Journal of Artificial Intelligence and Data Science (JAIDA)
e-ISSN: 2791-8335
https://dergipark.org.tr/pub/jaida

Vol. 4, No. 1, pp. 11-21, 2024
Research Article
Received: 15/03/2024 Accepted: 17/06/2024

The Age of Digitalization in Industry: From Digital Twins to Digital Product Passport

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Abstract

In the age of digitalization, new tools are emerging everyday accommodating Metaverse. Integration of the digital world to the real-world requires a flexible transition framework demonstrated by digital twins (DTs). By definition, DTs constitute a foundation enabling seamless connection using the existing and upcoming emerging technologies. The industry is not exempt from this shift as the digital transformation of industry is already on the way of updating from Industry 4.0 to 5.0. Currently, any transformation attempt is tightly associated with the sustainable development goals. The circular economy requirements challenge the efficiency of the ongoing production mechanisms phrased as smart manufacturing. Therefore, the objective of this paper is to bring to the fore the digital product passport (DPP) that envisioned being a way of pursuing the digitized information through the Internet of Things technology in a production life cycle chain. In this work, a guideline of digital transformation from DTs to DPP is provided on a smart manufacturing process implemented in a laboratory. The method displays the connection between DTs and DPP for a factory model, while discussing possible avenues as well as challenges for further development of the industrial Metaverse. As a result, this study serves as a foundation for companies under digital transformation in achieving better understanding of DT and DPP for a greener, sustainable circle economy.

Keywords: Factory Model; Industrial Metaverse; IoT; Smart Manufacturing; Sustainability.

1. Introduction

The Metaverse is expanding [1, 2]. Its evolution is directly related to the increasing number of user interactions, diverse implementations and proliferating applications. The emerging hardware and software components help to create a better experience with various contents generated in the virtual world. The digitalization effort becomes more apparent with the advanced augmented reality (AR), virtual reality (VR), and extended reality (XR) tools [3]. Previously, Metaverse was known for the composition of the virtual world itself. Today, it is often expressed as a medium for massive interaction centered on the content [4]. The connection of the already existing real-world to a generated virtual/digital world is satisfied through cyber-physical systems. Thus, Metaverse is becoming a foundation for information exchange among humans and those cyber-physical systems.

The undergoing digital transformation envisages shaping the future, embracing machines and humans. It already has significant influence in technological, sociological, and even ideological aspects. This domination will occur not only for building up digitized versions of big physical systems and environments, but also for assembling many small “things” that can be connected in a digital world. The Internet of Things (IoT) technology has enabled this connection through the computer and communication networks almost performing independent of time and physical localization. Due to the standardized enhancements, the IoT technology has now spread to general and everyday use, along with the increasing number of young generations who were born in a comparably higher level of digitalized world [5].

The IoT inevitably has found many extension areas in Industrial IoT (IIoT) where a digital transformation from Industry 4.0 to 5.0 is on the way with the use of artificial intelligence (AI) that particularly depends on machine learning (ML) and deep learning (DL) solutions, handling big amount of data retrieved from sensors through networking [6]. This transition may not be achieved with only a leap in technology. Aside from that it requires multidisciplinary, multiscale processes with coordinated cross functions considering available resources [7]. The digital transformation affects hugely in increasing the resource efficiency of the processes when handled with AI-connected IIoT solutions. It is identified as smart manufacturing that involves all product processes from procurement to recycling in a sustainable way. From this point of view, the manufacturing processes should not only be regarded as finding better efficient solutions for producing products, but also, they have to be designed to pay utmost attention to the environmental and social impacts of all production activities [8].

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The United Nations has announced the sustainable development goals and related supporting activities to be implemented in all member country actions [9]. The sustainability is also fostered by the European Union (EU) together with resilient and human-centered production for Industry 5.0 [10]. In compliance with both demands, circular manufacturing provides the means for increasing resource efficiency and reducing the use of natural resources. Moreover, it will aid in transition to a circular economy where the life cycle of products is extended using the recycled materials from a discarded product that retain their original quality [11, 12].

