applied sciences

MDPI

Article

Digital Twin Providing New Opportunities for Value Co-Creation through Supporting Decision-Making

Shaun West [1,*], Oliver Stoll [1], Jürg Meierhofer [2] and Simon Züst [1]

[1] Research Group for Digital Innovation, Department of Engineering and Architecture, Lucerne University of Applied Sciences and Arts (HSLU), 6002 Luzern, Switzerland; oliver.stoll@hslu.ch (O.S.); simon.zuest@hslu.ch (S.Z.)

[2] School of Engineering, Zurich University of Applied Sciences (ZHAW), 8400 Winterthur, Switzerland; juerg.meierhofer@zhaw.ch

* Correspondence: shaun.west@hslu.ch

Featured Application: The applications in this paper describe how and where digital twins can improve value co-creation by supporting decision-making. The use of digital twin-based approaches in production environments provides the opportunity to enhance decision-making and presents multiple perspectives on where and how it can support decision-making. In the authors' opinion, it will accelerate the adoption of these approaches in manufacturing environments.

Abstract: The application of digital twins provides value creation within the fields of operations and service management; existing research around decision-making and value co-creation is limited at this point. Prior studies have provided insights into the benefits of digital twins that combined both data and simulation approaches; however, there remains a managerial gap. The purpose of this paper is to explore this research gap using input from a multiple case study research design from both manufacturing environments and non-manufacturing environments. The authors use ten cases to explore how digital twins support value co-creation through decision-making. The authors were all involved in the development of the ten cases. Individual biases were removed by using the literature to provide the assessment dimensions and allowing a convergence of the results. Drawing on the lessons from the ten cases, this study empirically identified eight managerial issues that need to be considered when developing digital twins to support multi-stakeholder decision-making that leads to value co-creation. The application of digital twins in value co-creation and decision-making is a topic that has developed from practice and is an area where a research gap exists between theory and practice. A cross-case analysis was developed based on the literature and the ten cases (eight industrial and two pilot-scale cases) providing the empirical findings. The findings describe how firms can design, develop, and commercialize digital-twin-enabled value propositions and will initiate future research.

Keywords: big data; action research; decision-making; value proposition; value co-creation; digital twins

Citation: West, S.; Stoll, O.; Meierhofer, J.; Züst, S. Digital Twin Providing New Opportunities for Value Co-Creation through Supporting Decision-Making. *Appl. Sci.* **2021**, *11*, 3750. https://doi.org/10.3390/app11093750

Academic Editor: Filippo Berto

Received: 19 March 2021
Accepted: 17 April 2021
Published: 21 April 2021

1. Introduction

The motivation for this paper is to explore how digital twins can provide new opportunities for value co-creation by supporting decision-making. Prior studies [1,2] have provided insights into the benefits of digital twins that combined both data and simulation approaches, however there remaines a gap in our understanding of value creation in such sitations. Value propositions predicated on digital twins present new opportunities for the co-creation of value-within systems and currently there is a limited understanding of the details of the value creation process. In this paper, the digital twin is defined as: "*a dynamic virtual representation of a physical object or system across its lifecycle, using real-time data to enable understanding, learning and reasoning*" [3].

This paper is based on the assumption that in a business context, value is created when a decision is made and action is taken in a system, and that decision-making requires the transformation of technical data into relevant forms for the decision makers [4]. Kunath and Winkler [5] stated that a digital twin simulation allows the exploration and evaluation of decisions and consequences. Sala et al. [6] state that simulations are a commonly used decision support tool used in many situations within product-service-systems (PSS). Furthermore, in the literature [7–9], the application of digital twins for decision support is confirmed. Expert systems are another approach to support decision-making [10] and, as with simulations, they provide an approach to formalize knowledge between the actors and integrate it with data from machines [11]. In these examples of decision support systems, control remains with the actors who are making the decisions.

Value creation based on decision-making within a system is often dispersed and based on actor-to-actor interactions that can change depending on the particular situation [12,13]. This makes it complex to use traditional innovation approaches to identify the "requirements". System value co-creation also has different meanings in the business strategy, information systems, and service science literature streams and this may create challenges given the backgrounds of developers of solutions enabled on digital twins. A framework for development of innovative value propositions within industrial PSS system has been proposed by Kohtamäki et al. [14], while Kowalkowski and Ulaga [15] provided a two-by-two block approach for categorizing new digitally-enabled value propositions. Nevertheless, the approaches taken do not fully address the ecosystem role ambiguities when it comes to value co-creation [16]. On a conceptual basis and within the context of digitalization, combined value co-creation has been described by Autio and Thomas [17] and the role of actors by Ekman et al. [18]. Chandler and Lush [19] described the application of service systems and how they can influence the service experiences provided by solutions or value propositions.

Empirically, the managerial gap described here has been demonstrated by Meierhofer, Kugler, and Etschmann [20], focusing on small- and medium-sized enterprises (SME) where there was a limited understanding of how to integrate digital into their service offerings. Kohtamäki et al. [14] present this in their empirical study based around the "theory of the firm" where they confirm that value creation extends outside a firm's boundaries and that in a PSS setting, there are many different solutions. They provide a conceptual model to help understand the characteristics of solution offerings in digital business models. Both confirm that there remains a gap between the conceptual models and operationalization of the theory and the models to assist value co-creation within the context of digital twin enabled value propositions. Based on this, the research aims to explore how digital twins can provide new opportunities for value co-creation through supporting decision-making. This links to the research question:

> *"How can the digital twin provide new opportunities for value co-creation through supporting decision-making and which managerial issues need to be solved for this?"*

2. Literature Review

The literature was collected over the duration of the research project, and as such, a semi-systemic literature review [21] was undertaken primarily using the Web-of-Science database. The review here provides the reader first with an introduction to PPS and digital services, before considering the lifecycle of PSS, asset-intensive environments, and Smart Products. Value creation and decision support systems are then introduced in general before linking value creation within digitally-enabled PSS, where the concept of S-D logic is used to anchor the concept of value co-creation. The following sub-section takes the theme further by considering how value co-creation can take place with the support of information systems. Appendix A provides a detailed breakdown of the papers used in the literature review so as to give an indication of the current state of the art.

2.1. Classification of Products and Services with a Digital Context

With the global transition of industrial firms' business models toward increasing reliance on services, manufacturing firms have been extending the service component in their total offering following the industry value chain downstream (e.g., [22,23]). To gain more stable income, established manufacturing firms are moving forward from a product-centric business orientation into a PSS business approach [22,24]. Based on Vandermerwe and Rada [25], this shift of focus from goods to services has been labelled "servitization" in the industrial marketing and service operations management communities (e.g., [26–29]). The term servitization is comprehensive, leading researchers and practitioners to use different terms to describe the transformation of an industrial goods manufacturer into a service or integrated solution provider [30]. Such extensions downstream are based on developing a broad range of services to support customers with the core capital goods [29]; for example, as "transition from products to services" [31,32], "going downstream in the value chain" [33], "moving towards high-value solutions, integrated solutions and system integration" [34], and "transforming a manufacturing firm into a service business" [35–37].

Despite these potential benefits, adopting an industrial PSS point of view inevitably increases complexities for manufacturing firms to design and implement successful service strategies [7,24]. This is partly because the service-dominant logic proposes skills and knowledge as a unit of exchange, goods as a distribution mechanism for service provision, and the customer as a co-creator of value [38,39]. According to a Bain & Company survey, only 21% of the responding firms have had real success with their service strategy [40]. One fundamental problem is the transition process: the service strategies being adopted are not always fully developed [41]. Thus, instead of going through a successful transition, manufacturers move into what is known as "service paradox", where large investments in the development of service do not generate the expected financial returns [42]. A similar "paradox" is developing today with digitally-enabled solutions [14], which also applies to the digital twin as one of a number of pathways to digitally-enabled solutions.

The classification of digital services in an asset-intensive environment requires a number of different dimensions to provide detailed contextual understanding of the digital twin. To this end, a number of different sources have been researched. Kowalkowski and Ulaga [15] provide a classification of industrial services (Figure 1) based on the nature of the value proposition provided to the recipient. The recipient can receive a service that supports their processes or the product. In contrast, the provider (or supplier) can base their value proposition on a "promise to perform", where they consider the inputs, or a "promise to achieve performance", where they consider the outputs from the service. This framework provides a classification that is useful for understanding the nature of the services delivered. New business models that focus on output performance are also referred to as "advanced services" [43]. For these, the provider guarantees the customer an agreed outcome or performance. Advanced services embed risk transfer between the parties. Based on Tukker [44] and Kowalkowski and Ulaga [15], there are different classifications for the services, and these provided classifications of the different revenue models. A study by Raja et al. [45] gives a framework to discover value within systems where advanced services and solutions are developed to provide innovative value propositions based on a learning process. The move to digital solutions and the innovative value propositions they can create is described by Taylor et al. [46]; nevertheless, in an asset-intensive environment as in this study, the work of Kowalkowski and Ulaga [15] and Raja et al. [45] remains valid.

Thoben et al. [47] broke the product life cycle down into three clear phases: Beginning of Life (BOL), Middle of life (MOL), and End of Life (EOL). Data and information flows between the different phases were also identified, along with the possible consumers of information and producers of the data. In doing so, this provided a lifecycle perceptive on the dataflows. This model was further adapted where an asset's life cycle can be significantly extended through modification and upgrades during the MOL phase [48,49]. This model provides a categorization of where in the life cycle the actors—and in particular, beneficiaries—are, and where the data are initially produced and how and why information is consumed.

Nature of the value proposition	Service recipient: Service orientated towards the supplier's goods	Service recipient: Service orientated towards the customer's processes
Supplier's promise to perform (input-based)	Product life-cycle services	Process support services
Supplier's promise to achieve performance (output-based)	Asset efficiency services	Process delegation services

Figure 1. Service classification by Kowalkowski and Ulaga [15].

In asset-intensive environments, the product lifecycle becomes ever more important as a unit of reference [50,51]. Information flows around the lifecycle of the "avatar" that can impact on the operation, repair, and overhaul of the asset [52–55], as well as the manufacturers' perspective of the product lifecycles [56,57]. Wiesner et al. [58] considered the interactions between services from the MOL phase with the full Product Lifecycle Management (PLM) and found that there was no systematic approach to linking the two. This makes it even more important to identify the position in PLM and the perspective taken, and then to link data flows between the different phases.

Porter and Heppelmann [59] provided two different classifications using two different hierarchies to help understand the asset within its context: one dealing with the ecosystem, the other with the level of automation of the monitoring and diagnostics. The ecosystem classification was based on five levels: product, smart product, smart connected product, product system, and system of systems. This is a product centric ecosystem as it does not include the human actors or define the relationships. Porter and Heppelmann [59] identified four possible levels within the automation levels that were applicable to all points within the ecosystem: monitoring, control, optimization, and autonomy.

2.2. Value Creation with Decision Support Systems

Data are highly abstract and need to be translated into information (or insights) that are then internalized to create knowledge. Information becomes knowledge when it is put into a context that gives it meaning, and includes some relation to actions or nonactions based on active decision-making [60]. Rowley [61] and Liew [62] provided more detailed definitions of data, information, knowledge. and wisdom. Figure 2 shows the transformation, with wisdom as a future element in the model. Wisdom, therefore, is a human task that is based on experience of past events (or a knowledge base) and contextual knowledge that is outside the boundaries of the dataset.

Three fundamental components of a decision support system have been identified by Marakas [63] as: a knowledge base, a decision context and user criteria (or a model), and an interface (to allow human/machine interactions). The actors themselves are as essential as any other component, and a digital twin can become an equally important part of a decision support system. A digital twin fulfills these three fundamental components and is a decision support system, as defined by Marakas [63].

Decision-making itself is based on actively taking (or not taking) actions [60]; this requires information put into context. Guo [64] published the DECIDE model of decision-making based on six steps: define the problem, establish the criteria, consider the alternatives (and consequences), identify the best option, develop and implement, and evaluate and monitor/reflect on the solution. Decision-making generally [65] has three timeframes: operational, tactical, and strategic. Often, but not always, different actors are involved in each type of decision.

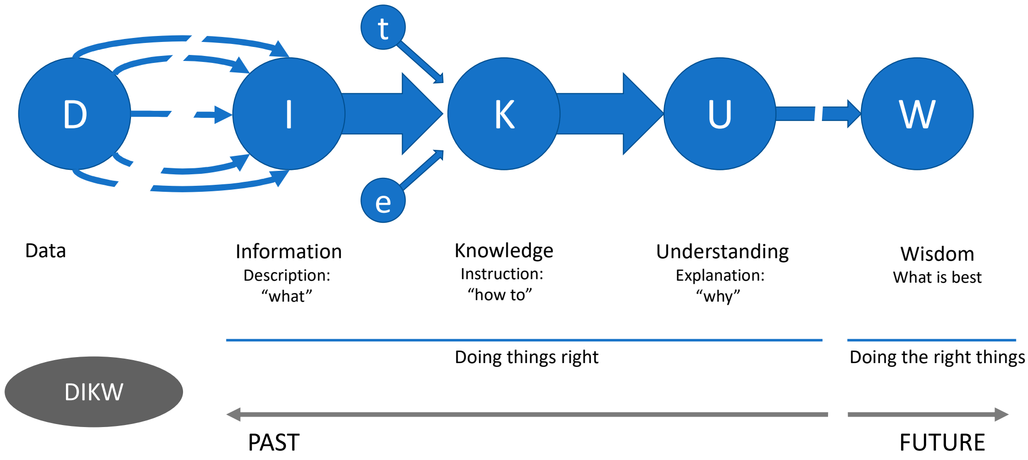

Figure 2. Transformation of data to wisdom and in doing so codifying the business processes (La Longa et al. [60]).

The use of digital technologies to support human decision-making has been described by Zeng et al. [66], while others [67,68] have more recently considered the interactions between the expert system advice provided by cyber-physical systems in different environments. In the cases examined, the digital system (a simulation, artificial intelligence, or machine learning system) provided a decision support tool, and they recognized the agency necessary in the actors to support decision-making. The digital technologies formalized the tacit information on different levels to support the decision process, coupled in some cases to live operational and machine data.

2.3. Value Creation within Digitally-Enabled PSS

PSS is a system of many actors, stakeholders, and beneficiaries, and is commonly applied in the context of servitization [69] where outcome- or performance-based contracts apply. Lusch and Nambisan [70] provided a S-D logic perspective on service innovation that can be placed with the development of value propositions and solutions for PSS. The PSS perspective is supported by the use of S-D logic [71]. The outcomes achieved, and hence value co-creation, on systems and individual transactions were analyzed by Nowicki, D., Sauser, B., Randall, W., and Lusch, R. [72]. Kohtamäki et al. [14] have explored different digital servitization business models that support value (co-)creation and value capture. Raja et al. [45] described the iterative learning process of value discovery in solution (and servitization). Sjödin et al. [73] support the iterative approach to service innovation when developing digital servitization solutions. The three papers confirm the challenges facing firms developing new digitally-enabled PSS value propositions when attempting to integrate data flows into their new solution.

