group and Organization Management. 2015;**40**:127-130. DOI: 10.1177/1059601115576425

[88] Hirschheim R. Some guidelines for the critical reviewing of conceptual papers. Journal of the Association for Information Systems. 2008;**9**:432-441

[89] Lukka K, Vinnari E. Domain theory and method theory in management accounting research. Accounting, Auditing and Accountability Journal. 2014;**27**:1308-1338

[90] Travaglioni M, Ferazzoli A, Petrillo A, Cioffi R, De Felice F, Piscitelli G. Digital manufacturing challenges through open innovation perspective. Procedia Manufacturing. 2020;**42**:165-172

[91] Jaakkola E. Designing conceptual articles: Four approaches. AMS Review. 2020;**10**:18-26. DOI: 10.1007/s13162-020-00161-0

[92] Petticrew M, Roberts H. Systematic Reviews in the Social Sciences: A Practical Guide. New York: John Wiley and Sons; 2008

[93] Seuring S, Müller M. From a literature review to a conceptual framework for sustainable supply chain management. Journal of Cleaner Production. 2008;**16**:1699-1710. DOI: 10.1016/J.JCLEPRO.2008.04.020

[94] Baldwin C, von Hippel E. Modeling a paradigm shift: From producer innovation to user and open collaborative innovation. Organization Science, INFORMS. 2011;**22**(6):1399-1417. DOI: 10.1287/orsc.1100.0618

[95] Esposito De Falco S, Renzi A, Orlando B, Cucari N. Open collaborative innovation and digital platforms. Production Planning and Control. 2017;**28**:1344-1353. DOI: 10.1080/09537287.2017.1375143

[96] Hekkert MP, Suurs RA, Negro SO, Kuhlmann S, Smits R. Functions of innovation systems: A new approach for analysing technological change. Technological Forecasting and Social Change. 2007;**74**:413-432. DOI: 10.1016/j.techfore.2006.03.002

[97] Van Geenhuizen M, Ye Q. Responsible innovators: Open networks on the way to sustainability transitions. Technological Forecasting and Social Change. 2014;**87**:28-40. DOI: 10.1016/j.techfore.2014.06.001

[98] Boudreau K. Open platform strategies and innovation: Granting access vs. devolving control. Management Science, INFORMS. 2010;**56**(10):1849-1872. DOI: 10.1287/mnsc.1100.1215

[99] Carayannis EG, Campbell DFJ. "Mode 3"and "quadruple helix": Toward a 21st century fractal innovation ecosystem. International Journal of Technology Management. 2009;**46**(3-4):201-234. DOI: 10.1504/ijtm.2009.023374

[100] Gambardella A, Panico C. On the management of open innovation. Research Policy. 2014;**43**(5):903-913. DOI: 10.1016/j.respol.2013.12.002

[101] Matschoss K, Repo P. Forward-looking network analysis of ongoing sustainability transitions. Technological Forecasting and Social Change. 2020;**161**:120288. DOI: 10.1016/j.techfore.2020.120288

[102] Parker G, Van Alstyne M. Innovation, openness and platform control. Management Science. 2018;**64**:3015-3032. DOI: 10.1287/mnsc.2017.2757

[103] Tidd J, Thuriaux-Alemán B. Innovation management practices: Cross sectorial adoption variation and effectiveness. R & D Management. 2016;**46**(3):1024-1043. DOI: 10.1111/radm.12199

[104] Fukuda K, Watanabe C. Japanese and US perspectives on the national innovation ecosystem. Technology in Society. 2008;**30**(1):49-63. DOI: 10.1016/j.techsoc.2007.10.008

[105] Gawer A, Cusumano MA. Industry platforms and ecosystem innovation. Journal of Product Innovation Management. 2013;**31**:417-433. DOI: 10.1111/jpim.12105

[106] Siedschlag I, Meneto S, Tong KM. Determinants of Green Innovations: Firm-Level Evidence. ESRI WP643. Economic and Social Research Institute (ESRI), Dublin. Working Paper; 2019

[107] Tidd J, Bessant J. Innovation management challenges: From fads

to fundamentals. International Journal of Innovation Management. 2018;**22**(5):1840007. DOI: 10.1142/s1363919618400078

[108] Aquilani B, Piccarozzi M, Abbate T, Codini A. The role of open innovation and value co-creation in the challenging transition from industry 4.0 to society 5.0: Toward a theoretical framework. Sustainability. 2020;**12**(21):1-21. DOI: 10.3390/su12218943