Digital twin (DT) [13] situated at the center of this digital transformation provides a gate for Metaverse in order to reach to the physical world [3]. Beginning with a virtual model of a product, it became a pillar technology enabling seamless connection of virtual and physical worlds in Metaverse platforms with IoT [14]. In the case of manufacturing, a DT may simulate any real-world object, which is not necessarily just being the product itself. It may simulate all other actions of production related processes and services. Moreover, DT does not only determine but also proposes solutions related to the real-world system [15]. Thus, the processes of manufacturing may have separate DTs or DT stages for consolidation subsequently in several contexts. Each stage then exploits the product's life cycle beginning with design, then following with prototyping, testing, production, usage, and recycling steps [16].

Therefore, creation of a system that can store and share all relevant information throughout a product's life cycle is an evident requirement to follow-up the digitized information attached to the product. The so-called digital product passport (DPP) introduced by the European Commission (EC) is a digital document that may be regarded as a CV of a product, which will help to acknowledge information of the product from design to the end of life. Thus, being a dynamic information structure, a DPP shall enable information capturing and data sharing in a standardized manner among the actors involved.

The importance of this work resides in managing the product life cycle with a DT connected with an informative acknowledgement mechanism of DPP. Therefore, the purpose of this study addresses digital transformation in industry by taking DT at the core and using DPP to reveal information for screening. While digitization might seem like a straightforward process, e.g. converting some real-world data to digital counterparts, there are many challenges that need to be considered for a product and related manufacturing processes. The accessibility of various sensors for manufacturing processes limits the digital transformation while the production phases are ongoing. To alleviate this problem this study offers an in-laboratory factory model applicable to pursue data flow with DT in order to demonstrate and validate both existing and forthcoming new manufacturing designs. This work also proposes to combine DT with DPP for further upcoming regulations for sustainability requirements.

1.1. Challenges and Motivations

In this work, some of the major challenges are addressed as following:

A DT is not limited to achieving a digital transfer of a product. DT also helps to acknowledge requirements for sustainability concepts. When combined with a new way of carrying product information in the life cycles of products, i.e. DPP, enabling a circular economy and greener impact becomes verifiable.

The scientific literature on those concepts is still limited. Unprecedented ideas and application areas are required while establishing new usages of DT and DPP. Standardization efforts help to reveal the relationship on identification of knowledge to be used and then to generalize them for further innovations. Therefore, companies may benefit from this work for a better understanding of DPP. Besides, they will literate digital transformation while implementing the digital technologies embedded in the DPPs.

1.2. Contributions

Our contributions are listed below, taking into account the above considerations:

- A brief summary of DTs and DPPs, including their relations for sustainable, green manufacturing and circular economy.
- Recommendations of using DTs with DPP within three major phases based on our in-laboratory factory model introduced to overcome the difficulties in obtaining data from a real factory.
- Disclosing the dissemination and standardization efforts, identification of some follow-up keywords and discussing opportunities for future research.

1.3. Outline

The rest of the paper is organized as follows: Section 2 presents the related preliminary concepts of DT and DPP with a discussion about the benefits of a DPP for a sustainable circular economy. Section 3 introduces the proposed method, an observable way of combining DTs with DPP in a laboratory model. It also lists requirements for achievement and realization. Finally, Section 4 concludes this study and presents some of the future ideas and keywords.

2. Related Work

2.1. Digital twin

2.1.1. *Concept*

Grieves provided the first characterization of the concept by defining the constituents of DT as real-world, imaginary (virtual) world, and the data/information exchange flow connecting these two worlds [13]. The concept offered for product lifetime management has been extended throughout the years to include not only the product itself but also all physical systems, their environment, and related processes [17]. It was one of the emerging technologies that became at the peak of the expectations in the Gartner curve in 2018 [18].