An understanding of service ecosystems has been developed by Frost et al. [74] based on S-D logic [75]. Nambisan [76] considers architecture and ecosystem; however, Frost et al. [74] combine these in a multilayer framework where the architecture consists of the system environment and system activities as well as the institutional arrangements. The multilayer framework, shown in Figure 3, is coherent with the system-of-systems view of the world, as it allows many service systems to be integrated into the overall service ecosystem [77]. Importantly, here, the framework supports a more detailed understanding of the actors, system resources, connection and interactions, performance metrics (or evaluation), logics, and rules. This framework can provide the basis for the insights necessary for service design [78]. Service needs to provide value in use to the actors involved [70] and this needs to take into account not only the functional, but also the social and emotional needs of these individuals. The value proposition (which defines the transaction) needs to be designed specifically for each actor of the ecosystem and for the different tasks within the lifecycle [50,51], ref. [79] or every actor transaction [74]. The multilayer service system frameworks provide a route to operationalize key aspects of S-D logic, which can then lead to ecosystem actor orchestration [80]. The operationalization of S-D logic is important for innovation and exchange actor roles, and therefore perspectives within the ecosystem can support innovation [81].

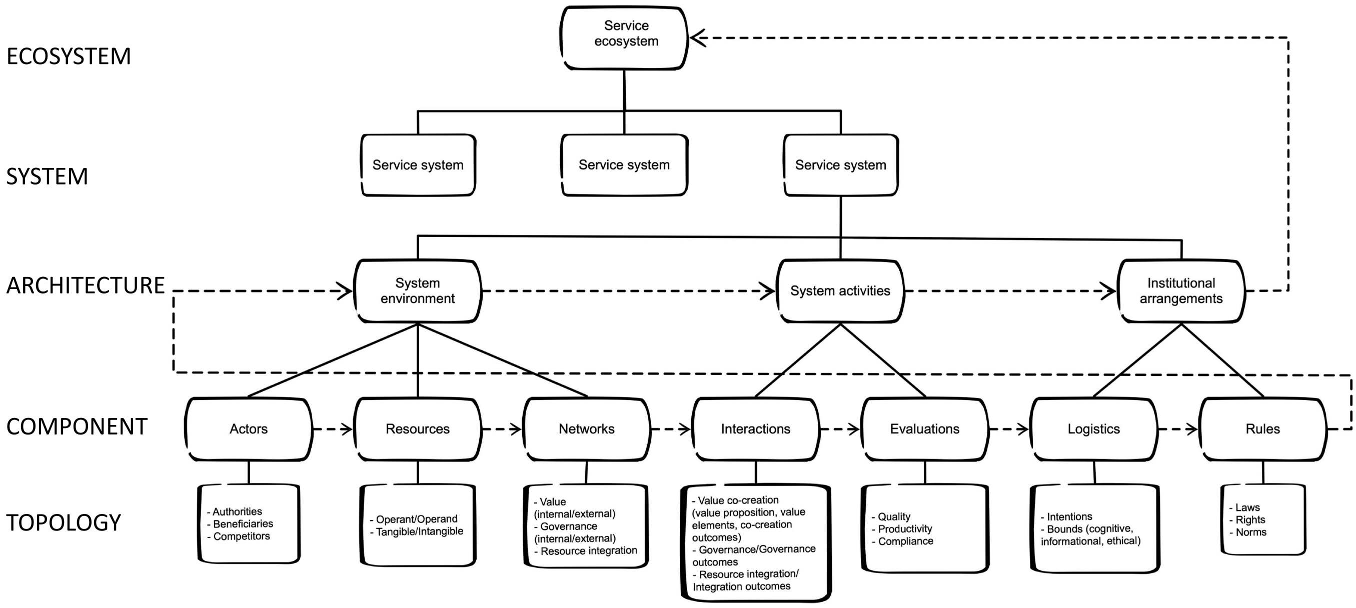

Figure 3. The multilayer service system framework (Frost et al. [74]).

In this context, technological changes—and in particular, advanced/smart technologies—can play a key role and this is therefore relevant to digital twin concepts. Indeed, digital technologies can create new connections within a service ecosystem, enabling new value co-creation opportunities and processes [82]. Thanks to internet technologies, digital resources (i.e., knowledge, relationships, money) can become fluid and flow across the ecosystem, enhancing resource density, changing, and opening space for value co-creation [70,83]. According to West et al. [79], there are three major dimensions of S-D logic that are especially relevant to service innovation in the digital age: service ecosystem, service platform, and value co-creation.

2.4. Value Co-Creation and Information Systems

The use of information system or software service platforms to support value (co-)creation within systems is an important consideration for the development of digitally-enabled PSS value propositions [84]. Given that a digitally-enabled PSS is in effect a digitally-augmented ecosystem, it is necessary, according to Kutsikos et al. [85], to identify the building blocks for the service ecosystem. This offers a decision-making mechanism for integrating the building blocks and provides a shared service infrastructure. The open nature of the information system and its ability to support ongoing value creation was confirmed by Gebregiorgis and Altmann [86], supporting the need to have a shared service infrastructure and actors to enable ongoing integration and value co-creation. Mansour [87] identified in digital service platforms the importance of the exchange, combination, and re-combination of resources within the value creation process. Within this context, the decision-making process that supports the value co-creation process occurs between multiple actors who may be from the same firm or from different firms and integration may be supported digitally when considering the multilayer service system framework [74]. Using this framework, intra-, inter-, and extra-firm (or ecosystem) relationships can be considered within the framework of value co-creation and linked with the intuitional aspects of decision-making, and this is in agreement with West et al. [79] and their consideration of the integration of actors within the context ecosystem and the lens of S-D logic.

Digital twins are a form of service platform that integrates and redistributes information, and part of decision support systems, within which simulation and AI approaches are the core [88]. In doing so, it links actors with resources and information to support the beneficiary. The development of digital twins required different elements of simulations when linking different lifecycle phases and architecture levels, referred to as “hybrid simulation” in the literature [89–96]. According to Scheidegger et al. [93], simulation in manufacturing systems focuses on discrete event simulation (DES). Jeon and Kim [90] offer a comprehensive overview of eight issues based around production and production planning, together with an indication of which simulation modelling approach (e.g., agent-based simulation (ABS), DES, and system dynamics of S-D) is best suited to each. Rondini et al. [91] describe a hybrid approach of ABS and DES for modelling a product-service system, compared to an approach based only on DES. This study confirmed that a hybrid approach is more useful for modelling the actor interaction in a service system due to variability in systems.

Rondini et al. [91] and Pezzotta et al. [97] both argue that simulation approaches are a suitable means to deal with these challenges of increased variability. They compare different hybrid approaches of ABS, DES, and S-D, and conclude that the combination of ABS and DES is well suited for the modelling of manufacturing issues, where ABS makes modelling actor variability easier and also allows the detection of phenomena as they emerge in the system. S-D modelling is focused on observation on the system level and used for strategic-level modeling [90,93].

Agency within the information system and decision-making is important [98] because the simulation has limited boundaries, outside which it has limited validity [99]. Simulation results should therefore be viewed as advisory [100].

3. Materials and Methods

This section outlines the research design and case selection before moving on to the data collection and analysis processes.

3.1. Research Design and Case Selection

The research objective was to understand and detail how digital twins can support decision-making and value co-creation. Given this and the research question and the objective together, a multiple case study research design [101] provides a suitable framework for such a study and offers the opportunity to provide tangible managerial recommendations. The approach also allows for the identification of repetition logic across the cases [102], and the increase of external validation while reducing bias from the observer [103,104].

A case study was developed to provide detailed descriptions of the cases under analysis, and to test the reliability of the theory [101,102]. All of the use cases are from the initial proof of concept stage, at a point where the effort involved in developing the proof of concept has yet to be defined. Ten cases of different digital twins were selected from a project with which the authors had direct involvement over an extended period. The company names are not provided to protect confidentiality. Each characteristic of the use case was independently evaluated by the four authors and cross-checked to converge towards a general consensus [105]. From the investigation of each individual case, a cross-case analysis was created for further discussion.

The cases chosen were all from a project funded by Innosuisse, which was set up with the aim of understanding and testing a wide range of environments to allow cross-case learning. The ten cases selected were considered to be the best formally documented cases.

3.2. Data Collection Process

The data collection process from the cases was based on the sketches and the data collected from the project in Miro (an online whiteboard, https://miro.com, accessed on

19 March 2021). Miro is an open platform where the problem could be described both in text and visually to help the team members to have a common understanding and to allow different points of view to be integrated into a single document. From the Miro document and discussions with the developers, the basic case descriptions were built up through an iterative process to create a more detailed common understanding of each case [102,103]. The data collection process and the categorization of the data collected meant that the authors were, to some degree, participants in the process rather than purely observers [106].

The basic data were captured for use cases, designed to provide the basic understanding of all cases on the same basis. The system purpose (or system job-to-be-done) and the digital twin's job-to-be-done was based on Christensen et al. [107] and Christensen [108]. Digital twin type was defined based on Uhlemann, Lehmann, and Steinhilper [109], Tao and Zhang [110], and Boschert and Rosen [111]. The actors, beneficiaries, avatars and their roles were based on West et al. [79], Frost et al. [74], Autio and Thomas [17], Polese et al. [112], Lusch and Nambisan [70], Lusch and Vargo [113], Wuest, Hribernik, and Thoben [114], Vargo and Lusch [115], Horváth and Rudas [116] and Hribernik et al. [117]. The main source of value drew from the work of Frost et al. [74], Anderson and Narus [118], and Anderson, Narus, and Van Rossum [119]. The business functions impacted direct or indirectly were defined by Porter [120,121], though the business model canvas [122] or the ten types of innovation [123] could have been used to help identify where in the firm innovation was taking place. The details of the data captured are provided in Appendix A.

3.3. Data Analysis Process

The data analysis that is presented in this paper is primarily based on the cross-case analysis from the data collection process. The analysis first provides an overview of the individual cases from the basic case descriptions; the basic case descriptions are described in detail in Appendix A. Table 1 was developed to enable the categorization of the digital twin based on a number of dimensions identified from the literature [120]. A digital twin classification was then created based on the seven dimensions (e.g., business functions, service classification, lifecycle, environment, Monitoring and Diagnostic (M&D), decision-making, and technical approach) [59]. These two steps were designed to provide a detailed understanding of the context of the use case; the final step was to explore the different digital twin concepts for their value creation potential based on Table 2. The multilayer system developed by Frost et al. [74] was integrated into the approach to ensure aspects were not overlooked. The assessment was based on the approach taken by West et al. [79] using a pre-defined S-D logic framework provided by Lusch and Nambisan [70] with three major dimensions (i.e., service ecosystem, service platform, and value co-creation). A 5-point Likert scale was used to score the relevance of the characteristics, and assessments were completed within the review where group meetings and individual follow-up were used to gain consensuses. The scoring using the 1–5 scale was perhaps less helpful than the discussions based around the three high-level aspects and the attributes. Scoring generally focused on justification rather than the discussions around the attributes that supported the development processes.

Table 1. Data collated to support the categorization of the digital twin use cases.

Aspect	Dimensions	References
Service classification	Product life cycle services, asset efficiency services, process support services, process delegation services	Kowalkowski & Ulaga [15]
Life cycle	BOL, MOL, EOL	Thoben et al. [47] Terzi et al. [50] Uhlenkamp et al. [124]
Environment	Product, smart product, smart connected product, product system, and system of system	Porter & Heppelmann [59]
Monitoring and diagnostics (M&D)	Monitoring, control, optimization, and autonomy	Porter & Heppelmann [59]
Decision-making horizon	Tactical, operation, and strategic	Little [65] Muñoz et al. [125]

Table 2. Assessment of the value co-creation potential (West et al. [79]).

Major Dimensions	Key Characteristics	Score (1, Worst)	Score (5, Best)
Service Ecosystem	Flexibility & integrity	No flexibility, no additional integration	Open system built on a flexible integrated architecture
	Shared view	Limited understanding today, no future view	Clear shared view, today and in the future
	Actor roles	Not defined	Multi-roles
Service Platform	Architecture	Closed	Open and secure
	Modular structure	No	Highly modular, with 3rd party integration
Value Co-creation	Rules of exchange	Poorly defined	Clearly defined
	Value creation between actors	One-way, single-actor	Two-way, multi-actor
	Interactions between diverse actors	Two actors	Multi-actor
	Accommodation of roles	Two roles only	Multi-roles/multi-actor
	Resource integration	Single resource	Integration of many resources

4. Results

The summary of the ten cases are given below as a snapshot of the cases for the reader; full details are in Appendix A. In this section, we classify the cases based on the chosen criteria and provide a cross-case analysis. The use cases that will be reported here are:

1. tunnel maintenance, repair, and overhaul (MRO);
2. operations scheduler digital twin for a joinery factory;
3. wood pattern cutting;
4. operations smart factory planning and materials flow;
5. smart factory asset management;
6. breakdown support twin for ships;
7. server room temperature management and control;
8. tunnel drainage system advisor;
9. footfall around interchanges;
10. operations support in facility management.

Case 1 is based on the maintenance, repair, and overhaul support for equipment in a major tunnel. Here, the digital twin supports maintenance planning and improves the efficiency of the field service engineering. Additionally, the digital twin should support the failure analysis and, in doing so, reduce repair time.

In Cases 2 and 3, the factory manufactures made-to-order wooden construction components; this means an effective lot size of one or close to one. Planning production runs is critical, as there are bottlenecks created by both the machines and the production team. There is a lack of real understanding of the true production time per operation, so optimization of scheduling can be challenging. Management has difficulties setting production targets in this environment. In cutting bespoke components from wood, selecting the best layouts in a three-dimensional system is both time-consuming and problematic. Maximizing the yield from the wood benefits the factory in terms of reduced waste—and therefore costs. Understanding the dimensions of the "off-cuts" also potentially increases the value of the wood that is not initially used.

A lab-scale smart factory was the basis for Cases 4 and 5, where a planning and material flow digital twin will be developed as a demonstrator to identify the value created. This will follow the value chain from goods inwards, through the processing operations, to the warehouse for shipment. The asset management twin would allow new machines to be integrated into the system allowing their impact on both operations and maintenance to be understood. The most basic maintenance scheduling tool would support both functions by making the maintenance window visible, based on the operations plan. The more advanced twin would be one that allowed for the integration of new equipment within the production line.

The firm in Case 6 manufactures cruise ships (an example of the visualization is given in Figure 4), many of which must operate with high day-time availability. Here, preventive maintenance is the preferred option of both the ship owners and the supplier; however, this does not necessarily improve a ship's overall availability, although it has an impact on reliability. In order to improve availability, reduce response time, and reduce repair time, a digital twin could support monitoring and reporting on each ship's condition.

