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Classification of Product Data for a Digital Product Passport in the Manufacturing Industry

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Abstract

The European Commission set out the goal of carbon neutrality by 2050, which shall be achieved by fostering the twin transition – sustainability through digitalization. A keystone in this transition is the implementation of a prospering Circular Economy (CE). However, product information required to establish a flourishing CE is hardly available or even accessible. The Digital Product Passport (DPP) offers a solution to that problem but in the current discussion, two separate topics are focused on: its architecture and its application on batteries. The content of the DPP has not been an essential part of the discussion, although access to high-quality data about a product's state, composition and ecological footprint is required to enable sustainable decision-making. Therefore, this paper presents a classification of product data for circularity in the manufacturing industry to emphasize the discussion about the DPP's content. Developed through a systematic literature review combined with a case-study-research based on common operational information systems, the classification comprises three levels with 62 data points in four main categories: (1) Product information, (2) Utilization information, (3) Value chain information and (4) Sustainability information. In this paper, the potential content structure of a DPP is demonstrated for a use case in the machinery sector. The contribution to the science and operations community is twofold: Building a guideline for DPP developers that require scientific input from available real-world data points as well as motivating manufacturers to share the presented data points enabling a circular product information management.

Keywords

Circular Economy; Circular Ecosystems; Digital Product Passport; Information modeling; Circular product management; Information systems

1. Introduction

Europe is considered to be a frontrunner in the Circular Economy (CE) with a dedicated Circular Economy Action Plan [1]. However, the development of CE is still in its infancy. Only about 13% of the materials used in the EU are secondary materials [2]. This comes at a time when the economy is faced with the challenge of handling disrupted supply chains while managing further import and export restrictions. Organizations are in the process of transforming their traditionally linear-oriented business models into closed resource cycles to secure the prosperity of our society in the long term. In that approach, the use of digital technologies will be central in enabling a fully developed CE [3]. They will provide crucial support in building a CE by disclosing relevant information about materials, substances and product components in a product's life cycle to relevant stakeholders [5,4]. However, this end-to-end transparency on product data is not sufficiently fulfilled today [7,6,5]. In the Circular Economy Action Plan, EU policy mentions digital solutions without being able to provide detailed information on their content and scope [1]. The success of a functioning CE, especially for complex and digitized machinery and equipment, depends on the joint optimization of a cross-company provision of data and the establishment of circular strategies. A potential

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solution is presented by the Digital Product Passport (DPP) [8]. The DPP is a configurable, digital record of an individual product with the objective to enable a circular product lifecycle [9]. Ensuring the implementation of a DPP, several conceptual steps are still required [8]. The first step on this journey is the presented classification of product data which helps in conceptualizing a comprehensive DPP.

2. Theoretical background

2.1 Circular Economy

The CE is a concept keeping products in a value-adding life cycle as long as possible [10,11]. It can be traced back to the approach of Industrial Ecology in the 1990s before modern definitions broadened its scope [13,12]. Modern concepts of the CE have expanded the scope to the complete product life cycle [15,14]. Although no universally accepted definition is known to the author, in practice, a common understanding has been established. According to KIRCHHERR ET AL., CE replaces the existing end-of-life concept by reducing, reusing, recycling and recovering materials in production and consumption processes [15]. Its objective is to preserve and recover as much of the economic and ecological value as possible to reduce the use of naturally limited resources [4,17,16]. Projections estimate that the CE has the potential to save 80-90 percent of raw materials and energy consumption leading to a 25-30 percent reduction in product prices [18].

2.2 Digital Product Passport

The idea of the DPP as a central, product-specific information tool has already been discussed for several years and integrated into the discussion of various instruments such as the digital twin, material passport or life cycle record file [8,9,19]. GÖTZ ET AL. define the DPP as an instrument that provides product information on energy consumption, emissions, production, repair or handling at the end of the utilization cycle [9]. For this purpose, all stakeholders are served in order to facilitate reporting obligations for companies, to enable customers to make sustainable consumption decisions, and to provide repair companies with the necessary instructions [9]. In contrary to GÖTZ ET AL., the DPP aims at supplying information at the end of a utilization cycle but also during its utilization. Nevertheless, the high degree of data transparency and openness required is seen controversial in the scientific community [20]. At the current point in time, the political measures strongly encourage the use of a DPP while the industrial digital capabilities enable an economically viable introduction of the DPP. Especially in the machining industry, connectivity and data processing of industrial equipment have reached a maturity level that supports the implementation of a DPP.