The ever-increasing value of DT after commencement within smart systems is due to its capability to comply with the digitization efforts. The real-time monitoring and control of the real-world from a distance may be the trivial use of DTs. Beginning from the Computer Aided Design (CAD), Computer Aided Manufacturing (CAM) tools; creation, analysis, manufacturing processes of products have already been computerized and thus related information has been transformed into digital domain. Besides, DT also includes scenario and risk assessment referring to the virtual world where many possible solutions may come up and tested for predictive purposes. One of the major outcomes of using DTs is to enable more efficient, safe, and informed decision support systems built upon considering many scenarios and what-if actions. Personalization and better documentation capabilities resulted with wide applicability of DTs in various areas, suited for diversified purposes [19]. A visualization of the real state of a manufacturing system could substantially improve benefits such as reliability and maintenance while preventing faults through simulations leading to cost effective solutions [7].

Although there is not yet a consensus on the organization of a DT, the building blocks of a DT can be formed in groups as: IoT or IIoT solutions for retrieving data from various physical product or processes; cyber-physical systems for monitoring, controlling and transferring physical sources into digital domain; solutions for dense computations performed with cloud or edge computing, either locally or globally; and solutions incorporating all aspects of data with ML and AI techniques [20]. Those communication, control, computing, and cooperation aspects (i.e., 4Cs) combined in a DT reveal the importance of DT and places it at the center of all schemes.

2.1.2. *Extensions*

The great breakthrough of DT models appeared when a manufacturing industry extended to include operations and services. They do not focus only to create a virtual representation of a prototype, a product, or a physical system but they rather target a more general concept of physical/virtual reality combination where physical systems, environment and related processes are considered together [17]. This reliable bridge of physical and digital domains can completely describe any behavior by means of data, thus it may provide all influencing factors and relationships that are yet unrevealed.

The role of DTs in digitalization helps to widen the perspective of production together with circular economy and sustainability concepts, using the popularized term “green” that is added to all relevant terminology, as in green DTs [21]. In theory, smart manufacturing should be green and sustainable [8]. Consequently, DTs improve the shortcomings of traditional manufacturing and maintain a digitizing platform converting conventional manufacturing to a smarter and hopefully a greener one.

As a result, there have been efforts to standardize DTs under the International Organization for Standardization (ISO). The ISO 23247, defines a DT framework for manufacturing to support the creation of DTs of observable manufacturing elements including personnel, equipment, materials, manufacturing processes, facilities, environment, products, and supporting documents [22]. It is based on the IoT reference architecture and extends it further to define entity-based and domain-based models with a functional view for DTs in manufacturing. When the standardization activities from other bodies such as ETSI and IEEE join together, a generally accepted standard will be available.

2.2. Digital product passport

2.2.1. Concept

Circular manufacturing is providing the means for increasing resource efficiency and reducing the use of natural resources. The information sharing mechanisms among the business and industry stakeholders, public authorities and consumers will increase awareness. It is indisputable that the digitalization positioned within DTs accelerates the shift to a more sustainable circular economy with ecological green designs. With these ideas, the EU as a regulatory body promotes the use of DPPs by its Eco-design for Sustainable Products Regulation (ESPR) [23, 24].

A product is simply composed of many components and subcomponents that are referred to as ingredients. In the perspective of sustainability, the product life cycle considers the product as a whole and thus it comprises of four action phases. It begins from the initial idea and design phase with provisioned requirements. Following is the production phase where the product is manufactured with fewer possible sources with highest efficiency, including resourcing of ingredient materials. Third stage is the operations phase, where the product is operated or used by the concerned parties including end-users while assuring materials to have longer duration in their best form. Final point is the disposal phase where no use of the product is available afterwards, additional actions should be incorporated [16].

A simplified view of the product life cycle conceptualized with the 10-R strategies framework [11] is presented in Figure 1. It describes strategies beginning from the smarter use of products and their manufacturing. Higher levels deal with extending the life of the product and its subparts. At the highest level the objective reaches utmost in achieving recycling and further possible usage of subcomponents, ingredients, or materials.