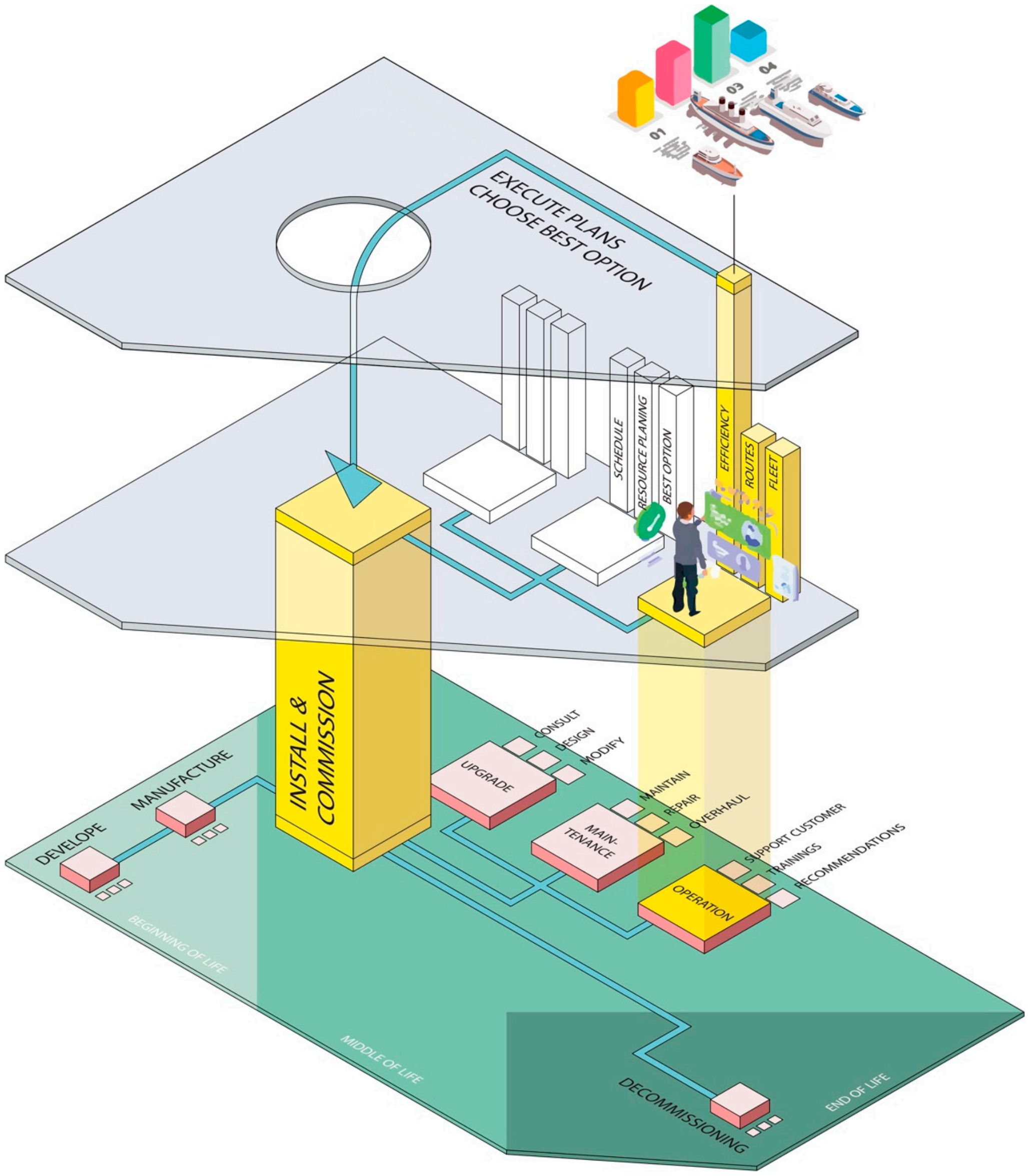

Figure 4. Example of a sketch from Case 3, showing the analysis simulation and application layers with the identification of the business challenges, business intelligence, and consequence. Visualization: Rohner, D., & Müller-Csernetzky, P.

The server room in Case 7 (Figure 5) provides 24/7 monitoring of company assets and enhanced regulation of critical technical room climate. This twin's principal task is to improve equipment up-time and provide business stability by mitigating equipment risks. Core to this is the temperature regulation in the room, including the integration of external temperature measurements. Along with this, the twin supports its ecosystem actors (operation employees) in a variety of operational tasks.

Case 8 describes a new tunnel equipped with various equipment from many different manufacturers and many different subsystems (shown in Figure 6). This use case focuses on the tunnel drainage system where several pumps are installed to remove water from the tunnel. Water ingress is via groundwater seepage and by water/snow that is brought into the tunnel by traffic, and this can present a safety challenge for the tunnel operator. The digital twin aims to monitor water levels and give predictions based on the weather conditions and other factors that influence the water level in the tunnel. The digital twin would then also be used as a training simulator to support the tunnel operation team developing appropriate mitigation.

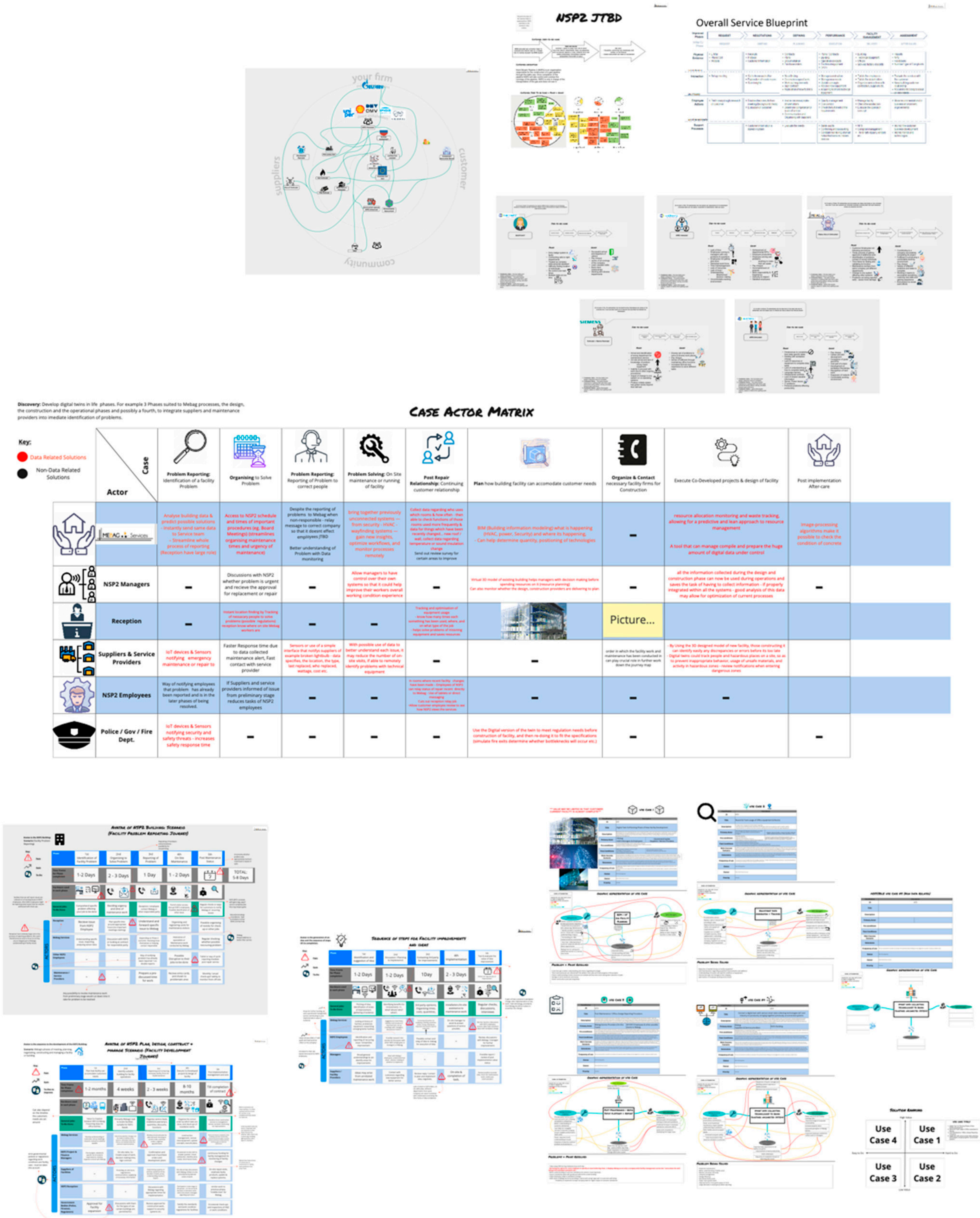

Figure 5. Example of a working from Miro for Case 7, showing the tools and the sketches for the case understanding. Visualization: Stoll, O., & Corcoran, F.

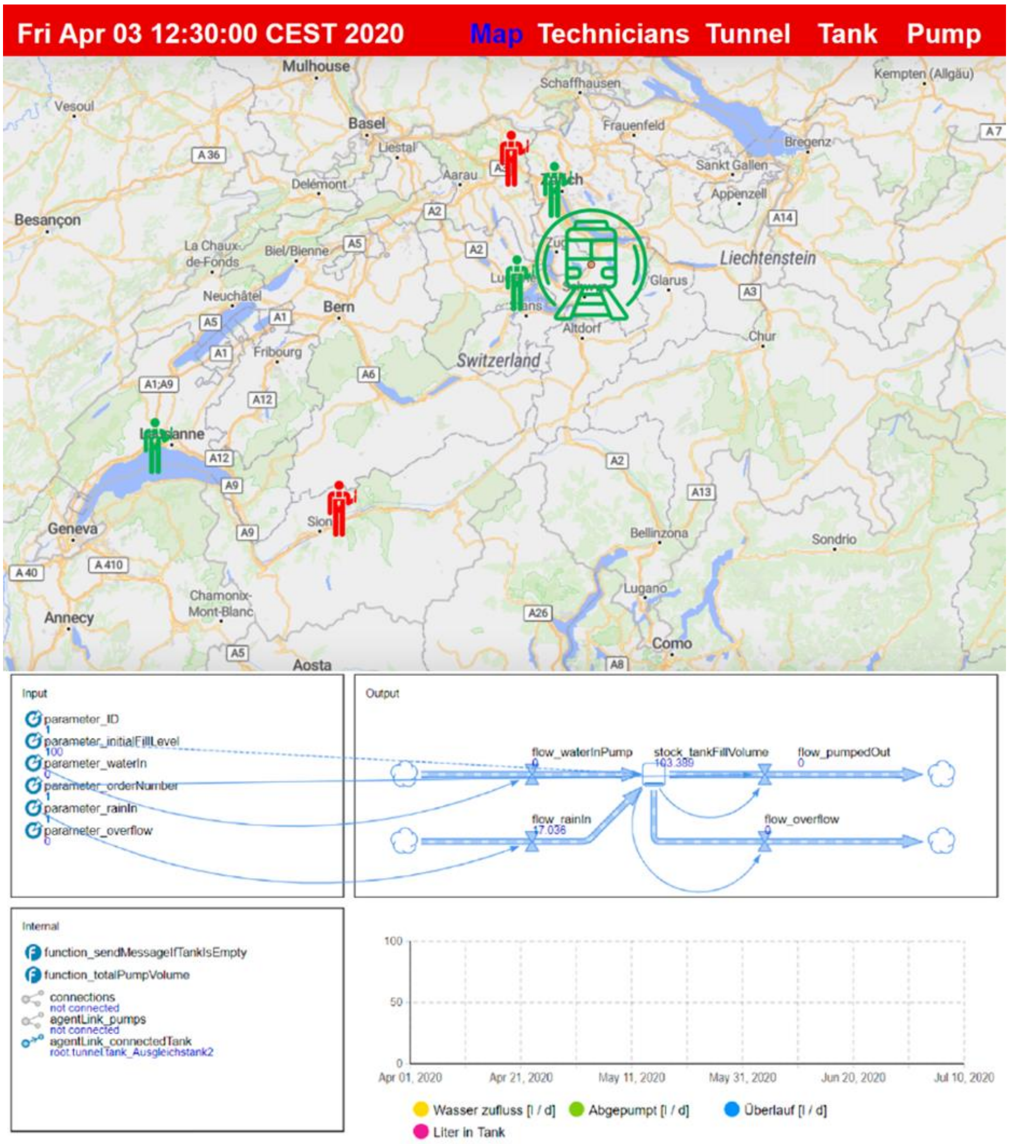

Figure 6. Example of a Case 8 showing the availability of staff relative to the tunnel and the current and forecast state of the tunnel pumping system. Visualization: Schweiger, L.

In Case 9, a digital twin is designed to simulate footfall around travel interchanges, assisting with safety, scheduling, rental income, and upgrade planning. It is a use case that provides value to many actors, based on the simulated flows of individuals around interchanges. The scheduling here has a major impact on the actual flow of individuals.

Facility management, in Case 10, requires the facility to be maintained correctly; the initial phase of this is to understand the status of the BIM system as it was built. This then has to be synchronized with the maintained state of the facility and integrated into the facility management processes and procedures.

The ten cases for the application of digital twin concepts provided very different examples. All of the concepts are early-stage digital twins, rather than deployed and operational digital twins. Therefore, the limitation of the research here is that the cases were early concepts for digital twins rather than deployed digital twins; they are, in effect, extended use case concepts. The projects were all from the early stage of a Swiss government-funded research project with the aim of creating Smart Twins. It was important for the partners that a common digital twin description was established to allow the digital twins to be analyzed, to provide the researchers with an understanding of the twins and the anticipated value they could deliver. Once developed and tested, the authors will review the work to validate the value that was delivered and gain insights into the lessons learnt from the development of the digital twins.

The basic descriptions gave a standardized approach to the different use cases in a digestible form. The raw use cases were in non-standard forms and did not clearly communicate the use case or the value expected. From the analysis of the twins, there are a number of clusters of digital twins that are starting to form, and this should be developed further. The development of a clear purpose and the main source of value for the digital twins was not easy, and there was a general drift to focus on the technology rather than to develop a clear purpose. This was in contrast to the identification of the digital twin types, which was easily completed, along with identification of the avatars. The people aspects were tougher: there were hidden actors with poorly defined roles to be identified to fully define the problem. Defining the basic job-to-be-done for each digital twin came from the twin's purpose, along with the questions that the digital twin was expected to answer. In general, the teams found it easier to define the twin's role from the questions that it was expected to answer rather than from another approach.

4.1. Classification of the Cases

The classification of the digital twins is provided in Table 3 and the goal was to identify differences and similarities. In the ten cases, twins are not only technical tools but can provide support across a range of business functions. This gave the teams an understanding of which generic business functions could benefit from a digital twin. This is an internally focused consideration as it does not consider the external actors and potential beneficiaries. It was assumed the list would support change management activities when using the digital twins. Discussions also considered overloading a single business area with new tools and approaches, as the digital twin is, in effect, only a tool.

The service classification shows that value could be created in each quadrant (Figure 1) from the digital twin's basic decision support. The four quadrants provided input to the types of value proposition that could be supported with the digital twins. Without the prompt of the service classification, for example, more traditional MRO-like solutions with limited process interaction may have been developed, although more data are required to confirm this initial finding.

Different phases of the life cycle of the assets were covered by the cases, and in some cases, linked. The three-level classification was overly simplistic and only BOL and MOL were used, even though the discussions focused on more specific lifecycle tasks. This should be better defined in the future. Environmental characterization was of limited use and was difficult to complete as all of the use cases exist within complex systems; in reflection, this dimension offered limited insight. The teams considered that all of the cases existed within the highest two levels of the model; this was due to the complex interconnection of the problem spaces of the use cases where the system comprised of actors, avatars, and processes. In hindsight, it is a reflection of how our understanding of the connection environment of Ind 4.0 has developed since 2014.

It was more useful to consider the capabilities/level of delegation given to the digital twins. This provided detailed insight into the application and the functionality of the digital twins as well as the interactions between the actors and resources. However, the use of autonomy clearly has boundaries and, in effect, is "delegated" autonomy within set criteria. Nevertheless, the digital twin's responsibilities or level of delegation provides a valuable insight to the expectations of the team developing the twin.