[109] Fukuda K. Science, technology and innovation ecosystem transformation toward society 5.0. International Journal of Production Economics. 2020;**220**:107460. DOI: 10.1016/j.ijpe.2019.07.033

[110] Holroyd C. Technological innovation and building a 'super smart' society: Japan's vision of society 5.0. Journal of Asian Public Policy. 2022;**15**(1):18-31. DOI: 10.1080/17516234.2020.1749340

[111] Argyres N, Rios LA, Silverman BS. Organizational change and the dynamics of innovation: Formal R&D structure and intrafirm inventor networks. Strategic Management Journal. 2020;**41**(11):2015-2049. DOI: 10.1002/smj.3217

[112] Brown JR, Martinsson G, Petersen BC. Do financing constraints matter for R&D? European Economic Review. 2012;**56**(8):1512-1529. DOI: 10.1016/j.euroecorev.2012.07.007

[113] Cassiman B, Veugelers R. In search of complementarity in innovation strategy: Internal R & D and external knowledge acquisition. Management Science, INFORMS. 2006;**52**(1):68-82. DOI: 10.1287/mnsc.1050.0470

[114] Denicolai S, Ramirez M, Tidd J. Overcoming the false dichotomy between internal R & D and external knowledge acquisition: Absorptive capacity dynamics over time. Technological Forecasting and Social Change. 2016;**104**:57-65. DOI: 10.1016/j.techfore.2015.11.025

[115] Ketata I, Sofka W, Grimpe C. The role of internal capabilities and firms' environment for sustainable innovation: Evidence for Germany. R & D Management. 2015;**45**(1):60-75. DOI: 10.1111/radm.12052

[116] Teece DJ. Firm organization, industrial structure, and technological innovation. Journal of Economic Behavior and Organization. 1996;**31**(2):193-224. DOI: 10.1016/S0167-2681(96)00895-5

[117] Ankrah S, AL-Tabbaa O. Universities–industry collaboration: A systematic review. Scandinavian Journal of Management. 2015;**31**(3):387-408. DOI: 10.1016/j.scaman.2015.02.003

[118] Du J, Leten B, Vanhaverbeke W. Managing open innovation projects with science-based and market-based partners. Research Policy. 2014;**43**(5):828-840. DOI: 10.1016/j.respol.2013.12.008

[119] Miozzo M, Desyllas P, H-fen L, Miles I. Innovation collaboration and appropriability by knowledge-intensive business services firms. Research Policy. 2016;**45**(7):1337-1351. DOI: 10.1016/j.respol.2016.03.018

[120] Berrutti F, Bianchi C. Effects of public funding on firm innovation: Transforming or reinforcing a weak innovation pattern? Economics of Innovation and New Technology. 2020;**29**(5):522-539. DOI: 10.1080/10438599.2019.1636452

[121] Cecere G, Corrocher N, Mancusi ML. Financial constraints and public funding

of eco-innovation: Empirical evidence from European SMEs. Small Business Economics. 2020;**54**(1):285-302. DOI: 10.1007/s11187-018-0090-9

[122] Miethling B. The evolution of interactivity-new insights into innovation system change and the role of the state. International Journal of Innovation Science. 2014;**6**(4):213-234. DOI: 10.1260/1757-2223.6.4.213

[123] Reznik N, Palchevich G, Popov V, Petrenko L. Strategic Vectors of the State Financial and Credit Incentives for Innovation. Lecture Notes in Networks and Systems, Springer, Cham.; 2021. p. 194. DOI: 10.1007/978-3-030-69221-6_17

[124] Rukanova B, Post S, Tan YH, Migeotte J, Slegt M, Wong S, et al. The role of public funding in the initiation and upscaling of collective innovation trajectories. In: ACM International Conference Proceeding Series. Association for Computing Machinery (ACM), Seoul, Republic of Korea; 2020. pp. 336-337. DOI: 10.1145/3396956.3397007

[125] Bocken NMP, Geradts THJ. Barriers and drivers to sustainable business model innovation: Organization design and dynamic capabilities. Long Range Planning. 2020;**53**:101950. DOI: 10.1016/j.lrp.2019.101950

[126] Crespi F, Ghisetti C, Quatraro F. Environmental and innovation policies for the evolution of green technologies: A survey and a test. Eurasian Business Review. 2015;**5**(2):343-370. DOI: 10.1007/s40821-015-0027-z