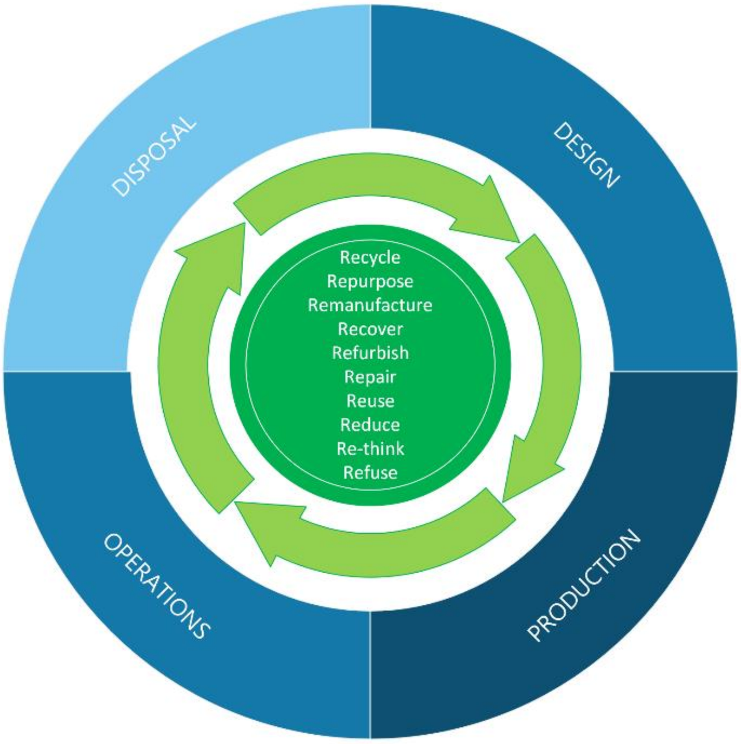

Figure 1. *Product life cycle with 10-R strategies framework.*

A DPP is a digital information document of a product that provides knowledge on the given four levels of life cycle stages considering environmental sustainability. The aim is to establish an extensive and reliable knowledge transfer through the value chain. Providing easily accessible data by scanning a data carrier, such as a watermark or a quick response (QR) code, it helps competent businesses and consumers to make informed choices, while public authorities are able to perform better regulation controls [24, 25].

A representation of DPP stakeholders is illustrated in Figure 2. The manufacturing industry and business part (shown on the upper left) manufactures their products by complying with the rules of public authorities (shown on the upper right) and serves them to users (shown below). The other actors supporting each stakeholder such as the material suppliers and service providers can be included in the industry part, while other bodies such as standardization and task groups may support the authorities. The corresponding digital information is then available to all stakeholders through a smart phone with an accessible QR code. It serves not only to any production or legislative stakeholders but also to any end-user requiring information about the product to check its quality, compliance with the standards, etc. In brief, DPP lies at an intersection of all.

Figure 2. *An illustration of DPP stakeholders.*

2.2.2. Envisaged main benefits of DPPs

Based on the requirements of a more sustainable circular economy with green or eco-design impact, there are many benefits of using DPPs. In compliance with the design of a DPP, it increases transparency such that each collaborator will trace unified information reliably at each stage of the value chain loop. The access and sharing of key product related information would have an impact in transition to a circular economy [26]. Although DPP is still in the pre-conceptual phase and it will more likely display static information, the DPP tool will enable it to follow many eco-design requirements not limited to the product itself but also extended to the sustainability of the product and related resources [27].

The awareness invoked by issuing DPPs will bring advantages on product durability and reliability, possibilities of evoking some of the R strategies from the 10-R model, displayed at the center in Figure 1. Expected major outcomes will be due to carbon footprint reduction and environmental impact tracked by product environmental footprint (PEF) indicators [28], boosting material and energy efficiency by optimizing product design [23]. Moreover, when served as a Product-as-a-Service (PaaS) activity, it will help consumers in making sustainable choices while allowing authorities to verify compliance with legal obligations including trade rules, tariffs, and taxes [29].