However, despite a lively scientific and political debate, the DPP is not beyond a pre-conceptual phase yet [8,21]. To develop the required input for its content and implementation, a large portion of the challenge remains within the research community. So far, political and industrial players have only defined requirements for the DPP on a basic level [9]. However, there are several digital technologies and industrial standards such as blockchain, the reference architecture model 4.0 (RAMI 4.0) or the Asset Administration Shell (AAS) that are available but have not prevailed yet. Complementing these requirements to ensure the DPP's usability and database summarizes the motivation for this paper. Especially, the manufacturing sector has been chosen due to its unique characteristics of high-value, complex and long-lasting products.

3. Research approach and method

This paper aims at providing a classification for users that are in the process of developing a specific DPP for its industrial equipment. Therefore, the applied methods are practice-oriented to ensure the applicability of this paper's results. The final classification is derived by defining general characteristics in a requirement analysis through a systematic literature review and matching these with existing information attributes that have been derived from a Data Analysis (see figure 1). Apart from a classification, the approach presents a Gap analysis of information that are theoretically existent and that are still not available.

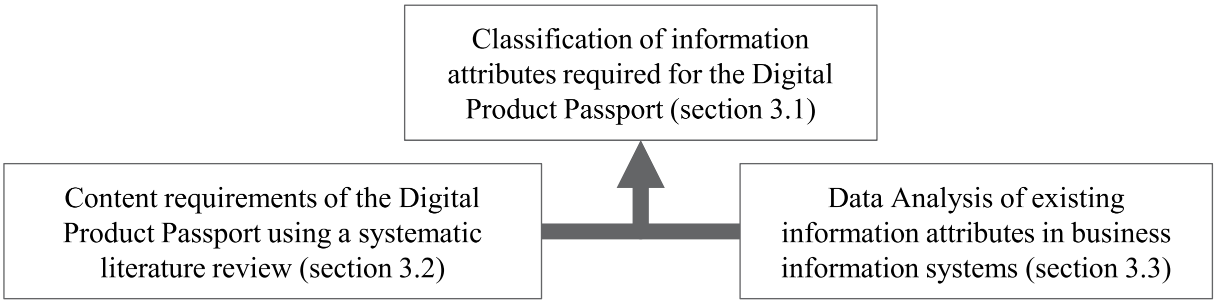

Figure 1 Research method applied in this paper

3.1 Classification

In computational science, classification systems are used as common method to share knowledge and develop a common terminology [22]. Presenting a common starting point for the content of a DPP, the classification method is chosen to reduce complexity and systematically research relevant circular information attributes. In general, classifications are describe by BAILEY as one of the most central conceptualization techniques to reduce complexity and characterize elements [23]. They are defined as *the ordering of entities into groups or class on the basis of their similarity* [23,24]. Therefore, a classification must be exhaustive and mutually exclusive, meaning that there must be a class for each element and no element can fit into two classes [23]. According to VESSEY ET AL., the classification process in computer science requires a *purpose of the classification, criteria for classification* and a *method for classification* [22]. Regarding the purpose, the authors developed a specific classification that primarily classifies relevant information of a DPP. The criteria of the classification are derived using a requirement analysis which is detailed in the next section. Regarding the method, this paper focuses on a qualitative classification with discrete and exhaustive categories.

3.2 Content requirements and systematic literature review

Identifying the content requirements of DPPs, the authors use the requirement approach outlined by the IEEE Computer Society [25]. The authors propose a four-step method containing of *elicitation, analysis, specification* and *validation* to perform a thorough requirement process [25]. Within this part of research, a specification and validation iterations have not been in the scope.

3.2.1 Elicitation

The *requirements elicitation is concerned with the origins of software requirements and how the software engineer can collect them* [25]. In this paper, the authors apply a systematic literature review to identify the passport's requirements scientifically accurately. The research discipline of literature review has established itself and is considered an essential step in the implementation of research projects [26]. It discloses existing research knowledge and established processes in order to gain new insights [26]. The literature search faces the challenge of accurately representing the field of inquiry that the researcher is trying to cover [26]. For this research paper, the PRISMA method (Pre-ferred reporting items for systematic reviews and meta-analyses) is chosen for the literature review process [27,28]. It consists of the four phases *identification*, *pre-selection*, *suitability*, and *final selection* [27]. Structuring the literature search through the appropriate selection of keywords in selected databases and using forward and backward search, relevant articles are efficiently identified [26]. After removing duplicates, the pre-selection is performed by evaluating title and abstract regarding the underlying topic [27]. Subsequently, the suitability of the articles is verified by an analysis of the full text and included in the final selection of the literature review [27].