[127] De Marchi V, Grandinetti R, Cainelli G. Does the development of environmental innovation require different resources? Evidence from Spanish manufacturing firms. Journal of Cleaner Production. 2015;**94**:211-221. DOI: 10.1016/j.jclepro.2015.02.008

[128] Mingaleva Z, Mirskikh I. The problems of legal regulation and protection of intellectual property. Procedia Social and Behavioral Sciences. 2013;**81**:329-333. DOI: 10.1016/j.sbspro.2013.06.437

[129] Wu B, Miao Y-N, Peng X-Q, Lin G-M, Deng S-J. Patent protection strategy of technical standards in medical innovation. Chinese Journal of New Drugs. 2018;**27**(5):494-497

[130] Awate S, Larsen MM, Mudambi R. Accessing vs. sourcing knowledge: A comparative study of R&D internationalization between emerging and advanced economy firms. Journal of International Business Studies. 2015;**46**(1):63-86. DOI: 10.1057/jibs.2014.46

[131] Cassiman B, Giovanni V. Open innovation: Are inbound and outbound knowledge flows really complementary? Strategic Management Journal. 2016;**37**(6):1034-1046. DOI: 10.1002/smj.2375

[132] Feller I. Industry-University R&D partnerships in the United States. In: 21st Century Innovation Systems for Japan and the United States. National Academies press. Washington, DC, USA; 2009. pp. 169-185

[133] Franke N, Shah S. How communities support innovative activities: An exploration of assistance and sharing among end-users. Research Policy. 2003;**32**(1):157-178. DOI: 10.1016/S0048-7333(02)00006-9

[134] Katz ML, Shapiro C. Systems competition and network effects. Journal of Economic Perspectives. American Economic Association. 1994;**8**(2):93-115. DOI: 10.1257/jep.8.2.93

[135] Mingaleva Z, Mingaleva A. Assessing innovation susceptibility

of regions and municipal districts. Procedia-Social and Behavioral Sciences. 2013;**81**:595-599. DOI: 10.1016/j.sbspro.2013.06.482

[136] Wagner M. Entrepreneurship, Innovation and Sustainability. Sheffield: Greenleaf Publishing, 2012

[137] Antonioli D, Borghesi S, Mazzanti M. Are regional systems greening the economy? Local spillovers, green innovations and firms' economic performances. Economics of Innovation and New Technology. 2016;**25**(7):692-713. DOI: 10.1080/10438599.2015.1127557

[138] Bahemia H, Squire B. A contingent perspective of open innovation in new product development projects. International Journal of Innovation Management. 2010;**14**(4):603-627. DOI: 10.1142/S1363919610002799

[139] Claisse F, Delvenne P. As above, so below? Narrative salience and side effects of national innovation systems. Critical Policy Studies. 2017;**11**(3):255-271. DOI: 10.1080/19460171.2015.1119051

[140] Khessina OM, Goncalo JA, Krause V. It's time to sober up: The direct costs, side effects and long-term consequences of creativity and innovation. Research in Organizational Behavior. 2018;**38**:107-135. DOI: 10.1016/j.riob.2018.11.003

[141] Todt G, Weiss M, Hoegl M. Mitigating negative side effects of innovation project terminations: The role of resilience and social support. Journal of Product Innovation Management. 2018;**35**(4):518-542. DOI: 10.1111/jpim.12426

[142] Antonioli D, Mancinelli S, Mazzanti M. Is environmental innovation embedded within high-performance organisational changes? The role of human resource management and complementarity in green business strategies. Research Policy. 2013;**42**(4):975-988. DOI: 10.1016/j.respol.2012.12.005

[143] Macher JT. Technological development and the boundaries of the firm: A knowledge-based examination in semiconductor manufacturing. Management Science. 2006;**52**(6):826-843. DOI: 10.1287/mnsc.1060.0511

[144] Sanchez P, Ricart JE. Business model innovation and sources of value creation in low income markets. European Management Review. 2010;**7**(3):138-154. DOI: 10.1057/emr.2010.16

[145] Amitrano CC, Tregua M, Russo Spena T, Bifulco F. On technology in innovation systems and innovation-ecosystem perspectives: A cross-linking analysis. Sustainability. 2018;**10**(10):3744. DOI: 10.3390/su10103744