On the other hand, DPP offers to be a tool for companies to monitor reaching and administering their sustainability levels, to develop business models enabling resource optimization as well as energy efficiency strategies extending their product lifetimes. The viability of DPPs promotes removing barriers between product manufacturers and end-users, making nimble decisions for better economic and environmental impact in a dynamic digital world.

2.2.3. DPP implementation efforts

As being a new tool under development, there are many efforts in realization of DPPs while overcoming their challenges. First of all, different circular economy activities have potential conflicts [30]. Some of the product related information might be unavailable to the stakeholders [25]. Therefore, it requires an orchestration of DPPs within and between industrial ecosystems while sharing pre-defined digitized information [31].

Secondly, a unified approach for each industry may not be possible or feasible. The duration and updating schedule about the collected data of a product's life cycle is still not clearly defined. Besides, there will always be confidential business information which should be addressed in security and privacy aspects of DPPs [29]. As this task is performed by information technologies using the Internet, solutions require deployment of digital solutions such as IIoT, Blockchain, and Distributed Ledger Technologies (DLT), etc., supported with a Metaverse interface [25, 32].

A recent work [33] lists the consolidated requirements for DPP systems based on system and software quality assessment, structured into eight sections: Legal obligations, functional suitability, security, accessibility, interoperability, modularity and modifiability, availability, and portability. It should be acknowledged that the ESPR provides a comprehensive overview of the requirements of the upcoming DPPs, both in the main text and in the annexes. It will also empower consumers in green transition [24]. Considering DPP as a complex socio-technical system of systems, a DPP Ecosystem is recently defined in order to describe the network of organizations and technologies [34].

Furthermore, a solution underway comes with the CIRPASS project [35], funded by the EC under the Digital Europe Programme. It aims to help in creating a concept for the DPP, demonstrating benefits and roadmaps for its deployment. An understanding of cross-sectoral DPP will build a common source of information for benchmarking purposes.

3. Proposed Work

It is obvious that there are many challenges in representing a real-world system into a digital system. Metaverse is handling some of the interaction issues especially among humans and the environment. Interactions within machines can be both controlled and visualized using DTs. Besides, any action in the digital world or in Metaverse has a consequence in the real-world. Thus requirements in either world must meet with limited resources. The actions should not be performed for today's short-sighted analog-to-digital conversion vision but they have to be over the horizon where the world will definitely be born-digital.

In terms of product manufacturing, digitalization offers a wide range of benefits linked with the circular economy with green or eco-friendly designs acquiring best performance in a sustainable way. Thus, the application of DT and DPP is envisaged to handle the main part in product activities from the design to the end of life. Therefore, they will become a foundation of major business interactions in the digital world when digital transactions, tokens or crypto-currency circulations are considered.

Consequently, one of the purposes of this work is to increase awareness of DT and DPP which will jointly become the leading actors in a digitized industry. However, implementation of these two concepts is not straightforward. Both concepts rely on the information gathered from the real system, particularly from the product itself or from the processes of manufacturing. One of the crucial points is how to access to the real-world data in an operating manufacturing factory. The sensors play the main job capturing data from the real system, however the working environment may cause many difficulties in retrieving data. The collected relevant information needs to be transferred, preferably by the locally displaced IoT devices. Then they become available to be used irrespective of location. Thus, the communication issues should be solved with local, edge, and global computational sources with storage capacity assessments. The other important bottleneck comes with the security issues which business specific information needs to be supervised, either publicly shared, or highly secured.

In order to investigate and offer solutions to overcome those limitations, we propose to use a smart model of a factory constructed in a laboratory while we are building up DT and DPP tools for an under-inspection product and processes. The main idea behind this solution is the ease of accessing the sensors and data in a laboratory environment. The simulation and validation of processes can be quickly demonstrated and verified. Also it brings a dynamic, extensible and adaptive framework where updates of DT and DPP can be performed easily, recalling that the standards and benchmarking are still under development. An illustration of our proposed scheme is presented in Figure 3. The real-world information can be directly transferred to DPP, or through the model factory and its DT while the information flow is bi-directional among these blocks.