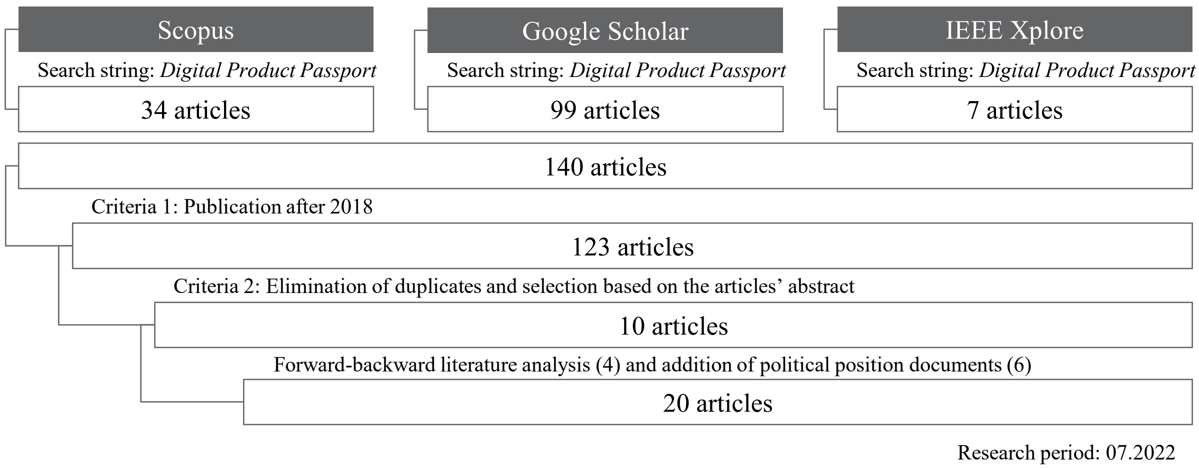

Figure 2 Systematic literature review for the content requirements (own visualization)

Figure 2 shows the literature review process used to identify the relevant literature. Eliminating publications before 2018 and duplicates, 10 articles were initially selected for an in-depth analysis. During this analysis, the forward-backward analysis disclosed additional four papers and it became apparent that the political environment expressed further demands. Therefore, a total of 20 articles were included into the requirement analysis.

3.2.2 Analysis

The requirement analysis traditionally concerns the classification of requirements into a structure that can be implemented [25]. Scanning the identified articles for political and practical expectations regarding the DPP, the requirements have been classified and listed. In total, 19 requirements were identified in table 1.

Table 1: Content requirements for the DPP in the machinery sector

Requirement	**Description of requirement**	**Source**
Production method	Ensure availability of components and parts by disclosing production method and technique	[9,29]
Product design	Enable repair and (de-)assembly by making design information public	[8,21,30,9,31,29]
Material composition	Enable recycling by delivering detail information about a product's material composition	[33,9,31,32,29,20]
Product identification	Ensure unique identification of products by integrating individual recognition features	[8,34,29]
Standardization	Disclose information on applied standards and norms	[9,35]
General information	Make available universal product information	[31,35,20]
Storage and transport	Ensure a product's mobility by releasing storage and transport information	[29]
Utilization characteristics	Enable product-specific R-strategies by analyzing utilization data	[29,35,19]
Status assessment	Enable transparency of a product's status and "health" by gathering relevant status information	[7,21,34,9,32,29,19,20]
Performance history	Measure the product performance to derive a product's performance history	[21,29]
Value analysis	Enable information basis to analyze a product's value	[29,20]
Trustworthiness	Ensure reliability of information by including security measures	[7,20]
Compliance	Ensure compliance of Europe-wide and national regulations by including value-chain information	[20]

Location	Map the current and historical locations of a product	[19,20]
Traceability	Ensure tracking and tracing of products and components through different lifecycles	[8,34,30,35,19,20]
End-of-Life	Make available important information on the End-of-Life options	[8,33,30,32,29]
Ecological impact	Make transparent the ecological impact of a product through data transparency	[21,9,31,20]
Social impact	Make transparent the social impact of a product by gathering the relevant information	[20]

3.3 Data Analysis selecting existing information attributes

Within the requirement analysis, it was highlighted that the DPP should be built upon existing information that is easily accessible in organizations. Therefore, a Data Analysis has been applied to identify the content and information baseline of current organizational information systems. Applying a case study research approach, a selection of information systems to scan for data points was made based on the list created by BOOS AND ZANCUL [36,37]. The selection of the information systems is featured in figure 3. Subsequently, a longlist of data points that can be tracked by these systems was derived and summed up to 1.128 data points. Focussing the longlist on a data analysis, two criteria for the selection were established: the abstraction level of *information* must be met and the data point must be product-related. In total, 51 information attributes were selected (see figure 3).