[146] Busch L, Ransom E, Mckee T, Middendorf G, Chesebro JE. Paradoxes of innovation: Standards and technical change in the transformation of the US soybean industry. International Library of Environmental, Agricultural and Food Ethics. 2006;**6**:137-155. DOI: 10.1007/1-4020-3984-0_8

[147] Friedrich D. Normative market regulation by means of early standardization: A descriptive policy analysis for the biobased industry. Journal of Cleaner Production. 2019;**232**:1282-1296. DOI: 10.1016/j.jclepro.2019.05.362

[148] Hu J, Guan Y, Zhou L, Wang Y. Influence mechanism of ambidextrous innovation on technological catch-up in latecomer enterprises of technical standards alliance. Journal of Advanced Computational Intelligence and Intelligent Informatics. 2020;**24**(3):251-259. DOI: 10.20965/jaciii.2020.p0251

[149] Konwin K, Gravitz P, Oates W, Gustavson P. Igniting Innovation in the Creation of Future Technical Capabilities: A Standards Profile for Use of Modeling & Simulation across the Acquisition Life Cycle. SIW: Workshop; 2015

[150] Kováč E, Žigić K. International competition in vertically differentiated markets with innovation and imitation: Trade policy versus free trade. Economica. 2014;**81**(323):491-521. DOI: 10.1111/ecca.12093

[151] Morita H, Nguyen X. FDI and quality-enhancing technology spillovers. International Journal of Industrial Organization. 2021;**79**:102787. DOI: 10.1016/j.ijindorg.2021.102787

[152] Peñasco C, del Río P, Romero-Jordán D. Analysing the role of international drivers for eco-innovators. Journal of International Management. 2017;**23**(1):56-71. DOI: 10.1016/j.intman.2016.09.001

[153] Adner R, Kapoor R. Value creation in innovation ecosystems: How the structure of technological interdependence affects firm performance in new technology generations. Strategic Management Journal. 2010;**31**(3):306-333. DOI: 10.1002/smj.821

[154] Amit R, Zott C. Creating value through business model innovation. MIT Sloan Management Review. 2012;**53**(3):41-49

[155] Baden-Fuller C, Haefliger S. Business models and technological innovation. Long Range Planning. 2013;**46**(6):419-426. DOI: 10.1016/j.lrp.2013.08.023

[156] Bolton R, Hannon M. Governing sustainability transitions through business model innovation: Towards a systems understanding. Research Policy. 2016;**45**:1731-1742. DOI: 10.1016/j.respol.2016.05.003

[157] Boons F, Montalvo C, Quist J, Wagner M. Sustainable innovation, business models and economic performance: An overview. Journal of Cleaner Production. 2013;**45**:1-8. DOI: 10.1016/j.jclepro.2012.08.013

[158] Dietl H, Royer S, Stratmann U. Value creation architectures and competitive advantage. California Management Review. 2009;**51**:24-39. DOI: 10.2307/41166492

[159] Osorno R, Koria M. Delia Del Carmen Ramírez-Vázquez open innovation with value Co-creation from university-industry collaboration. Journal of Open Innovation Technology Market and Complexity. 2022;**8**(1):32. DOI: 10.3390/joitmc8010032

[160] Snihur Y, Bocken N. A call for action: The impact of business model innovation on business ecosystems, society and planet. Long Range Planning. 2022:102182. In Press. DOI: 10.1016/j.lrp.2022.102182

[161] Chouaibi S, Chouaibi J. Social and ethical practices and firm value: The moderating effect of green innovation: Evidence from international ESG data. International Journal of Ethics and Systems. 2021;**37**(3):442-465. DOI: 10.1108/IJOES-12-2020-0203

[162] De Marchi V. Environmental innovation and R & D cooperation: Empirical evidence from Spanish manufacturing firms. Research Policy. 2012;**41**:614-623. DOI: 10.1016/j.respol.2011.10.002

[163] Di Simone L, Petracci B, Piva M. Economic sustainability, innovation,

and the ESG factors: An empirical investigation. Sustainability. 2022;**14**(4):2270. DOI: 10.3390/su14042270

[164] Horbach J. Determinants of environmental innovation-new evidence from German panel data sources. Research Policy. 2008;**37**(1):163-173. DOI: 10.1016/j.respol.2007.08.006

[165] Katsamakas E, Miliaresis K, Pavlov OV. Digital platforms for the common good: Social innovation for active citizenship and ESG. Sustainability. 2022;**14**(2):639. DOI: 10.3390/su14020639