The decision-making horizon supported understanding on all three levels and was key to the definitions of the use cases. In some cases, asking the question of the decision-making horizon supported the development of different views on the actors and the value co-creation process. This was not as clear initially to the development teams and needed to be linked closely to the questions that the digital twin was expected to answer.

Table 3. Classification of the ten use cases.

Case	Supported Business Functions	Service Classification	Lifecycle	Environment	Capabilities/Level of Delegation	Decision-Making Horizon
Tunnel MRO digital twin	Operations, infrastructure, technological development, service	Product life cycle services	BOL, MOL	System of system	Monitoring, control, optimization	Operational, tactical
Operations scheduler digital twin for a joinery factory	Logistics, operations, marketing and sales human resources management	Process support services	MOL	System of system	Monitoring, control, optimization	Operational, tactical
Wood pattern cutting digital twin	Logistics, operations, outbound logistics, marketing and sales, service, human resources management	Process delegation services	MOL	System of system	Optimization	Operational
Operations smart factory planning and materials flow digital twin	Inbound logistics, operations, outbound logistics, marketing and sales, procurement	Services, process delegation services	MOL	System of system	Optimization	Operational, tactical
Smart factory asset management digital twin	Operations	Product life cycle services, asset efficiency services	BOL, MOL	System of system	Optimization	Strategic and tactical
Breakdown support twin for ships	Inbound logistics, operations, service	Product life cycle services, process support services	MOL	Smart products/System of system	Monitoring, optimization	Operational, tactical
Server room temperature management and control digital twin	Service, infrastructure	Product life cycle services, process support services	BOL MOL	System of system	Monitoring, optimization, autonomy	Operational
Tunnel drainage system advisor	Operations Infrastructure	Asset efficiency services, process support services	(BOL) MOL	System of system	Monitoring, optimization,	Operational
Footfall around interchanges	Operations Infrastructure	Asset efficiency services, process support services	(BOL) MOL	System of system	Monitoring, optimization,	Operational Strategic
Operations support in facility management	Operations Infrastructure	Process delegation services	(BOL) MOL	System of system	Monitoring, optimization,	Operational Strategic

4.2. Assessment of Value Co-Creation Potential

The West et al. [79] assessment tool provides an approach to estimate the value co-creation potential. The actual business value that the digital twin could potentially create was specific to each use case, and the raw score between different use cases is not relevant. Each digital twin was assessed, as shown in Table 4. This was applied during the development phase to assess the likely "smartness" of the resulting value propositions based on the solutions developed. Discussions with the teams confirmed that the assessment provided support in terms of not overlooking aspects that could improve or hinder value co-creation within the system. The scoring using the 1–5 scale was perhaps less helpful than the discussions based around the three high-level aspects and the attributes. Scoring generally focused on justification rather than the discussions around the attributes that supported the development processes.

Table 4. Assessment of value co-creation potential.

Major Dimensions	Key Characteristics	Tunnel MRO Digital Twin	Operations Scheduler Digital Twin for a Joinery Factory	Wood Pattern Cutting Digital Twin	Operations Smart Factory Planning and Materials Flow Digital Twin	Smart Factory Asset Management Digital Twin	Breakdown Support Twin for Ships	Server Room Temperature Management and Control Digital Twin	Tunnel Drainage System Advisor	Footfall Around Interchanges	Operations Support in Facility Management
Service Ecosystem	Flexibility & integrity	3	2	1	4	4	3	3	3	3	4
	Shared view	3	4	3	4	4	3	4	3	3	4
	Actor roles	3	4	3	4	3	4	3	3	4	4
Service Platform	Architecture	3	3	2	5	4	3	4	3	3	4
	Modular structure	4	3	4	5	5	4	3	4	4	4
Value Co-creation	Rules of exchange	3	4	3	4	4	3	3	3	4	3
	Value creation between actors	3	4	3	4	4	4	3	3	4	4
	Interactions between diverse actors	3	4	3	5	4	3	4	3	4	4
	Accommodation of roles	3	4	3	5	4	3	4	3	4	4
	Resource integration	3	5	3	5	4	4	4	3	4	4

The developers were not experts in S-D logic and therefore had limited a comprehension of the core concepts of value co-creation or value in use. The S-D logic attributes provided a check list that supported the development of solutions that could offer increased value.

5. Discussion

During the development of the digital twins, the co-creation of value was seen to take place within and between the different use cases. The development process allowed the sharing of know-how, and integration and formalization of that through the development process. The formalization was achieved by having clear descriptions of the systems, experts from a contextual background and experts from an information system background. The digital twins supported collaboration between the multi-disciplined team. Here, visualization of the problem using Miro helped share contextual issues from multiple perspectives, although more formal structures and templates would support the process. According to Lusch, Vargo, and Gustafsson [113], multiple- or trans-disciplinary need support to co-create value and the use of formalized tools (such as templates) can support this process.

The classification of the digital twins was helpful as it provided a common language to discuss each twin. This offered a number of dimensions to support a mutual understanding of the use case and the practicality of the development, in effect a common language for discussion. This helped provide context for the digital twin's impact within the business.

The business functions impacted (supplier of data/consumer of information) were taken from Porter [120,121], which provided a simple format. It allowed the identification of the business areas that could be disrupted by the digital twin, and as such could help identify the actors and their roles. Interestingly, identifying actors also helped pinpoint the business functions, in an iterative process.

The service classification matrix [15] widened the areas where the twin could operate, and early concepts focused on asset efficiency services rather than other quadrants. The model guides the development of the initial concepts and supports the development of new ideas that otherwise might not have occurred. The use of this model may make developers focus on new solutions that are more disruptive or have the ability to provide more value. The service classification matrix is similar to Tukker's [44] revenue models and offers digital twin developers new areas for exploration that they may not have originally considered.

Life cycle classifications and linking between BOL and MOL supported the transition to the operational phase and the capture of the appropriate data that could later become information, while the use of the three categories forced people to look both backwards and forwards. It also supported the application of digital twins where major renovations [48] were taking place. The high level three-dimension selection supports linking different layers; however, it does not provide sufficient detail, and the secondary definitions from Terzi et al. [50] would provide more specifics that would support the high-level definitions of this model. This model complements that of Thoben et al. [47], which described the information flows between the three phases of the life cycle.

The environmental categories taken from Porter and Heppelmann [59] supported the positioning of the digital twin within its environment, although depending on the system boundaries the results ended with the "system-of-system" positioning. The system boundaries are expected to limit the reliability of the digital twin, which confirms that agency must be supported with the digital twin and that full autonomy may not be fully desirable. Lawrence, Suddaby, and Leca [99] confirm the importance of agency for the actors in making decisions.

The level of capabilities or delegation was focused in the twins from control to optimization; the difference between control and autonomy was not always as clear as expected. Control was based around instructing the digital twin to control something within set limits and report back. Optimization twins support the firm to improve a situation and give advice in some cases—for example, allowing the operator to make the final decisions. Thus, describing an advisory role by providing options with consequences for the decision taker. Autonomy was often more complex to assign; here, issues around "what is autonomy?" were common. As in all cases, the digital twins exercised some degree of self-autonomy within set delegations, with agency remaining with the actors making decisions. The description of "autonomy" has been well documented by Lee [126] and Endsley [127], both of whom provide a framework to identify the level and form of autonomy.

Decision-making horizons were different depending on the use case of the digital twin. This is hardly surprising given the specificity of the use cases. None of the twins focused on what could be considered "machine protection", where actions are required very rapidly; this is not surprising due to the speed of response required. Higher decision-making support from the digital twins focused on operational, tactical, and strategic levels, where the digital twin's advice helped those making decisions. The product life-cycle services tended to be more tactical to strategic in nature, reflecting the longer-term decision-making of asset management, as compared to operations or maintenance tasks. In the cases where advisory services supported decision-making, it was shown that the actors needed to understand the consequences to enable them to take the optimal decision for the business.

The problems defined from the cases are, in effect, ecosystems with a number of focal actors and avatars, and it is therefore important that the actors/resource integration opportunities are used effectively with the support of the digital twin [128]. Resource integration here can be viewed as the activity and motivation [129] of actors with agency, using operant resources and acting on operand resources [130]. It is important that agency is increased rather than decreased by using the digital twin. This supports the use of questions to define the tasks of the digital twins and the development of options to assist the decision-making processes of the actors involved in value co-creation. This finding is in line with Jonas et al. [131] who described innovation in service ecosystems.

"Agency" is important [97], as the simulation results should be viewed as advisory and limited by the system boundaries [99]. There are many instances where the digital twin will be missing key management information. It should provide the projected consequences of the advice it gives to the actors and offer alternative options. In effect, we are suggesting that the data-driven models do not hold all the answers, but rather they are assisting decision-making within the ecosystem [4,132]. A simple example of digital twins providing advisory information to actors are the widely-used navigation apps and their travel services: options are provided both in terms of the mode of transport and routes—the digital twin provides the consequences (e.g., travel times and complexity of journey). Finally, a digital helper then instructs the traveler, who makes the final decisions.

The digital twin is an advisory service agent in many cases, and it should provide advice within the constraints of its boundaries, as well as options allowing the actors to take action. It needs the use cases to be well understood and described, and the sources of data and the beneficiaries of information to be defined. Based on this, we conclude that however the system is simulated, it should all be brought to the same level: people, machines, and other objects as well as digital twins (including digital helpers) are all actors within the ecosystem.

In summary, when starting out on the development of a solution predicated on digital twins, this study and the literature identified eight managerial issues that should be considered and integrated into the development process. These are described in detail in Table 5, which integrates key managerial issues observed from the cases into eight issues.

Table 5. Managerial issues to consider when designing solutions based on digital twins.

Issue	Details
Understand the service aspects over the technology	The digital twin must deliver a service to support the actors. Use questions (to ask the digital twin) that help define the cases clearly.
Understand the problem space from multiple perspectives	Visualize the problem and the wider ecosystem. Use the direct and indirect stakeholders to provide the initial perspective. Consider the decision-making time horizons.

Table 5. *Cont.*

Issue	Details
Understand the focal purpose of the system	Clearly define the main source of value in the system.
Understand actors in the system	Clarify the actors' roles and the business functions.
Understand the focal beneficiaries	Define their roles and behaviors. Journey map typical situations and highlight crucial dyads.
Understand the avatars in the system	Link the key machines together in the focal value creation process. Identity the actors who interact directly and indirectly with the avatars. Identify the lifecycle phases and the situations where support is required.
Understand the capabilities and level of delegation	Identify the level of monitoring, control, optimization, and delegation expected.
Assess the value co-creation potential	Assume that S-D logic is important but not "operationalized". Use a simple assessment to help maximize value co-creation.

6. Theoretical Implications

To aid the reader, the theoretical implications open with a discussion on visualization to add understanding and to improve decision-making, before considering the value co-creation potentials and then how the digital twin can support value co-creation. This section closes by providing an answer to the research question.

6.1. Visualization of the Cases to Add Understanding and Improve Decision-Making

The visualization of the actors, the avatars, and the flows within the problem space helped to describe to the designers the formation of the dyads that were supporting the value co-creation. Questioning the digital twins helped understand the beneficiary's motivations and supported the design of a digital twin to support them in the decision-making processes. Outside of the decision-making literature, there is a lack of material that describes the importance of system visualization within service science and how it supports the problem understanding. This is contrary to the lean management and service design literature that is rich in its use of visualization techniques as tools to share knowledge and information between different stakeholders. This would produce a more creative environment to allow the development of value propositions based on the digital twin. The development of the system purpose in focus would have been clearer during this understanding phase when the learning is important to support the value discovery. Rules to support the identification of dyads and the actor-to-actor transactions could be imagined and based around potential situations.

The use of visualization within the decision-making process to support the transformation and synthesis of data into knowledge is powerful and should be further investigated. The visuals produced (examples provided in Figure 6) from the simulation software forced the teams to question their assumptions and helped them to integrate knowledge of the processes and the value creation (and destruction) during the modelling development. For example, in Case 8, the visualization of the staff made the partner question the location of the service centers and the time of arrival following a call out. The same visual provided the input for a training simulator based on the digital twin. The new use cases came about prior to the completion of the work. This all points to the fact that more research should be undertaken on the basic visualization of the problem spaces so that they are well understood, allowing the tacit and contextual know how to be integrated with the simulation or statistical models.

6.2. Value Co-Creation Potential

The use of the lens of S-D logic provided many insights into the development process and as a tool provides a check list that operationalized S-D logic. The approach of S-D logic, while not a new approach in the academic environment has, to date, limited application in the practitioner's world where traditionally, a set of requirements would be developed from a high-level use case. Generally, the developers of digital systems have become accustomed to considering a single "user" within the environment. Moving to a multi-actor ecosystem with multiple actor-to-actor transactions and a range of passive and active providers and beneficiaries creates a complex system that requires simplification to allow understanding [18]. The link to value co-creation is improved when exploring the problem with multiple actors who can build a joint solution by providing different perspectives. The potential value co-creation will only be achieved when commitment, trust, and ownership are high [133]. The extended conceptualization of customer solutions [130] is an example of such a framework.

6.2.1. Service Ecosystem

The service ecosystem provided a framework for S-D logic to be incorporated into the concepts and the design of the digital twin. Grönroos [134] described how value was created and who co-created values by providing a revision to S-D logic, an approach that is in line with actor-to-actor value co-creation [12,17,135] and ecosystem orchestration [80,136]. The provision of four aspects (i.e., reliability and integrity, shared views, actor roles, architecture) supports the potential value creation of the digital twin by making the ecosystem aspect of S-D logic more tangible to those developing the twins. The service innovation within a complex ecosystem is difficult to understand and the sub-dimensions provide context to the generally abstract term of "service ecosystem". The information of the actors (rather than users) and shared views aids value co-creation, which will be discussed later. Using the four attributes as prompts, it supports the building of a flexible architecture that is able to deliver a solution that better fulfils the requirements. During the process of developing the solutions, the actor-to-actor (or avatars) exchanges within the service system were mapped out and defined.

6.2.2. Service Platform

The prompts in the service platform (i.e., modular structure, rules of exchange) dimensions provided a form of check list. Rules of exchange needed to be identified from the ecosystem and the individual actors and avatars to allow them to be coded. The application of the modular structure allowed improved placement within what was in most cases a "system-of-systems". Given that today PSS is a system that is part of a system, the exchanges between models needs to be clearly defined, along with the rules of exchange.

The process of developing the digital twin using simulations in effect codes into the digital twin the actual processes and the rules of exchange. Validation is always needed to confirm the applicability of the rules of exchange within the system; the modular approach can be supported again though the development of different simulation modules meaning that a digital twin can be successfully "orphaned" from the live data flows being generated within the wider system. This approach makes the digital twin both easier to integrate into the system and more robust to failures.

6.2.3. Value Co-Creation

Value co-creation is a core tenet of S-D logic and the application here of the sub-dimensions associated with the value creation (i.e., value creation between actors, interactions between diverse actors, accommodation of roles, and resource integration) make the important value creating aspects more tangible. Understanding the actors and their roles in the system, along with the context of the use case, supports the value co-creation, possible with the help of the digital twin. Understanding the actors and their roles allowed the resources to be integrated into the process.