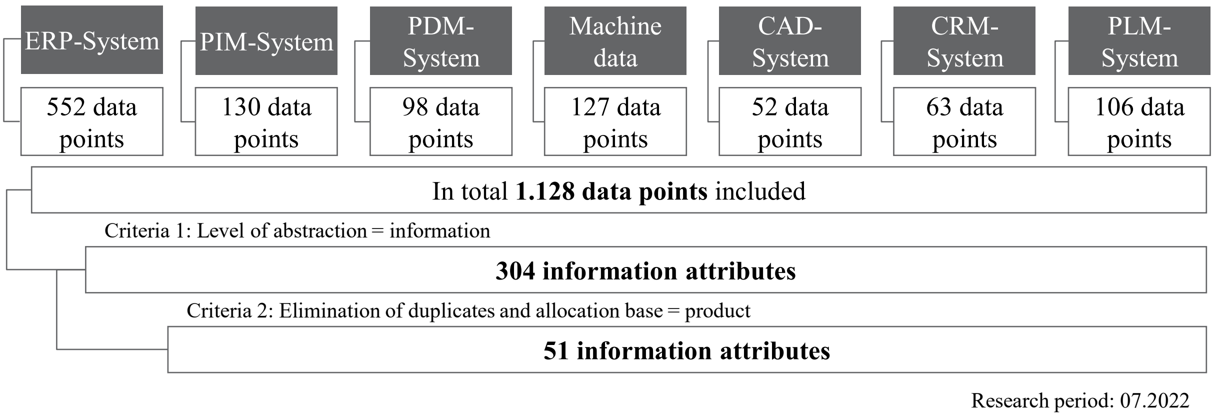

Figure 3 Qualitative data analysis of information systems (own visualization)

4. Classification of Product Data for a Digital Product Passport

Having detailed the research methodology, the classification of Product Data for a DPP of industrial equipment is presented. In total, the classification contains 62 information attributes in 21 sub-categories and 4 main categories. 51 information attributes can be met by current information systems while 11 still need to be developed to meet the DPP's demand. In total, the classification consists of 3 category-levels that are presented in the following. With this classification, software developers have a starting point to build the content architecture of the DPP.

4.1 Categories of the classification

Especially the four main categories and its 21 sub-categories give an indication of the scope of the DPP. This classification allows any user to obtain an overview of relevant content areas when implementing its specific DPP. The four main categories are adapted from BERGER ET AL. and contain *Product information, Utilization information, Value chain information* and *Sustainability information* [21]. The *Product Information* describe master information about the product itself that is mostly non-changeable and known after designing or manufacturing. In contrast, the *Utilization Information* are configurable data that can dynamically be adjusted during its lifecycle and largely consist of usage and service data. The *Value chain Information* contain adjustable data of a product's supply chain to increase transparency along its stakeholders. This especially focuses on its supply chain actors. The *Sustainability Information* contain data to generate a digital twin of ecological, social, and circular information. Figure 4 presents the main and sub-category.