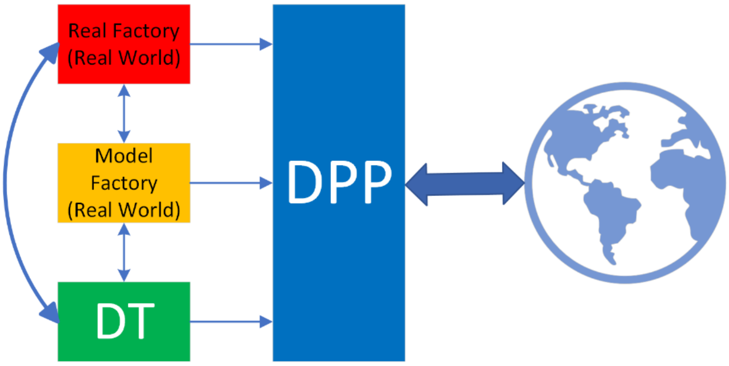

Figure 3. *Information flow transfer from the factory, its model, its DT to DPP.*

In order to implement a DPP of a smart model factory imitated in a laboratory, a holistic three-phase flow is envisaged based on the aforementioned literature screening with DT residing at the core. In each recommended phase, the main motivation is the assignment of DTs that are able to deliver key information to a DPP.

3.1. Recommendations

3.1.1. *Phase 1: Design to manufacture*

The objective of this phase is to create design models of products and manufacturing systems using different types of software programs. Beginning from the CAD, CAM tool drawings, the material information building up the product is required such as the origin and physical properties of the raw material(s). This information is also the first entry for DPP to follow up the product ingredients, materials, usage, and life cycle.

The product manufacturing processes and information flow for building up DTs are also considered in this stage. The detailed drawings are indispensable for building smart manufacturing systems. Initialized with battery, textile, electronics being among the dedicated focus areas [28], extension to other sectors that have high impact on resources with high circularity potential is foreseen. Recently, an example considered in our model factory laboratory for production is marble stones based on a real marble producer production line. The oven models of the production line will enable data acquisition and tracking, such as temperature and humidity of the environment and the product. A selection of main processes or detailed product information for various stakeholders may become available to be released for its DPP. A selection of some utilities or a simplified version of a DPP tool might be considered for the end-users as well.

3.1.2. *Phase 2: Digital twining*

This phase considers building DTs of each production step including machines and supporting system environments. As DT is a software, it is crucial to determine the type, capability, interoperability of the software selected. Steering sensor information into DT and reciprocally sending control commands for actuators in the factory model is the main concern of this phase. Initially defining and further following the key performance indices (KPIs) and PEF indicators become feasible. The ease of definition and calculation of KPIs will help in building scenarios for time, job, human, and energy resource management, as well as reporting with respect to each contributor. Performing what-if actions and exploring the outcomes with ML and AI techniques are the main advantages of a DT. Using the DT-DPP connection, any process specific data or any of the resource management issues are shared for legal regulation controls while they enable access for certain stakeholders. This access is foreseen to be realized with Metaverse connectivity using AR, VR, and XR user-interfaces. On the other hand, Industrial Metaverse (IM) [36, 37] is already available to inform workers on the machines that they use, or to train them with those interfaces before beginning to work in a real environment. Therefore, this stage covers IM that will be extended to integrate content generation with the physical industrial economy [38]. Models with a service-oriented DT within Metaverse-as-a-Service (MaaS) framework can be one of the DT-based solutions [37].