[166] Xu J, Liu F, Shang Y. R&D investment, ESG performance and green innovation performance: Evidence from China. Kybernetes. 2021;**50**(3):737-756. DOI: 10.1108/K-12-2019-0793

[167] Gambardella A, McGahan AM. Business-model innovation: General purpose technologies and their implications for industry structure. Long Range Planning. 2010;**43**:262-271. DOI: 10.1016/j.lrp.2009.07.009

[168] Lupova-Henry E, Dotti NF. Governance of sustainable innovation: Moving beyond the hierarchy market-network trichotomy? A systematic literature review using the 'who-how-what' framework. Journal of Cleaner Production. 2019;**210**:738-748

[169] Antonioli D, Mazzanti M. Towards a green economy through innovations: The role of trade union involvement. Ecological Economics. 2016;**131**:286-299

[170] Nagy K, Hajrizi E, Palkovics L. Responsible innovation in support of society 5.0 - aspects of audit and control. IFAC-Papers Online. 2020;**53**(2):17469-17474. DOI: 10.1016/j.ifacol.2020.12.2123

[171] Dahlander L, Gann DM. How open is innovation? Research Policy. 2010;**39**(6):699-709. DOI: 10.1016/j.respol.2010.01.013

[172] Fatemi A, Glaum M, Kaiser S. ESG performance and firm value: The moderating role of disclosure. Global Finance Journal. 2018;**38**:45-64. DOI: 10.1016/j.gfj.2017.03.001

[173] Fu X. How does openness affect the importance of incentives for innovation? Research Policy. 2012;**41**(3):512-523. DOI: 10.1016/j.respol.2011.12.011

[174] Henkel J, Schöberl S, Oliver A. The emergence of openness: How and why firms adopt selective revealing in open innovation. Research Policy. 2014;**43**(5):879-890. DOI: 10.1016/j.respol.2013.08.014

[175] Schneider S, Spieth P. Business model innovation: Towards an integrated future research agenda. International Journal of Innovation Management. 2013;**17**(1):1302001:1-1302001:130200134. DOI: 10.1142/S136391961340001X

[176] Cenamor J, Frishammar J. Openness in platform ecosystems: Innovation strategies for complementary products. Research Policy. 2021;**50**:104148. DOI: 10.1016/j.respol.2020.104148

[177] Colombo MG, Foss NJ, Lyngsie J, Lamastra CR. What drives the delegation of innovation decisions? The roles of firm innovation strategy and the nature of external knowledge. Research Policy. 2021;**50**(1):104134. DOI: 10.1016/j.respol.2020.104134

[178] Osorno R, Medrano N. Open innovation platforms: A conceptual design framework. IEEE Transactions on Engineering Management. 2022;**69**(2):438-450. DOI: 10.1109/TEM.2020.2973227

[179] Mingaleva Z, Mirskikh I. Psychological aspects of intellectual property protection. Procedia-Social and Behavioral Sciences. 2015;**190**:220-226. DOI: 10.1016/j.sbspro.2015.04.938

[180] Wang BL. Artificial intelligence technology simulation university three whole education moral education model research. Advances in Intelligent Systems Computing. 2021;**1303**:844-850

[181] Ahn MJ, Chen Y-C. Digital transformation toward AI-augmented public administration: The perception of government employees and the willingness to use AI in government. Government Information Quarterly. 2022; **39**(2):art.no.101664. DOI: 10.1016/j.giq.2021.101664

[182] Keating SJ, Leland JC, Cai L, Oxman N. Toward site-specific and self-sufficient robotic fabrication on architectural scales science. Robotics. 2017;**2**(5):art.no.eaan8986. DOI: 10.1126/scirobotics.aam8986

[183] Motomura Y. Interdisciplinary open innovation through activities in AIST artificial intelligence technology consortium: The scenario towards society 5.0 by artificial intelligence (AI) technologies that enable mutual understanding between AI and humans. Synthesiology. 2021;**13**(1):1-16. DOI: 10.5571/synth.13.1_1

[184] Takaoka K, Yamazaki K, Sakurai E, Yamashita K, Motomura Y. Development of an integrated AI platform and an ecosystem for daily life, business and social problems. Advances in Intelligent Systems and Computing. 2019;**787**:300-309. DOI: 10.1007/978-3-319-94229-2_29

[185] Yang G-Z, Bellingham J, Dupont PE, Wang ZL, Wood R. The grand challenges of science robotics. Science Robotics. 2018;**3**(14):eaar7650