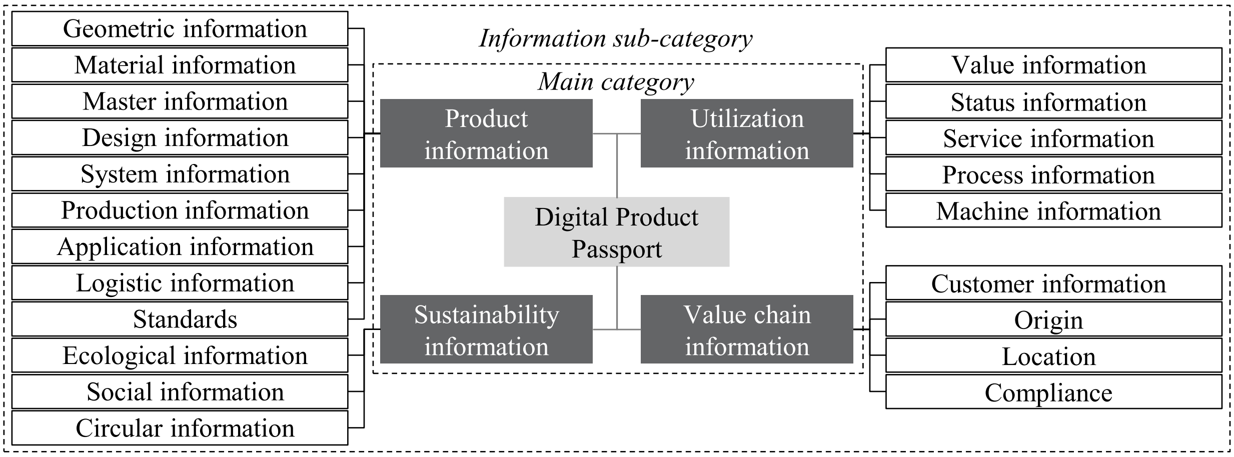

Figure 4 Main categories and sub-categories for the content of a DPP in the manufacturing industry

4.2 Information attributes of the classification of Product Data for a Digital Product Passport in the manufacturing industry

In the following, each sub-category and their information attributes are presented in detail.

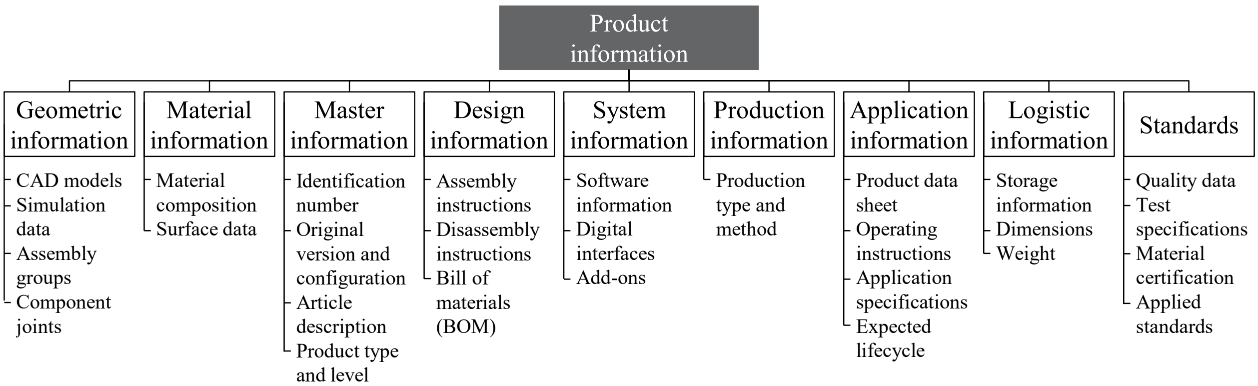

Figure 5 Information attributes of the main category "Product information"

The main category of *Product information* holds 9 sub-categories. The sub-category of *Geometric information* focuses on digital three-dimensional models of a product's components and their grouping. The sub-category *Material information* contains data about the material composition and surface structure of a component. *Master information* consists of identifying and additional data about a product's characteristics. *Design information* provides data about the (de-)assembly and components of a product and industrial equipment. *System information* characterizes a product's digital and software capabilities. *Production information* presents further data about manufacturing processes and applied methods. *Application information* is the category providing further information on how to use and operate the machinery efficiently. *Logistic information* contains all data required to store and transport a product or its components. *Standards* comprises data to achieve test specifications and standards that have been used for the product.

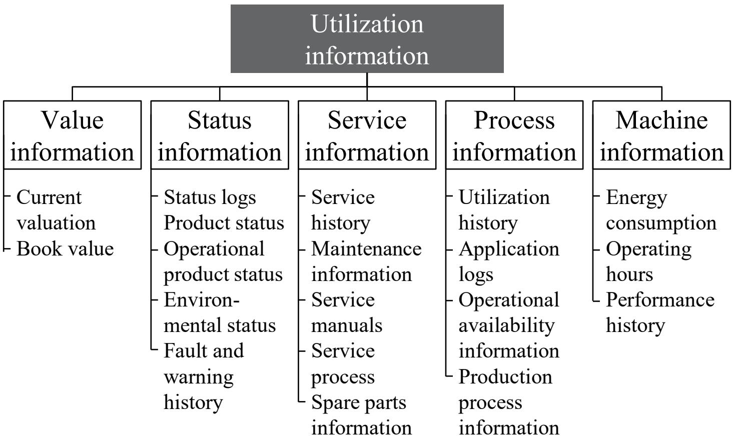

Figure 6 Information attributes of the main categories "Utilization information"

The main category of *Utilization information* has 5 sub-categories. *Value information* is a dynamic figure that stores the current valuation and book value of the industrial equipment. *Status information* describes data of the current and historical condition of the machine storing logs and the warning history. *Service information* stores data about maintenance and service from manuals to service history. *Process information* includes information about the production processes that can be utilized to analyze a machine's physical condition and performance. *Machine information* contains information about the historical performance and energy consumption that can support in a machine's condition monitoring.