The analysis of the digital twins lacks the comparison of the state before and after in terms of value. Monetization of the potentially improved state with the digital twin is also missing and needs to be investigated more deeply for these cases. It must not be forgotten that the digital twins in the use cases here are at an early stage of development; however, the next steps are to build and test the digital twins. The financial implications of what the digital twin costs must be estimated and compared to the economic benefits of the digital twin's capabilities in use. Stoll et al. [137] have developed and tested a

2×2 decision matrix based on "effort to develop" and "estimated business value" to support the development of a road map, and this should have been applied here. The application of a simple valuation tool would have provided early indications of a return on investment (ROI) for each digital twin. ROI is a very traditional way of assessing value and is widely used for making investment decisions. However, it misses many of the "hard to quantify" aspects of value in a more "social context" (mainly intangible aspects) of value co-creation [138,139]. From the business perspective [140], KPIs to measure the value creation (both tangible and intangible aspects) of digital twins may be required.

6.3. Using Digital Twin Technologies to Support Value Co-Creation

Based on the research question of how digital twin technologies can actually enhance value co-creation, we have seen from ten different digital twin cases that, independent of the degree of autonomy, they can indeed aid value co-creation. The digital twin supports the overall purpose or motivation [129] and provides information, along with alternative options or recommendations, in a form that supports decision-making between a number of actors within the system through the integration of resources and actors [129]. This allows the digital twin to then support the decision-making of other actors [141] who are able to integrate knowledge from outside the system boundaries with the information the twin provides, in effect moving into the domain of wisdom and allowing the actors who always retain final agency to make better-informed decisions. Interestingly, simulations based on the digital twins developed can provide value in terms of offering training opportunities or supporting the development of additional processes based on the scenarios that they can describe.

Digital twins have been used in the past in PSS [92,142] and manufacturing [5,110]. However, the integration of S-D logic to explain technology-driven service innovation here is novel, and thus represents the major contribution of this paper to the current research. The systematic analysis of the wide variety of the use cases (as early concepts) provided an opportunity to understand and support the development of the digital twins in a systematic way, supported in the main by S-D logic. Managers reading the paper can find useful inspiration about the platforms that can be leveraged to different extents, to innovate manufacturing firms' service business.

Applying the framework to operationalize S-D logic could help support the development of Smart Twins as it provides prompts that help digital twin designers understand the complex system and the actors around it. The digital twin is a tool that integrates insights from the various actors, from the system, translating the raw data into a form that can be considered as information by (individual) actors within the ecosystem and support them to make joint decisions and develop the system wisdom from the codified information [60,61]. The digital twin falls within the definition of a Smart Service System as defined by Maglio and Lim [83].

For the value co-creation process, the aspects of governance are important in the development and operation of digital twins. Basic issues of granularity of the history, data privacy, system security, data/information access, and long-term maintenance were not considered in this paper. Moreover, also not fully analyzed was the importance of the "real-time data" requirement of a digital twin as used in the definition of Bolton et al. [3]. Reflections on the use cases suggest that the digital twin does not have to use "real-time" data to allow multi-actor decision-making, although this may be limited to more strategic and tactical decision-making. The authors also recognize the limitations of an "orphaned" digital twin when it comes to effective decision-making.

6.4. The Digital Twin as a Tool to Provide New Opportunities for Value Co-Creation through Supporting Decision-Making

Returning to the research question that formed the motivation for this study: the digital twin has provided new opportunities for supporting value co-creation through supporting decision-making. It has also provided a framework that has supported the co-creation of knowledge during the development phase; this was not something that the work had been planned around. The assessment criteria used have also been applied by the teams and therefore may have had an impact on the outcome of this study. The managerial issues that the digital twin supports are many and varied from simple planning advice, to more complex roles where delegated autonomy is required, or as a trainer. The opportunities are based on the questions that the digital twin is in effect asked to provide help with.

7. Managerial/Practical Implications

The study highlighted three managerial implications for the application of digital twins, where the digital twin aims to support decision-making and aid value co-creation. There is a need for a guide to support integrating the three managerial implications into a practical approach that firms can use to support the exploitation of digital twins. Some of the tools used to assess the cases and some of the visual methods could support firms to develop new opportunities where digital twins could support decision-making and value co-creation between multiple actors. Within this context, the digital twin is relegated to a tool that can support the firm, and as such, may be substituted with other technologies (e.g., simulations or digital threads). The technological focus has its place in early-stage innovation or proof of concept, but the application must be driven by identifying the business value first.

The first implication is that a digital twin is a tool that can support joint decision-making by translating technical considerations into a business context and helping to identify the consequences of different options. It is often best to start with a managerial question rather than starting with the digital twin (i.e., the technology). A question helps focus on the opportunity around the decision and the value co-creation process itself rather than focusing on the technology per se.

The second implication is the description from multiple perspectives of the use case to identify the actors, roles, and motivations (the key issues are described in Table 5). The study confirmed that this is best done visually and needs to be subsequently re-confirmed. This step is a value co-creation phase that focuses on the problem space and considers a complex system rather than a set of abstract and unrelated technical problems. This links strongly back to the questions (or business challenges) where the digital twin supports the decision-making process. Decision-making in firms is generally a multi-actor process where the beneficiary may be identified, although traditional dyadic and triadic relationships provide an oversimplification of a situation. On this basis, the supplier/customer relationships do not necessarily describe the contextual situations where the digital twin can support value co-creation. Additionally, it may be the case where other digital technologies (e.g., simulations that become the basis of training systems) can provide similar value co-creation.

The third implication from the study is that the exploitation internally within a firm may be simpler to achieve than the commercialization of the technology embedded within a new value proposition. The commercialization of a value proposition where the beneficiaries are distributed widely within a firm creates a difficult situation for any sales process. This area of study needed further research; nevertheless, it is consistent with other Industry 4.0 developments where integrating digital into existing or creating new value propositions has been problematic for many firms.

8. Limitations and Further Research

As with any research, there are limitations to the work and further research is recommended. It is important to remember that the cases examined in this paper are in an early stage, and with increasing maturity, more will be learnt. The development of the ten cases examined could have been assessed using action research as an approach and this could have produced a different outcome in terms of a development pathway for digital twins. This would have been a valid approach, as the assessment dimensions offered opportunities for the developers to reflect upon their work.

The detailed instances of the value co-creation processes were not modeled from an ecosystem perspective and, in reflection, perhaps should be in the future. This may provide more evidence on the transformation process of data into actionable knowledge. In particular, we would like to understand which of the steps in the decision-making process contribute to value co-creation and why.

A systemic framework was not applied to the development of the digital twins and here, action research could be applied to help develop a digital twin that supports decision-making based on value co-creation in complex system could be created. This would provide a more innovation management perspective of the process, rather than a service science perspective.

9. Conclusions

In this paper, we explored how digital twin technologies can enhance value co-creation according to S-D logic through 10 different use cases. These were from different industries and different life cycle phases of the assets, which gave a degree of robustness to the findings. The cases are all from the early development of the digital twin services, and therefore the value creation may well be overstated, as it cannot be confirmed at this point in time.

Creating standard definitions of the cases supported those developing the digital twins by giving them a common language to describe the jobs that they expected the twins to do, and how the twin might interact with the other actors within the system. The use of the lifecycle helps to improve the applicability of the developed concepts, as bridging the phases with the digital twin is considered important. Having analyzed these digital twins, it is clear that generic twins could be developed with defined roles.

The use of S-D logic to help to understand the digital twin was helpful for the design team. To support the design of the digital twin, the approaches provided a check list that could be considered "Smart" and helpful for value co-creation by assisting decision-making. S-D logic helped identify agency as an important aspect of the value co-creation, with the digital twin providing decision-supporting advice based on delegated autonomy.

A follow up study is recommended of the digital twins that reach maturity and are developed further from concepts to operational digital twins. From this, the development and the value co-creation processes can be better understood. The follow up should include an assessment of the value of agency in the decision-making process and delegated autonomy.

The paper has not examined governance issues and data storage and sharing regulations; these issues have been identified as important by Almeida, Doneda, and Monteiro [143]. The topic of data privacy and ownership should be investigated in a separate paper, giving insights on how to integrate concepts within existing laws and how to sustainably develop data-enabled services for organizations. However, the cases in the paper came across some difficulties and concerns regarding data privacy and ownership. Due to the early development phase of the digital twins, very little attention was paid to the subject, allowing the developers to innovate freely.

The cases are in an early stage, and with increasing maturity, more details should be added to the cases, elaborating more precisely how the digital twins act as resources that support value co-creation within S-D logic. This would also help to develop the detailed managerial investment criteria for the development of the digital twins. The roles, capabilities, and resources needed to develop and operate a digital twin should also be to be investigated.

Author Contributions: Conceptualization, S.W. and J.M.; methodology, S.Z., S.W. and O.S.; validation, S.Z., S.W., O.S. and J.M.; formal analysis, S.Z., S.W. and O.S.; investigation, S.Z., J.M., S.W. and O.S.; resources, J.M., S.W. and O.S.; data curation, S.W. and O.S.; writing—original draft preparation, S.W.; writing—review and editing, S.Z. and O.S.; visualization, S.W.; supervision, S.W.; project administration, O.S.; funding acquisition, S.W. and J.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Innosuisse (Project 35258.1 IP-SBM).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The cases are reported in depth in the Appendix A.

Acknowledgments: The authors would like to thank the Lucerne University of Applied Sciences and Arts and the Zurich University of Applied Sciences for supporting this work.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Appendix A

The Appendix provides a breakdown of the literature from the literature review and describes the ten cases where the digital twin concepts were fundamental to the value proposition that was being delivered.

Table A1 provides a breakdown of the literature used in the literature review, broken into primary topics and secondary topics. The references are numbered based on the source with the title of the paper.

Table A1. Breakdown of the literature used in the literature review.

Primary	Secondary	References
Classification of products and services with a digital context	Servitization	[22] Servitising manufacturers: The impact of service complexity and contractual and relational capabilities [23] Servitization: revisiting the state-of-the-art and research priorities", International Journal of Operations and Production Management [24] A customization-oriented framework for design of sustainable product/service system [25] Servitization of business: Adding value by adding services [26] The servitization of manufacturing: A review of literature and reflection on future challenges [27] State-of-the-art in product-service systems [28] From products to services and back again: Towards a new service procurement logic [29] Meta-model of servitization: The integrative profiling approach [30] Service business development: Strategies for value creation in manufacturing firms [31] Behavioral implications of the transition process from products to services [32] Managing the transition from products to services [33] Go downstream: The new profit imperative in manufacturing [34] Manufacturing firms and integrated solutions: Characteristics and implications [35] Product service system: A conceptual framework from a systematic review [36] Competitive advantage implication of different Product Service System business models: Consequences of 'not-replicable' capabilities
	PSS	[37] The value architecture of servitization: Expanding the research scope [7] Analytics with digital-twinning: A decision support system for maintaining a resilient port [14] Digital servitization business models in ecosystems: A theory of the firm [24] A customization-oriented framework for design of sustainable product/service system [38] From goods to service(s [39] Inversions of service-dominant logic [40] From products to services: Why it's not so simple [41] The relevance of service in European manufacturing industries [42] Overcoming the service paradox in manufacturing companies
	classification of digital services	[15] Service strategy in action: a practical guide for growing your B2B service and solution business [43] Servitization of the manufacturing firm [44] Eight types of product–service system: eight ways to sustainability? [45] Learning to discover value: Value-based pricing and selling capabilities for services and solutions
	Product lifecycles	[47] "Industrie 4.0" and smart manufacturing-a review of research issues and application examples [48] Midlife upgrade of capital equipment [49] Review on upgradability—a product lifetime extension strategy in the context of PSS
	Product lifecycles and digital	[50] Product lifecycle management—From its history to its new role [51] Design and Development of Product Service Systems [52] Maintenance, Repair, and Overhaul [53] Product lifecycle management in aviation maintenance, repair and overhaul [54] Lean maintenance, repair, and overhaul [55] Aerospace maintenance, repair, and overhaul [56] Several aspects of information flows in PLM [57] Big Data in product lifecycle management [58] Interactions between service and product lifecycle management [59] How Smart, Connected Products Are Transforming Competition

Table A1. *Cont.*

Primary	Secondary	References
Value creation with decision support systems	DIKW	[60] Educational strategies to reduce risk: A choice of social responsibility [61] The wisdom hierarchy: Representations of the DIKW hierarchy [62] Understanding Data, Information, Knowledge And Their Inter-Relationships
	decision support system	[63] Upper Saddle River, New Jersey: Prentice Hall [64] DECIDE: A decision-making model for more effective decision-making by health care managers [65] The role of time frames in design decision-making
	digital technologies supporting human decision-making	[11] Next generation digital platforms: toward human-AI hybrids [66] Operations simulation of on-demand digital print [67] Drilling with digital twins [68] A service design approach to healthcare innovation: from decision-making to sense-making and institutional change
Value creation within digitally-enabled PSS	Value and S-D logic	[14] Digital servitization business models in ecosystems: A theory of the firm [45] Learning to discover value: Value-based pricing and selling capabilities for services and solutions [69] Effective product-service systems: A value-based framework [70] Service innovation: A service-dominant logic perspective [71] Servitization and operations management: A service dominant-logic approach [72] Service-dominant logic and performance-based contracting: A systems thinking perspective [73] An agile co-creation process for digital servitization: A micro-service innovation approach [50] Product lifecycle management—From its history to its new role
	Ecosytems within S-D logic	[70] Service Innovation: A Service-Dominant logic Perspective [74] A Multilayer Framework for Service System Analysis [75] Evolving to a new dominant logic for marketing [76] Architecture vs. ecosystem perspectives: Reflections on digital innovation [77] The service system is the basic abstraction of service science [78] This is Service Design Doing: Using Research and Customer Journey Maps to Create Successful Services [79] Exploring technology-driven service innovation in manufacturing firms through the lens of Service Dominant logic [80] Network orchestration for value platform development [81] An expanded and strategic view of discontinuous innovations: Deploying a service-dominant logic
	Integration of technology	[70] Service Innovation: A Service-Dominant logic Perspective [79] Exploring technology-driven service innovation in manufacturing firms through the lens of Service Dominant logic [82] Technology-enabled value co-creation: An empirical analysis of actors, resources, and practices [83] On the Impact of Autonomous Technologies on Human-centered Service Systems
Value co-creation and information systems	software service platforms	[74] A Multilayer Framework for Service System Analysis [79] Exploring technology-driven service innovation in manufacturing firms through the lens of Service Dominant logic [84] Digital Transformation of ABB Through Platforms: The Emergence of Hybrid Architecture in Process Automation [85] Developing and managing digital service ecosystems: A service science viewpoint [86] IT Service Platforms: Their Value Creation Model [87] Value Creation in Digital Service Platforms–
	digital twins (and AI)	[88] Exploring the role of Digital Twin for Asset Lifecycle Management [89] Simulation Modeling and Hybrid Approaches [90] A survey of simulation modeling techniques in production planning and control [91] Hybrid simulation modelling as a supporting tool for sustainable product service systems [92] Business process simulation for the design of sustainable Product Service System [93] An introductory guide for hybrid simulation modelers on the primary simulation methods in industrial engineering identified through a systematic review of the literature [94] Hybrid simulation modelling in operational research: A state-of-the-art review [95] Hybrid simulation: Historical lessons, present challenges and futures [96] Hybrid simulation models–when, why, how? [97] Evaluation of discrete event simulation software to design and assess service delivery processes
	Agancy	[98] Digital Service: Technological Agency in Service Systems [99] Institutional work—Actors and agency in institutional studies or organizations [100] The role of shared intentions in the emergence of service ecosystems

The basis case descriptions, which were based on eight aspects with defined dimensions supported by the literature, are provided in Table A2. The use cases that will be reported here are:

1. tunnel MRO digital twin Table A3;
2. operations scheduler digital twin for a joinery factory Table A4;
3. wood pattern cutting digital twin Table A5;
4. operations smart factory planning and materials flow Table A6;
5. smart factory asset management Table A7;
6. breakdown support twin for ships Table A8;
7. server room temperature management and control Table A9;
8. tunnel drainage system advisor Table A10;
9. footfall around interchanges Table A11;
10. operations support in facility management Table A12.