3.1.3. Services, consumption, recycling

This phase deals with the usage of the product till its disposal. This stage collects information from end-users in order to maintain each of the R framework concepts. The duration of the product or any parts supporting the product is important to determine the end of life and then initiate recycling processes. Tracking codes given to the product, displaying necessary time and place information, the profit of using the product denoted by KPI and PEF indicator levels should be displayed by DPP to inform users for increasing awareness in product sustainability. With AI support, all after-production phases can be handled with online-offline scenarios to be performed afterwards.

The proposed phases are organized in the Table 1 according to the general requirements, exemplar DPP display information and associated examples for further clarification.

Table 1. *Recommendations for implementing a DPP.*

Phase	Requirements	DPP Information	Examples
Design to manufacture	Digitized designs; manufacturing system; process information	Product and ingredients; life duration; key production processes; designer, producer, brand information; relevant codes	Origin, physical properties; picture or drawing; brand logo; NACE code; product code, certificates
Digital twining	DT software with options of AR, VR, XR, Metaverse interfaces (e.g., IM)	Product-based information; relevant sensor information; process information	Battery (type, chemicals, metal plate, dimensions, pH)
Services, consumption, recycling	DT software augmented with ML and DL for tracking of data, scenario design	Tracking code; regulations, standards; important dates and conditions; cost; energy savings; services	QR code; standard number; production and best before date; end of life; recovered or recycled material ratio; level of energy saved, carbon footprint; transportation and retail services

3.2. Technical Challenges and Discussions

The phases in Table 1 summarizes the main stages expected in the life cycle of a product. However, there remain many technical problems to tackle for each requirement. The major challenges are grouped and recapitulated as follows.

The first challenge is to obtain the drawings of the product and manufacturing system in a digital format. As there are many CAD/CAM models initiating the design step of a product, convertibility/operability of software files is crucial. Visualization and rendering of 3D animations for DT purposes with various software tools needs to be handled properly. This must be followed by a production system digitalization. Likewise, the production system models are required with individual part drawings to reflect their counterparts in DT. Creating a platform independent tool is foreseen as the best way of overcoming this challenge. Open-source software might be combined in a suitable framework [39].

The second challenge is to obtain data from the real factory. DTs bring their advantages enabling data from sensors then transferring them to the IoT devices. However, real data acquisition is always cumbersome. It requires proper sensors fitted for the purposes. Nevertheless, a sensor model and its DT should be attainable. There comes our proposal that may help to determine which of the data is essential and which can be negligible for the ease of achieving identifiable targets. By the model in a laboratory, these demands can be more easily pursued with a nearby DT. Establishing the connection of manufacturing system data to DT remains mostly production-oriented. Therefore, the solution of this challenge resides in describing the best or preferably the most useful model. Granularity is the key concept to determine the level of accuracy for sufficient and required resolutions. Digitized data always includes rounding errors that should be properly handled.

The storage of data in the cloud systems must be handled where information safety is also entangled to accessing the relevant information with separation of anonymous and authorized users. An additional challenge comes from these security issues that should be considered through all phases. The so-called cyber-security is also one of the major challenges of the digital world including Metaverse. Blockchain and other technologies such as DLT, offer a traceable and verifiable way of managing security issues as well as privacy or sharing options.

The next biggest challenge is due to the usage of the product. The consumption, recycling or PaaS activities may not be fully realized in a laboratory environment. However, MaaS activities will help to embrace DTs and Metaverse which enhanced creation of further digital clones. Then, the sustainability concepts can be tracked through the consumption amount values, time or other KPI information within DT and displayed through DPP.

Nevertheless, with the capability of creating and simulating the scenarios supported by open-software and AI tools [40], DTs are able to handle those challenges. The only challenge left here is to elaborate more realistic scenarios or what-if actions fitted for the real-world.

The final challenge is to incorporate and display data in a DPP such that all the stakeholders can reach appropriate information. As of now, a simple QR code supplying an entry of information coupled within smartphone applications seems to be the common solution.

As a summary, the abovementioned challenges grouped in four D-domain sections, i.e., design, data, deploy, and DPP, are illustrated in Figure 4 with respect to their easiness of achievability. DPP user interface with QR code access is relevantly fulfilled while deploying the sustainability concepts with AI tools requires much more effort.