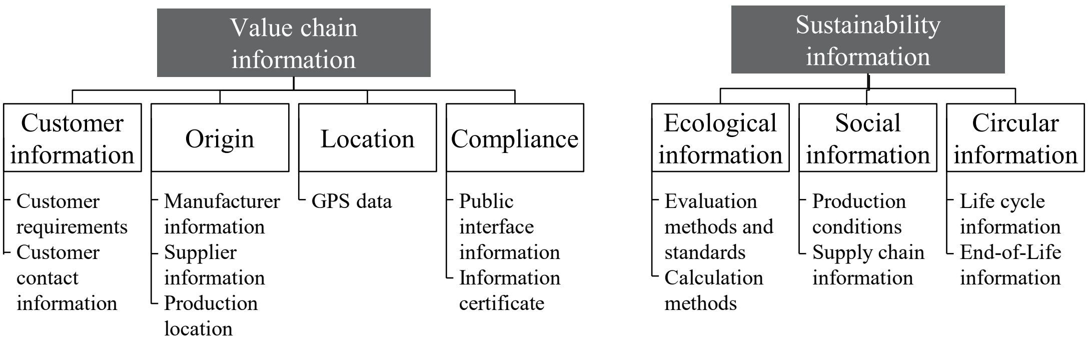

Figure 7 Information attributes of the main categories "Value chain information" and "Sustainability information"

The main category of *Value chain information* comprises 4 sub-categories. *Customer information* includes information about previous users and customers including their specific requirements and usage history. *Origin* stores information about the machine's origin including location of manufacturing. *Location* contains information about the GPS data and the current location of the machine. *Compliance* describes a class that stores information about interfaces and security measures to comply with public regulations.

The main category of Sustainability information comprises the 3 sub-categories of *ecological, social* and *circular information.* These sub-categories contain all information that is required to generate a comprehensive sustainable picture of the machine.

5. Conclusion and future research

The developed content classification of a DPP in the manufacturing industry is a significant step forward in order to enable organizations to benefit from the potentials of a digital CE. This paper should be seen as opportunity starting a scientific discussion about what information is necessarily required and what is optional. The four categories of *Product Information, Utilization Information, Value chain Information* and *Sustainability Information* give an indication of the information types and areas that are required. The 21 sub-categories enable a comprehensive scope of required information types, that still offer a configurable space depending on the specific use case. In contrast, the 62 information attributes should be seen as initial proposition of relevant material to enable the objective of a digitally enabled CE. It is beneficial that 51 attributes are, in theory, already existing and accessible. However, there is still the challenge to specify 11 attributes that are demanded but not existent in current information systems.

Still undefined is the question of detailing the level of a product-based or component-based DPP. Ideally, component-based DPPs consolidate into a product-based DPP but further research is required to detail the approach. In addition, the classification still requires a validation to review if further information is missing. A validation with software and industry experts should be aimed for to ensure full applicability and integrity. The high abstraction level of the presented classification also necessitates a more detailed data model before implementation. Therefore, future research should focus on connecting the presented information attributes to explicit information software systems and derive a strategy of how to implement common interfaces. This also applies to the information accessibility between different stakeholders in the lifecycle of a machine. This element will be addressed in further research by the authors enabling a digital ecosystem. From an industrial perspective, the industrial players should start building trusted ecosystems in which they can deploy a basic version of the DPP using the identified main categories and gather firsthand experience. Fundamental questions such as a centralized or decentralized architecture can be tested under real-world conditions.

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Biography

Lukas Stratmann holds an M.Sc. RWTH degree in Mechanical Engineering and Business Administration from the RWTH Aachen University. He is currently doctoral candidate at the FIR Institute for Industrial Management and team leader for Ecosystem Design. His specific focus is research in circular ecosystems and how stakeholders can be incentivized to implement a Circular Economy.

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