Table A2. Basic case descriptions.

Aspect	Dimensions	References
System purpose (or system job-to-be-done)	Basic description of the purpose of the system	Christensen [108] Christensen et al. [107]
Digital Twin type	Process, physical, people	Boschert & Rosen [111] Tao & Zhang [110] Uhlemann, Lehmann & Steinhilper [109]
Business functions	Inbound logistics, operations, outbound logistics, marketing and sales, service, infrastructure, technological development, human resources management, and procurement	Porter [120,121]
Actors and roles	Description of the actors and their roles	Autio & Thomas [17] Frost et al. [74] Lusch & Vargo [12] Polese et al. [112] Vargo & Lusch [115]
Avatars	Overview of the equipment and other critical inputs	Frost et al. [74] Horváth & Rudas [116] Hribernik et al. [117] West et al. [144] Wuest, Hribernik & Thoben [114]
Digital twin job-to-be-done	Tasks the twin should do List of questions (advisory)	Christensen [108] Christensen et al. [107]
Beneficiary actors	Who collects the value	Autio & Thomas [17] Frost et al. [74] Lusch & Nambisan [78]
Main source of value	A description of the value that accrues and where it comes from	Anderson & Narus [118] Anderson, Narus, & Van Rossum [119] Frost et al. [74]

Table A3. Case 1—tunnel maintenance, repair, and overhaul digital twin.

Aspect	Case Details
System purpose (or system job-to-be-done)	The tunnel shortens journey times in a mountainous region: availability is important. Supporting the MRO on the tunnel is critical to maintain the expected availability, further support is required on familiar analysis.
Digital Twin type	Representation of a complex physical asset
Actors and roles	Field service engineers, MRO team, dispatching manager, technical support operator
Avatars	Field service engineers, MRO team, dispatching manager, technical support operator
Digital twin job-to-be-done/Questions to the digital twin	Water pumps, pipes, storage basins, ventilators
Beneficiary actors	Operators: fewer breakdowns and reliable improved troubleshooting capabilities from supplier MRO team (operator and supplier): scheduling MRO activities to minimize downtime.
Main source of value	Keeping the tunnel operational.

Table A4. Case 2—operations scheduler digital twin for a joinery factory.

Aspect	Case Details
System purpose (or system job-to-be-done)	The factory manufactures made-to-order wooden construction components, giving the factory an effective lot size of one or close to one. Planning production runs is critical as there are bottlenecks in the production created by both the machines and the competencies of the production team. There is a lack of real understanding of the true production time (e.g., set up and production time) per operation and so optimization of scheduling can be challenging for operations. Management has difficulties setting production targets in this environment.
Digital Twin type	Representation of a process including the interaction of people and physical assets.
Actors and roles	Sales: sell furniture with a known delivery date. Production manager: plan, manage, and run production. Operators: operate the machines according to schedule; identify competency bottlenecks.
Avatars	Warehouse, machinery, production process
Digital twin job-to-be-done/Questions to the digital twin	To provide scheduling advice for production and lead times sales. What is the current availability of the production line? How much capacity do we have? What is the efficiency? What are the job statuses?
Beneficiary actors	Production manager (for this particular use case) HR for training and development needs Procurement Sales
Main source of value	Efficient production planning for batch size 1 with known delivery date and cost.

Table A5. Case 3—wood pattern cutting digital twin.

Aspect	Case Details
System purpose (or system job-to-be-done)	The factory manufactures made-to-order wooden construction components; wood delivered to the factory must be selected for a particular job and then cut to shape. Optimal selection of the best arrangements/layouts in a three-dimensional system is both time consuming and problematic. However, maximizing the yield of the incoming material has advantages for the factory in terms of reduced waste and therefore costs. Understanding the dimensions of the "off-cuts" also potentially increases the value of the wood that is not initially used.
Digital Twin type	Representation of the processes and a physical representation of the raw materials and semi-finished goods.
Actors and roles	Procurement: improved raw materials planning. Production manager: improved materials usage from the optimized patterns.
Avatars	Raw materials, machinery, production process, semi-finished materials.
Digital twin job-to-be-done/Questions to the digital twin	To provide cutting pattern advice for raw materials and inventory stock of semi-finished goods. How many pieces can I cut from the wood? What will my yield be from the wood? What off-cuts do we have, can we re-use them?
Beneficiary actors	Production manager (for this particular use case) Procurement
Main source of value	Efficient use of raw materials and re-use of "off-cuts"

Table A6. Case 4—operations smart factory planning and materials flow.

Aspect	Case Details
System purpose (or system job-to-be-done)	Using a lab-scale smart factory, where different approaches to planning and materials flows can be tested as a demonstrator of a real factory, new use approaches to improve production can be tested. The lab-scale smart factory follows the value chain from goods inwards, through the processing operations, to the final warehouse prior to shipment.
Digital Twin type	Processes and system capabilities
Actors and roles	Production manager: plan, manage, and run production. Sales: sell furniture with a known delivery date. Operators: operate the machines according to schedule; identify competency bottlenecks.
Avatars	Warehouse, machinery, production process
Digital twin job-to-be-done/Questions to the digital twin	To provide planning options to support optimization of the production planning process so that the team can consider different production routines to fulfil orders. How long will it take to produce the parts ordered? When can we produce them, when will they be ready for shipment? What materials will we need to produce the parts? Do we have enough materials in stock? What is the impact of a rushed order on our current plan? What is the impact on the schedule now that a machine is broken? What does our planned maintenance schedule look like with this production?
Beneficiary actors	Production manager: opportunity to create demand-driven production Sales: understand the real production lead-times. Procurement: material pull for production.
Main source of value	Provision of planning support allowing the "optimal" production schedule to be created and for this to become an agile planning tool where the cost of changes can be presented along with a different planning solution.

Table A7. Case 5—smart factory asset management.

Aspect	Case Details
System purpose (or system job-to-be-done)	Using a lab-scale smart factory, where different approaches to planning and materials flows can be tested as a demonstrator of a real factory, and new use approaches to improve asset management can be tested. The lab-scale smart factory follows the value chain from goods inwards, through the processing operations, to the final warehouse for shipment.
Digital Twin type	Processes and system capabilities
Actors and roles	Production manager: to integrate maintenance into operations and to understand the implications; to understand the impact of new equipment Maintenance: to better plan maintenance events. Finance: to support cost optimization and understand the value capture with new equipment
Avatars	Warehouse, machinery, production, and maintenance process
Digital twin job-to-be-done/Questions to the digital twin	To model the system so that the interrelationships between operations and maintenance can be clearly shared and understood. The model would also be able to integrate new equipment into the simulation. When is planned maintenance next due? What maintenance events are anticipated? What is the expected duration of the maintenance? Is our unplanned maintenance running higher than expected? What happens to our capacity when we buy new equipment?

Table A7. *Cont.*

Aspect	Case Details
Beneficiary actors	Production: understanding of what and when the next MRO event is due; understand how to increase production (quality or volume) at lowest cost. Maintenance: understand the next maintenance events and the necessary pre-planning; understand the impact to MRO of an CMU. Finance: understand the value capture associated with new equipment acquisitions.
Main source of value	Delivery of an agile O&M schedule, allowing run-ons to be examined for additional maintenance costs. By benchmarking performance, improvement plans can be created to support the importation of CMUs that capture value.

Table A8. Case 6—breakdown support twin for ships.

Aspect	Case Details
System purpose (or system job-to-be-done)	The availability and reliability of cruise ships is important to ensure schedules are adhered to. Preventative maintenance is a preferred option of both the ship owners and the supplier, however this does not necessary improve ship availability. In order to improve availability, reduced response time and reduced repair time is required.
Digital Twin type	Representation of physical assets (ships) and status, including their location
Actors and roles	MRO manager: plan maintenance Dispatching manager: assign the ships to jobs
Avatars	Ships and dispatching map
Digital twin job-to-be-done/Questions to the digital twin	To provide a mimic showing the current position and status of the ship allowing ship-to-shore communications to support remote trouble shooting, and to provide options to the dispatching manager to adjust the dispatch plan. What is the status of the ship? What are the best options for MRO? What if I repair now, vs. later? When is the ship going to be ready again?
Beneficiary actors	MRO manager Dispatching manager
Main source of value	Reduced disruption, down-time associated with an unplanned event.

Table A9. Case 7—server room temperature management.

Aspect	Case Details
System purpose (or system job-to-be-done)	The servers in the server room are critical and must have high availability; temperature management is critical to their reliability and there is a need to improve overall equipment up-time and provide further business stability through equipment risk mitigation.
Digital Twin type	Representation of physical asset performance and operational processes
Actors and roles	FM team: carry out routine system checks, improve maintenance services Operations: in the event of failure, able to understand key system knowledge (What? Who? How long? Why?) IT audit team: carry out the system audits to confirm compliance.
Avatars	Avatars: sensor types (temp, air quality, air flow, humidity, air pressure), redundant power systems, key technical room equipment (servers, ventilation, coolers), specific spare parts of tech assets.
Digital twin job-to-be-done/Questions to the digital twin	The digital twin will provide compliance history for the equipment in the condition as it is operated. It will support the temperature management and audit; it will provide information on failure rates and replacement part information. What is the status of the assets as they are maintained and operated? What is the current status of the system? When do parts reach end-of-life? What is the availability of spares (stock and supply chain)? What are the main failures? What is the mean time to repair? What is the impact on the server of the failure?
Beneficiary actors	Facility operators IT team Facility management contractor Maintenance technicians (Operators and IT), supplier maintenance technicians
Main source of value	Providing crucial knowledge to system actors for how to handle situations and providing them with important reports for, e.g., audit reports, health-check reports, and information on which to base their decisions to maintain a stable technical room and thus a stable pipeline.

Table A10. Case 8—tunnel drainage system advisor.

Aspect	Case Details
System purpose (or system job-to-be-done)	The tunnel shortens journey times in a mountainous region; availability is important. The tunnel is equipped with various equipment from many different manufacturers and composed of many different subsystems. Water ingress is dependent on many different factors. Providing a trainer and the operational support tool will support the safe and reliable operation of the tunnel.
Digital Twin type	Representation of a complex physical asset
Actors and roles	Dispatching manager, technical support operator
Avatars	Water pumps, pipes, storage basins, ventilators, wagons
Digital twin job-to-be-done/Questions to the digital twin	To provide advice on the continued safe operation of the tunnel and to provide a simulator training environment to develop mitigation actions. How long do we have until we have to stop operation? How long do we have with pump X out of operation?
Beneficiary actors	Operators: improved risk management through improved risk forecasting and training
Main source of value	Keeping the tunnel safe and operational.

Table A11. Case 9—footfall around interchanges.

Aspect	Case Details
System purpose (or system job-to-be-done)	The multi-modal interchange needs travelers to flow safely around, and for this flow to be coordinated with arrival and departure schedules so overcrowding is not an issue.
Digital Twin type	Representation of a complex physical system integrated with individuals.
Actors and roles	Travelling individuals: taking and changing trains, shopping, using facilities Shopper: access to shops Shops: to sell products and services to the shoppers Station staff: management of the safe operation of the interchange Real-estate management: management of the rental locations
Avatars	Trains, interchange estate
Digital twin job-to-be-done/Questions to the digital twin	To provide simulations of passenger flows. How do we schedule trains to platforms based on travelers? What trains do people take/change to/from? Where and when are there overcrowding events? What is the footfall past each rental location? When switching trains, how long do travelers have for shopping? What is the impact of new extensions to the estate?
Beneficiary actors	Travelers, shoppers, shops, interchange staff, real estate.
Main source of value	Improved safety for travelers, improved rental income from shops, improved shop revenues, improved shopping opportunities.

Table A12. Case 10—operations support in facility management.

Aspect	Case Details
System purpose (or system job-to-be-done)	Facility management requires the facility to be maintained correctly; the initial phase of this is to understand the status from the BIM system as it was built. Routine and planned maintenance needs to be coordinated and integrated with unplanned failures. This has to be synchronized with the maintained state of the facility and integrated into the facility management processes and procedures.
Digital Twin type	BIM and process-based digital twin
Actors and roles	Facility management operations: to provide the facility management on site. The building owner: to own the building and to ensure their investment is managed. The building renter: to know that the building is managed for safety. Facility management procurement: to procure replacement parts and additional services.
Avatars	The building and the components within the building
Digital twin job-to-be-done/Questions to the digital twin	To maintain the BIM system that includes reporting and procurement in addition to supporting maintenance activities. Where is x within the building? How do I do the required task on x? How do we know that the task on x was completed, when is the next service needed? Where can I get a replacement for x?
Beneficiary actors	Facility management operations. The building owner. The building renter. Facility management procurement.
Main source of value	Value will accrue in the form of time saving from the digitalization of the processes: scheduling a task, supporting the task, confirmation the task is completed, automation of reporting, supply chain integration for replacement of components.
Main source of value	Value will accrue in the form of time saving from the digitalization of the processes: scheduling a task, supporting the task, confirmation the task is completed, automation of reporting, supply chain integration for replacement of components.