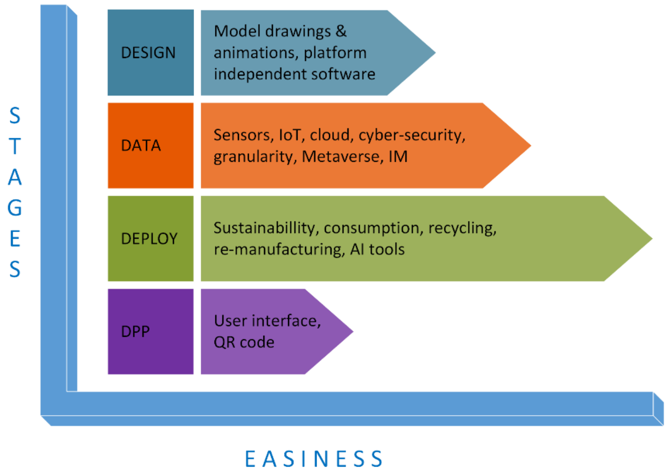

Figure 4. *Technical challenges attempting to satisfy the recommendations of DPP*.

4. Conclusions

The digital transformation has many aspects. In terms of manufacturing products, it may vary from simple digital twinning of a product to a more general benefit of circular and green economy targets with DPP attached to the product and related product-spaces. While the DTs effect in digitalization is obvious, this study demonstrates that DPP becomes inseparable from DTs from a circular economy and sustainability point of view. Therefore, by combining DTs with DPPs, digitalization efforts will be expected to be eco-friendlier or greener, while economic and social benefits will increase in due time.

As summarized in the previous sections, the challenges remain to be solved. Beginning with the digitalization of the manufacturing system, the technical achievements in image processing, computer vision, and related software tools will lead to a better representation of a real-world, thus increasing Metaverse experience. Meanwhile, an indispensable outcome of this digitalization relies on the data acquired from the sensors. The gathering, processing, and storing data in an efficient way with IoT will become the main road of next generation industrial systems with the transformation of systems compatible with the AI technologies.

Therefore, this study attempts to offer solutions by bringing those problems in a laboratory. With a nearby solution where sensor-based information is reliably controlled and where DT is built as close as to the model framework, digitalization aims will be more fulfilled. Besides, any data-oriented solution can be applied such as KPIs where ML and DL techniques aid. Our solution is of course neither covering all issues nor complete in realization of a fully functional DT serving for a DPP. However, it will live and grow up with the uprising of those techniques. Beginning from a simple interface of demonstrating the product origin information, it will cover all necessary and relevant information agreed upon with the upcoming standards scheme. It will always be possible to make updates, extensions or modifications in this framework. The potential avenues for further investigation of concern is relatively wide, ranging from a simple IIoT sensor model representation with its DT to a general system block analysis for prevention of system errors and prediction of failures.

While the main objective of this study is to underline the importance of DT for DPP, the limitations bounded the work in some aspects. First of all, this study remarks that the literature on DT and DPP is rather new. Standards, benchmarks and use-cases are still at their primitive stages and necessitates more groups to gather efforts to predict and manage those shortcomings. As there are many existing technologies available to be used in digitalization, orchestration is required. Moreover, the technological readiness levels for each technique are different. However, it is expected to be merged to higher levels in the following years while some of the standards will be set. This inevitably includes the use of IM and related technologies of Metaverse. This study proposing a laboratory-based solution contributes to the wider discussion on the digitalization specified to DT and DPP, as the future is ineluctable digital.

Declaration of Interest

The authors declare that there is no conflict of interest.

Acknowledgements

The authors thank Smart Factory Systems Application & Research Center (AFSUAM). This study was supported by Scientific and Technological Research Council of Turkey (TUBITAK) under the Grant Number 123E288. The authors thank to TUBITAK for their supports.

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