References

1. Peters, C.; Maglio, P.; Badinelli, R.; Harmon, R.R.; Maull, R.; Spohrer, J.C.; Tuunanen, T.; Vargo, S.L.; Welser, J.J.; Demirkan, H.; et al. Emerging digital frontiers for service innovation. *Commun. Assoc. Inf. Syst.* **2016**, *1*. [CrossRef]
2. Ardolino, M.; Rapaccini, M.; Saccani, N.; Gaiardelli, P.; Crespi, G.; Ruggeri, C. The role of digital technologies for the service transformation of industrial companies. *Int. J. Prod. Res.* **2018**, *56*, 2116–2132. [CrossRef]
3. Bolton, R.N.; McColl-Kennedy, J.R.; Cheung, L.; Gallan, A.; Orsingher, C.; Witell, L.; Zaki, M. Customer experience challenges: Bringing together digital, physical and social realms. *J. Serv. Manag.* **2018**, *29*, 776–808. [CrossRef]
4. Bingham, G.; Bishop, R.; Brody, M.; Bromley, D.; Clark, E.T.; Cooper, W.; Costanza, R.; Hale, T.; Hayden, G.; Kellert, S.; et al. Issues in ecosystem valuation: Improving information for decision making. *Ecol. Econ.* **1995**, *14*, 73–90. [CrossRef]
5. Kunath, M.; Winkler, H. Integrating the Digital Twin of the manufacturing system into a decision support system for improving the order management process. *Procedia CIRP* **2018**, *72*, 225–231. [CrossRef]
6. Sala, R.; Pezzotta, G.; Pirola, F.; Huang, G.Q. Decision-Support System-based Service Delivery in the Product-Service System Context: Literature Review and Gap Analysis. *Procedia CIRP* **2019**, *83*, 126–131. [CrossRef]
7. Zhou, C.; Xu, J.; Miller-Hooks, E.; Zhou, W.; Chen, C.-H.; Lee, L.H.; Chew, E.P.; Li, H. Analytics with digital-twinning: A decision support system for maintaining a resilient port. *Decis. Support Syst.* **2021**, *143*, 113496. [CrossRef]
8. Khan, S.; Farnsworth, M.; McWilliam, R.; Erkoyuncu, J. On the requirements of digital twin-driven autonomous maintenance. *Annu. Rev. Control.* **2020**, *50*, 13–28. [CrossRef]
9. Xia, K.; Sacco, C.; Kirkpatrick, M.; Saidy, C.; Nguyen, L.; Kircaliali, A.; Harik, R. A digital twin to train deep reinforcement learning agent for smart manufacturing plants: Environment, interfaces and intelligence. *J. Manuf. Syst.* **2021**, *58*, 210–230. [CrossRef]
10. Henrion, M.; Breese, J.S.; Horvitz, E.J. Decision analysis and expert systems. *AI Mag.* **1991**, *12*, 64.
11. Rai, A.; Constantinides, P.; Sarker, S. Next generation digital platforms: Toward human-AI hybrids. *MIS Q.* **2019**, *43*, iii–x.
12. Lusch, R.F.; Vargo, S.L. It's all actor-to-actor (A2A). In *Service-Dominant Logic*; Cambridge University Press: Cambridge, UK, 2014; pp. 101–118.
13. Wu, L.W. Co-production in service-dominant logic: Antecedents and consequences. *NTU Manag. Rev.* **2016**, *27*, 25–62. [CrossRef]
14. Kohtamäki, M.; Parida, V.; Oghazi, P.; Gebauer, H.; Baines, T. Digital servitization business models in ecosystems: A theory of the firm. *J. Bus. Res.* **2019**, *104*, 380–392. [CrossRef]
15. Kowalkowski, C.; Ulaga, W. *Service Strategy in Action: A Practical Guide for Growing Your B2B Service and Solution Business*; Service Strategy Press: Scottsdale, AZ, USA, 2017; ISBN 978-0-692-81910-4.
16. Sjödin, D.R.; Parida, V.; Wincent, J. Value co-creation process of integrated product-services: Effect of role ambiguities and relational coping strategies. *Ind. Mark. Manag.* **2016**, *56*, 108–119. [CrossRef]
17. Autio, E.; Thomas, L.D.W. Ecosystem value co-creation. *Acad. Manag. Proc.* **2018**, *2018*. [CrossRef]
18. Ekman, P.; Raggio, R.D.; Thompson, S.M. Service network value co-creation: Defining the roles of the generic actor. *Ind. Mark. Manag.* **2016**, *56*, 51–62. [CrossRef]
19. Chandler, J.D.; Lusch, R.F. Service Systems. *J. Serv. Res.* **2014**, *18*, 6–22. [CrossRef]
20. Meierhofer, J.; Kugler, P.; Etschmann, R. Challenges and approaches with data-driven services for SMEs: Insights from a field study. In Proceedings of the Spring Servitization Conference: Delivering Services Growth in the Digital Era, Linköping, Sweden, 13–15 May 2019; pp. 39–49.
21. Snyder, H. Literature review as a research methodology: An overview and guidelines. *J. Bus. Res.* **2019**, *104*, 333–339. [CrossRef]
22. Kreye, M.E.; Roehrich, J.K.; Lewis, M.A. Servitising manufacturers: The impact of service complexity and contractual and relational capabilities. *Prod. Plan. Control.* **2015**, *26*, 1233–1246. [CrossRef]
23. Baines, T.; Bigdeli, A.Z.; Bustinza, O.F.; Shi, V.G.; Baldwin, J.; Ridgway, K. Servitization: Revisiting the state-of-the-art and research priorities. *Int. J. Oper. Prod. Manag.* **2017**, *37*, 256–278. [CrossRef]
24. Song, W.; Sakao, T. A customization-oriented framework for design of sustainable product/service system. *J. Clean. Prod.* **2017**, *140*, 1672–1685. [CrossRef]
25. Vandermerwe, S.; Rada, J. Servitization of business: Adding value by adding services. *Eur. Manag. J.* **1988**, *6*, 314–324. [CrossRef]
26. Baines, T.; Lightfoot, H.; Benedettini, O.; Kay, J.M. The servitization of manufacturing. *J. Manuf. Technol. Manag.* **2009**, *20*, 547–567. [CrossRef]
27. Baines, T.S.; Lightfoot, H.W.; Evans, S.; Neely, A.; Greenough, R.; Peppard, J.; Roy, R.; Shehab, E.; Braganza, A.; Tiwari, A.; et al. State-of-the-art in product-service systems. *Proc. Inst. Mech. Eng. Part B J. Eng. Manuf.* **2007**, *221*, 1543–1552. [CrossRef]
28. Lindberg, N.; Nordin, F. From products to services and back again: Towards a new service procurement logic. *Ind. Mark. Manag.* **2008**, *37*, 292–300. [CrossRef]
29. Brax, S.A.; Visintin, F. Meta-model of servitization: The integrative profiling approach. *Ind. Mark. Manag.* **2017**, *60*, 17–32. [CrossRef]
30. Fischer, T.; Gebauer, H.; Fleisch, E. *Service Business Development: Strategies for Value Creation in Manufacturing Firms*; Cambridge University Press: Cambridge, UK, 2012.
31. Gebauer, H.; Friedli, T. Behavioral implications of the transition process from products to services. *J. Bus. Ind. Mark.* **2005**, *20*, 70–78. [CrossRef]
32. Oliva, R.; Kallenberg, R. Managing the transition from products to services. *Int. J. Serv. Ind. Manag.* **2003**, *14*, 160–172. [CrossRef]

33. Wise, R.; Baumgartner, P. Go downstream: The new profit imperative in manufacturing. *Harv. Bus. Rev.* **1999**, *77*, 133–141.
34. Windahl, C.; Andersson, P.; Berggren, C.; Nehler, C. Manufacturing firms and integrated solutions: Characteristics and implications. *Eur. J. Innov. Manag.* **2004**, *7*, 218–228. [CrossRef]
35. Annarelli, A.; Battistella, C.; Nonino, F. Product service system: A conceptual framework from a systematic review. *J. Clean. Prod.* **2016**, *139*, 1011–1032. [CrossRef]
36. Annarelli, A.; Battistella, C.; Nonino, F. Competitive advantage implication of different Product Service System business models: Consequences of 'not-replicable' capabilities. *J. Clean. Prod.* **2020**, *247*, 119121. [CrossRef]
37. Martin, P.C.G.; Schroeder, A.; Bigdeli, A.Z. The value architecture of servitization: Expanding the research scope. *J. Bus. Res.* **2019**, *104*, 438–449. [CrossRef]
38. Vargo, S.L.; Lusch, R.F. From goods to service(s): Divergences and convergences of logics. *Ind. Mark. Manag.* **2008**, *37*, 254–259. [CrossRef]
39. Vargo, S.L.; Lusch, R.F. Inversions of service-dominant logic. *Mark. Theory* **2014**, *14*, 239–248. [CrossRef]
40. Baveja, S.S.; Gilbert, J.; Ledingham, D. From products to services: Why it's not so simple. *Harv. Manag. Update* **2004**, *9*, 3–5.
41. Lay, G.; Copani, G.; Jäger, A.; Biege, S. The relevance of service in European manufacturing industries. *J. Serv. Manag.* **2010**, *21*, 715–726. [CrossRef]
42. Gebauer, H.; Fleisch, E.; Friedli, T. Overcoming the Service Paradox in Manufacturing Companies. *Eur. Manag. J.* **2005**, *23*, 14–26. [CrossRef]
43. Baines, T.; Lightfoot, H.W. Servitization of the manufacturing firm. *Int. J. Oper. Prod. Manag.* **2013**, *34*, 2–35. [CrossRef]
44. Tukker, A. Eight types of product–service system: Eight ways to sustainability? Experiences from SusProNet. *Bus. Strat. Environ.* **2004**, *13*, 246–260. [CrossRef]
45. Raja, J.Z.; Frandsena, T.; Kowalkowskibc, C.; Jarmatza, M. Learning to discover value: Value-based pricing and selling capabilities for services and solutions. *J. Bus. Res.* **2020**, *114*, 142–159. [CrossRef]
46. Taylor, S.A.; Hunter, G.L.; Zadeh, A.H.; Delpechitre, D.; Lim, J.H. Value propositions in a digitally transformed world. *Ind. Mark. Manag.* **2020**, *87*, 256–263. [CrossRef]
47. Thoben, K.-D.; Wiesner, S.; Wuest, T. "Industrie 4.0" and Smart Manufacturing—A Review of Research Issues and Application Examples. *Int. J. Autom. Technol.* **2017**, *11*, 4–16. [CrossRef]
48. Khan, M.A.; West, S.; Wuest, T. Midlife upgrade of capital equipment: A servitization-enabled, value-adding alternative to traditional equipment replacement strategies. *CIRP J. Manuf. Sci. Technol.* **2020**, *29*, 232–244. [CrossRef]
49. Khan, M.; Mittal, S.; West, S.; Wuest, T. Review on upgradability—A product lifetime extension strategy in the context of Product Service Systems. *J. Clean. Prod.* **2018**, *204*, 1154–1168. [CrossRef]
50. Terzi, S.; Bouras, A.; Dutta, D.; Garetti, M.; Kiritsis, D. Product lifecycle management—From its history to its new role. *Int. J. Prod. Lifecycle Manag.* **2010**, *4*, 360. [CrossRef]
51. Wuest, T.; Wellsandt, S. Design and Development of Product Service Systems (PSS)—Impact on Product Lifecycle Perspective. *Procedia Technol.* **2016**, *26*, 152–161. [CrossRef]
52. Soares, C. Maintenance, Repair, and Overhaul. In *Gas Turbines*; Elsevier: Amsterdam, The Netherlands, 2008; pp. 493–547.
53. Lee, S.G.; Ma, Y.; Thimm, G.L.; Verstraeten, J. Product lifecycle management in aviation maintenance, repair and overhaul. *Comput. Ind.* **2008**, *59*, 296–303. [CrossRef]
54. Srinivasan, M.M. Lean Maintenance, Repair, and Overhaul. In *The Routledge Companion to Lean Management*; Routledge: London, UK, 2016; pp. 311–320. [CrossRef]
55. Spreen, W. Aerospace maintenance, repair, and overhaul. In *The Aerospace Business*; Routledge: New Delhi, India, 2019; pp. 312–324.
56. Jun, H.-B.; Kiritsis, D. Several Aspects of Information Flows in PLM. In *IFIP Advances in Information and Communication Technology*; Springer Science and Business Media LLC: Berlin, Germany, 2012; Volume 388, pp. 14–24.
57. Li, J.; Tao, F.; Cheng, Y.; Zhao, L. Big Data in product lifecycle management. *Int. J. Adv. Manuf. Technol.* **2015**, *81*, 667–684. [CrossRef]
58. Wiesner, S.; Freitag, M.; Westphal, I.; Thoben, K.-D. Interactions between Service and Product Lifecycle Management. *Procedia CIRP* **2015**, *30*, 36–41. [CrossRef]
59. Porter, M.E.; Heppelmann, J.E. How Smart, Connected Products Are Transforming Competition. *Harv. Bus. Rev.* **2014**, *92*, 64–88.
60. La Longa, F.; Camassi, R.; Crescimbene, M. Educational strategies to reduce risk: A choice of social responsibility. *Ann. Geophys.* **2012**, *55*. [CrossRef]
61. Rowley, J. The wisdom hierarchy: Representations of the DIKW hierarchy. *J. Inf. Sci.* **2007**, *33*, 163–180. [CrossRef]
62. Liew, A. Understanding data, information, knowledge and their inter-relationships. *J. Knowl. Manag. Pract.* **2007**, *8*, 1–8. Available online: http://www.tlainc.com/articl134.htm (accessed on 19 April 2021).
63. Marakas, G.M. *Decision Support Systems in the 21st Century*; Prentice Hall: Upper Saddle River, NJ, USA, 1999.
64. Guo, K.L. Decide: A decision-making model for more effective decision making by health care managers. *Health Care Manag.* **2008**, *27*, 118–127. [CrossRef]
65. Little, S. The role of time frames in design decision-making. *Des. Stud.* **1987**, *8*, 170–182. [CrossRef]
66. Zeng, J.; Jackson, S.; Lin, I.-J.; Gustafson, M.; Hoarau, E.; Mitchell, R. Operations simulation of on-demand digital print. In Proceedings of the IEEE Conference Anthology, Chongqing, China, 1–8 January 2013; pp. 1–5. [CrossRef]

67. Nadhan, D.; Mayani, M.G.; Rommetveit, R. Drilling with Digital Twins. In Proceedings of the IADC/SPE Asia Pacific Drilling Technology Conference, APDT, Singapore, 22–24 August 2018.
68. Patrício, L.; Teixeira, J.G.; Vink, J. A service design approach to healthcare innovation: From decision-making to sense-making and institutional change. *AMS Rev.* **2019**, *9*, 115–120. [CrossRef]
69. Kuijken, B.; Gemser, G.; Wijnberg, N.M. Effective product-service systems: A value-based framework. *Ind. Mark. Manag.* **2017**, *60*, 33–41. [CrossRef]
70. Lusch, R.F.; Nambisan, S. University of Wisconsin–Milwaukee Service Innovation: A Service-Dominant Logic Perspective. *MIS Q.* **2015**, *39*, 155–175. [CrossRef]
71. Smith, L.A.; Maull, R.; Ng, I.C. Servitization and operations management: A service dominant-logic approach. *Int. J. Oper. Prod. Manag.* **2014**, *34*, 242–269. [CrossRef]
72. Nowicki, D.; Sauser, B.; Randall, W.; Lusch, R. Service-Dominant Logic and Performance-Based Contracting: A Systems Thinking Perspective. *Serv. Sci.* **2018**, *10*, 12–24. [CrossRef]
73. Sjödinab, D.; Paridaabc, V.; Kohtamäkiabc, M.; Wincentde, J. An agile co-creation process for digital servitization: A micro-service innovation approach. *J. Bus. Res.* **2020**, *112*, 478–491. [CrossRef]
74. Frost, R.B.; Cheng, M.; Lyons, K. A Multilayer Framework for Service System Analysis. In *Handbook of Service Science*; Maglio, P., Kieliszewski, C., Spohrer, J., Lyons, K., Patrício, L., Sawatani, Y., Eds.; Service Science: Research and Innovations in the Service Economy; Springer: Cham, Switzerland, 2019; Volume II. [CrossRef]
75. Vargo, S.L.; Lusch, R.F. Evolving to a New Dominant Logic for Marketing. *J. Mark.* **2004**, *68*, 1–17. [CrossRef]
76. Nambisan, S. Architecture vs. ecosystem perspectives: Reflections on digital innovation. *Inf. Organ.* **2018**, *28*, 104–106. [CrossRef]
77. Maglio, P.P.; Vargo, S.L.; Caswell, N.; Spohrer, J. The service system is the basic abstraction of service science. *Inf. Syst. e-Bus. Manag.* **2009**, *7*, 395–406. [CrossRef]
78. Stickdorn, M.; Hormess, M.; Lawrence, A.; Schneider, J. *This is Service Design Doing: Using Research and Customer Journey Maps to Create Successful Services*; O'Reilly UK Ltd.: Sebastopol, CA, USA, 2017.
79. West, S.; Gaiardelli, P.; Rapaccini, M. Exploring technology-driven service innovation in manufacturing firms through the lens of Service Dominant logic. *IFAC-PapersOnLine* **2018**, *51*, 1317–1322. [CrossRef]
80. Perks, H.; Kowalkowski, C.; Witell, L.; Gustafsson, A. Network orchestration for value platform development. *Ind. Mark. Manag.* **2017**, *67*, 106–121. [CrossRef]
81. Michel, S.; Brown, S.W.; Gallan, A.S. An expanded and strategic view of discontinuous innovations: Deploying a service-dominant logic. *J. Acad. Mark. Sci.* **2007**, *36*, 54–66. [CrossRef]
82. Breidbach, C.F.; Maglio, P.P. Technology-enabled value co-creation: An empirical analysis of actors, resources, and practices. *Ind. Mark. Manag.* **2016**, *56*, 73–85. [CrossRef]
83. Maglio, P.; Lim, C. On the Impact of Autonomous Technologies on Human-centered Service Systems. In *The SAGE Handbook of Service-Dominant Logic*; Vargo, S.L., Lusch, R.F., Eds.; SAGE: Los Angeles, CA, USA, 2019; pp. 689–699.
84. Sandberg, J.; Holmström, J.; Lyytinen, K. Digital Transformation of ABB through Platforms: The Emergence of Hybrid Architecture in Process Automation. In *Digitalization Cases. Management for Professionals*; Urbach, N., Röglinger, M., Eds.; Springer: Cham, Switzerland, 2019.
85. Kutsikos, K.; Konstantopoulos, N.; Sakas, D.; Verginadis, Y. Developing and managing digital service ecosystems: A service science viewpoint. *J. Syst. Inf. Technol.* **2014**, *16*, 233–248. [CrossRef]
86. Gebregiorgis, S.A.; Altmann, J. IT Service Platforms: Their Value Creation Model and the Impact of their Level of Openness on their Adoption. *Procedia Comput. Sci.* **2015**, *68*, 173–187. [CrossRef]
87. Stadelmann, C.; Ludwin, S.; Tabira, T.; Guseo, A.; Lucchinetti, C.F.; Leel-Össy, L.; Ordinario, A.T.; Brück, W.; Lassmann, H. Tissue preconditioning may explain concentric lesions in Baló's type of multiple sclerosis. *Brain* **2005**, *128*, 979–987. [CrossRef] [PubMed]
88. Macchi, M.; Roda, I.; Negri, E.; Fumagalli, L. Exploring the role of Digital Twin for Asset Lifecycle Management. *IFAC-PapersOnLine* **2018**, *51*, 790–795. [CrossRef]
89. Chandra, C.; Grabis, J. Simulation Modeling and Hybrid Approaches. In *Supply Chain Configuration*; Springer: Berlin, Germany, 2016; pp. 173–195.
90. Jeon, S.M.; Kim, G. A survey of simulation modeling techniques in production planning and control (PPC). *Prod. Plan. Control.* **2016**, *27*, 360–377. [CrossRef]
91. Rondini, A.; Tornese, F.; Gnoni, M.G.; Pezzotta, G.; Pinto, R. Hybrid simulation modelling as a supporting tool for sustainable product service systems: A critical analysis. *Int. J. Prod. Res.* **2017**, *55*, 6932–6945. [CrossRef]
92. Rondini, A.; Tornese, F.; Gnoni, M.G.; Pezzotta, G.; Pinto, R. Business process simulation for the design of sustainable Product Service Systems (PSS). In Proceedings of the IFIP International Conference on Advances in Production Management Systems, Novi Sad, Serbia, 30 August–3 September 2015; pp. 646–653.
93. Scheidegger, A.P.G.; Pereira, T.F.; de Oliveira, M.L.M.; Banerjee, A.; Montevechi, J.A.B. An introductory guide for hybrid simulation modelers on the primary simulation methods in industrial engineering identified through a systematic review of the literature. *Comput. Ind. Eng.* **2018**, *124*, 474–492. [CrossRef]
94. Brailsford, S.C.; Eldabi, T.; Kunc, M.; Mustafee, N.; Osorio, A.F. Hybrid simulation modelling in operational research: A state-of-the-art review. *Eur. J. Oper. Res.* **2019**, *278*, 721–737. [CrossRef]

95. Eldabi, T.; Balaban, M.; Brailsford, S.; Mustafee, N.; Nance, R.E.; Onggo, B.S.; Sargent, R.G. Hybrid Simulation: Historical lessons, present challenges and futures. In Proceedings of the 2016 Winter Simulation Conference (WSC), Washington, DC, USA, 11–14 December 2016; pp. 1388–1403.
96. Lättilä, L.; Hilletofth, P.; Lin, B. Hybrid simulation models–when, why, how? *Expert Syst. Appl.* **2010**, *37*, 7969–7975. [CrossRef]
97. Pezzotta, G.; Rondini, A.; Pirola, F.; Pinto, R. Evaluation of discrete event simulation software to design and assess service delivery processes. In *Service Supply Chain Systems: A Systems Engineering Approach*; CRC Press: Boca Raton, FL, USA, 2016; Volume 8, pp. 83–100.
98. Pakkala, D.; Spohrer, J. Digital Service: Technological Agency in Service Systems. In Proceedings of the 52nd Hawaii International Conference on System Sciences, Maui, HI, USA, 8–11 January 2019.
99. Lawrence, T.B.; Suddaby, R.; Leca, B. *Institutional Work—Actors and Agency in Institutional Studies or Organizations*; Cambridge University Press: New York, NY, USA, 2009.
100. Taillard, M.; Peters, L.D.; Pels, J.; Mele, C. The role of shared intentions in the emergence of service ecosystems. *J. Bus. Res.* **2016**, *69*, 2972–2980. [CrossRef]
101. Yin, R.K. *Case Study Research: Design and Methods*; Sage Publications: Thousand Oaks, CA, USA, 2009.
102. Eisenhardt, K.M. Building Theories from Case Study Research. *Acad. Manag. Rev.* **1989**, *14*, 532–550. [CrossRef]
103. Eisenhardt, K.M.; Graebner, M.E. Theory building from cases: Opportunities and challenges. *Acad. Manag. J.* **2007**, *50*, 25–32. [CrossRef]
104. Voss, C.; Tsikriktsis, N.; Frohlich, M. Case research in operations management. *Int. J. Oper. Prod. Manag.* **2002**, *22*, 195–219. [CrossRef]
105. Baxter, P.; Jack, S. Qualitative Case Study Methodology: Study Design and Implementation for Novice Researchers. *Qual. Rep.* **2008**, *13*, 544–559. Available online: https://nsuworks.nova.edu/tqr/vol13/iss4/2 (accessed on 1 February 2021).
106. Kemmis, S. Critical theory for action research. In *Handbook of Action Research: Participative Inquiry and Practice*; SAGE Publications: Thousand Oaks, NY, USA, 2008.
107. Christensen, C.M.; Hall, T.; Dillon, K.; Duncan, D.S. Know your customers' "jobs to be done". *Harv. Bus. Rev.* **2016**, *94*, 54–62.
108. Christensen, C.M. Integrating around the Job to Be Done, Module Note. Harvard Business School General Management Unit Case 611-004. 2010. Available online: https://www.hbs.edu/faculty/Pages/item.aspx?num=39192 (accessed on 1 February 2021).
109. Uhlemann, T.H.-J.; Lehmann, C.; Steinhilper, R. The Digital Twin: Realizing the Cyber-Physical Production System for Industry 4.0. *Procedia CIRP* **2017**, *61*, 335–340. [CrossRef]
110. Tao, F.; Zhang, M. Digital Twin Shop-Floor: A New Shop-Floor Paradigm towards Smart Manufacturing. *IEEE Access* **2017**, *5*, 20418–20427. [CrossRef]
111. Boschert, S.; Rosen, R. Digital Twin—The Simulation Aspect. In *Mechatronic Futures*; Springer Science and Business Media LLC: Berlin, Germany, 2016; pp. 59–74.
112. Polese, F.; Sarno, D.; Troisi, O.; Grimaldi, M. From B2B to A4A: An Integrated Framework for Viable Value Co-Creation. *Mercat. E Compet.* **2018**, 135–161. [CrossRef]
113. Lusch, R.F.; Vargo, S.L.; Gustafsson, A. Fostering a trans-disciplinary perspectives of service ecosystems. *J. Bus. Res.* **2016**, *69*, 2957–2963. [CrossRef]
114. Wuest, T.; Hribernik, K.; Thoben, K.-D. Digital Representations of Intelligent Products: Product Avatar 2.0. In *Smart Product Engineering, Proceedings of the 23rd CIRP Design Conference, Bochum, Germany, 11–13 March 2013*; Springer: Berlin, Germany, 2012; pp. 675–684.
115. Vargo, S.L.; Lusch, R.F. It's all B2B . . . and beyond: Toward a systems perspective of the market. *Ind. Mark. Manag.* **2011**, *40*, 181–187. [CrossRef]
116. Horváth, L.; Rudas, I.J. Method to enhance intelligent content in integrated product representations. In Proceedings of the IEEE 8th International Symposium on Intelligent Systems and Informatics, Subotica, Serbia, 10–11 September 2010; pp. 647–652. [CrossRef]
117. Hribernik, K.A.; Rabe, L.; Thoben, K.D.; Schumacher, J. The product avatar as a product-instance-centric information management concept. *Int. J. Prod. Lifecycle Manag.* **2006**, *1*, 367. [CrossRef]
118. Anderson, J.C.; Narus, J.A. Business marketing: Understand what customers value. *Harv. Bus. Rev.* **1998**, *76*, 53–55, 58–65. Available online: https://hbr.org/1998/11/business-marketing-understand-what-customers-value (accessed on 10 January 2021). [PubMed]
119. Anderson, J.C.; Narus, J.A.; Van Rossum, W. Customer value propositions in business markets. *Harv. Bus. Rev.* **2006**, *84*, 90. Available online: https://hbr.org/2006/03/customer-value-propositions-in-business-markets (accessed on 10 January 2021). [PubMed]
120. Porter, M.E. *Competitive Advantage: Creating and Sustaining Superior Performance*; Free Press: New York, NY, USA, 1998. [CrossRef]
121. Porter, M.E. Technology and competitive advantage. *J. Bus. Strat.* **1985**, *5*, 60–78. [CrossRef]
122. Osterwalder, A.; Pigneur, Y.; Smith, A.; Movement, T. *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*; Wiley: Hoboken, NJ, USA, 2010.
123. Keeley, L.; Pikkel, R.; Quinn, B.; Walters, H. *Ten Types of Innovation. The Discipline of Building Breakthroughs*; Wiley: Hoboken, NJ, USA, 2013.

124. Uhlenkamp, J.-F.; Hribernik, K.; Wellsandt, S.; Thoben, K.-D. Digital Twin Applications: A first systemization of their dimensions. In Proceedings of the 2019 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC), Valbonne Sophia-Antipolis, Valbonne, France, 17–19 June 2019.
125. Muñoz, E.; Capón, E.; Lainez, J.M.; Moreno-Benito, M.; Espuña, A.; Puigjaner, L. Operational, Tactical and Strategical Integration for Enterprise Decision-Making. In *Computer Aided Chemical Engineering*; Elsevier BV: Amsterdam, The Netherlands, 2012; Volume 30, pp. 397–401.
126. Lee, J.D. Perspectives on Automotive Automation and Autonomy. *J. Cogn. Eng. Decis. Mak.* **2018**, *12*, 53–57. [CrossRef]
127. Endsley, M.R. Level of Automation Forms a Key Aspect of Autonomy Design. *J. Cogn. Eng. Decis. Mak.* **2017**, *12*, 29–34. [CrossRef]
128. Wieland, H.; Hartmann, N.N.; Vargo, S.L. Business models as service strategy. *J. Acad. Mark. Sci.* **2017**, *45*, 925–943. [CrossRef]
129. Findsrud, R.; Tronvoll, B.; Edvardsson, B. Motivation: The missing driver for theorizing about resource integration. *Mark. Theory* **2018**, *18*, 493–519. [CrossRef]
130. Peters, L.D.; Löbler, H.; Brodie, R.J.; Breidbach, C.F.; Hollebeek, L.D.; Smith, S.D.; Sörhammar, D.; Varey, R.J. Theorizing about resource integration through service-dominant logic. *Mark. Theory* **2014**, *14*, 249–268. [CrossRef]
131. Jonas, J.M.; Sörhammar, D.; Röndell, J. Extending Innovation—From Business Model Innovation to Innovation in Service Ecosystems. In *The SAGE Handbook of Service-Dominant Logic*; SAGE Publications: Thousand Oaks, CA, USA, 2018; pp. 655–671.
132. Wehmeyer, M.L.; Shogren, K.A.; Little, T.D.; Lopez, S.J. Decision Making. In *Development of Self-Determination through the Life-Course*; Springer: Berlin, Germany, 2017; pp. 261–270.
133. Petri, J.; Jacob, F. The customer as enabler of value (co)-creation in the solution business. *Ind. Mark. Manag.* **2016**, *56*, 63–72. [CrossRef]
134. Grönroos, C. Service logic revisited: Who creates value? And who co-creates? *Eur. Bus. Rev.* **2008**, *20*, 298–314. [CrossRef]
135. Cova, B.; Salle, R. Marketing solutions in accordance with the S-D logic: Co-creating value with customer network actors. *Ind. Mark. Manag.* **2008**, *37*, 270–277. [CrossRef]
136. Kijima, K.; Arai, Y. Value Co-creation Process and Value Orchestration Platform. In *Global Perspectives on Service Science: Japan*; Springer: New York, NY, USA, 2016; pp. 137–154.
137. Stoll, O.; West, S.; Rapaccini, M.; Barbieri, C.; Bonfanti, A.; Gombac, A. Upgrading the Data2Action Framework: Results Deriving from Its Application in the Printing Industry. In Proceedings of the International Conference on exploring Service Science, Porto, Portugal, 5–7 February 2020.
138. Corsaro, D. Capturing the broader picture of value co-creation management. *Eur. Manag. J.* **2019**, *37*, 99–116. [CrossRef]
139. Line, N.D.; Runyan, R.C.; Gonzalez-Padron, T. Multiple stakeholder market orientation: A service-dominant logic perspective of the market orientation paradigm. *AMS Rev.* **2018**, *9*, 42–60. [CrossRef]
140. Takenaka, T.; Nishino, N.; Nishikori, H. Service benchmarking for the co-creation of service ecosystem. *Procedia CIRP* **2018**, *67*, 574–576. [CrossRef]
141. Jarrahi, M.H. Artificial intelligence and the future of work: Human-AI symbiosis in organizational decision making. *Bus. Horiz.* **2018**, *61*, 577–586. [CrossRef]
142. Zhang, H.; Ma, L.; Sun, J.; Lin, H.; Thürer, M. Digital Twin in Services and Industrial Product Service Systems: Review and analysis. *Procedia CIRP* **2019**, *83*, 57–60. [CrossRef]
143. Almeida, V.A.; Doneda, D.; Monteiro, M. Governance Challenges for the Internet of Things. *IEEE Internet Comput.* **2015**, *19*, 56–59. [CrossRef]
144. West, S.; Stoll, O.; Müller-Csernetzky, P. Avatar journey mapping for manufacturing firms to reveal smart-service opportunities over the product life-cycle. *Int. J. Bus. Environ.* **2020**, *11*, 298–320. [CrossRef]