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# An ODP-based Ontology for the Digital Product Passport

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**Abstract**

The challenges posed by climate change can only be met by changing the economic mindset to one that focuses on the idea of a circular economy (CE). Digitalization, data collection and data storage play a crucial role here: Product-related data should be collected in a consistent manner throughout the entire life cycle of the product and stored in a Digital Product Passport (DPP). The DPP should give all stakeholders of the CE access to the necessary data. Overarching modelling is required to ensure that a DPP can be used as a structure across application domains in an interoperable way. Ontologies can act as an interlingua between domains, incorporating the required domain knowledge and the full range of requirements for the DPP. Following a modular approach based on Ontology Design Patterns, this paper develops a DPP ontology with a focus on the R-strategies within the CE. Furthermore, the paper builds a bridge to the standardized approach of Industry 4.0, the modelling and storage of structured domain knowledge in Asset Administration Shells (AAS). Data can be seamlessly integrated and used for decision-making in each product life cycle phase. In addition, the reuse of existing concepts defined by others is demonstrated. The developed ontology is then evaluated on a CE use case.



*Keywords:* Circular Economy; Digital Product Passport; Ontology; Ontology Design Patterns, Asset Administration Shell

## 1. Introduction

At the moment, humanity is consuming more resources than the planet can provide. In order to overcome this, we must shift from a linear economy to a Circular Economy (CE). One key instrument in the CE is the Digital Product Passport (DPP) which is described, e.g., in the EU's Circular Economy Action Plan [1] and the Eco-design for Sustainable Products Regulation [2]. The DPP is supposed to facilitate communication among the stakeholders of a product's life cycle such that product-related information can be propagated and shared. However, there is not only a multitude of stakeholders along the product life cycle [3], but also across different sectors and industries. One big challenge is to ensure that all those diverse stakeholders understand each other, otherwise the DPP will be of limited use. Hence, the DPP must be interoperable, and the information it contains must be findable. Furthermore, it must be ensured that different stakeholders can contribute information to the DPP. One common way to achieve this is to model information in ontologies [4]. An ontology for the DPP could greatly improve its interoperability and, ultimately, its usability.

However, there are major challenges in semantic technology that hinder stakeholders from benefiting from an ontological information model: Diverse backgrounds, languages, tools, and techniques are a major barrier to effective communication among people and organizations which prevent conceptual understanding in each subject area. The authors believe this can be improved by breaking down a concept into small blocks which, in turn, can facilitate reuse, sharing, interoperability, and a more reliable ontological model. This is also in line with the FAIR data principles [5], which constitute a guideline for information modelling. It states that data should be *Findable*, *Accessible*, *Interoperable*, and *Reusable*.

To achieve both interoperability and to follow the FAIR principles, a series of Ontology Design Patterns (ODPs) for the DPP are created and introduced in this paper. Specifically, the ODPs act as an Ontology Engineering Tool in building a modular ontology of the DPP. For evaluating the modular DPP ontology, a use case from the CircThread project is considered. In this use case, the DPP ontology is employed to facilitate end-of-life decisions related to damaged products.

The rest of the paper is organized as follows: Section 2 describes the current state-of-the-art. In Section 3, the methodology used for building the ODP and the resulting ontology is discussed. In Section 4, the use case is described. In Section 5 the creation of the set of ODPs and the resulting ontology and their evaluation are explained, respectively. Finally, in Section 6 the conclusion and future work are presented.

## 2. Background and Related Work

### 2.1. Information requirements for the DPP

Implementing the DPP requires meeting several specific requirements. Plociennik et al. [3] focused specifically on the requirements for DPPs to enhance the CE, while Berger et al. [6] and Soufi et al. [7] discussed the requirements for DPPs related to Electric Vehicle Batteries (EVBs). Götz et al. [8] identified the key elements and additional requirements for DPPs. Neligan et al. [9] described the DPP as a reliable information source, or "product memory," accessible to various stakeholders throughout a product's life cycle and addressing environmental impacts by including sustainability details. Saari et al. [10] explored how DPPs fit into the CE ecosystem, discussing R-strategies and offering some requirements for DPPs. Stratmann et al. [11] provided a table of DPP requirements, including descriptions and sources, and discussed various information attributes. Westerlund [12] examined the requirements and challenges associated with implementing DPPs. We performed a review of the recent DPP literature and distilled a list of the most prominent information requirements for the DPP. Table 1 presents a detailed mapping of these requirements to the corresponding publications that mention them.

Table 1. Required information for the DPP

| Req. | Description | References |
|---|---|---|
| R1 | Product unique identifier | [6, 1, 8, 10, 7, 11, 3, 12] |
| R2 | Manufacturer information | [6, 8, 13, 10, 11, 12] |
| R3 | Product technical information and characteristics | [14, 6, 1, 8, 13, 10, 7, 11, 15, 12] |
| R4 | User manuals and instructions (e.g., disassembly, safety) | [14, 6, 1, 8, 13, 10, 7, 11, 3, 15, 12] |
| R5 | Lifecycle data or product history (e.g., running hours, service log) | [14, 13, 10, 11, 3, 15, 12] |
| R6 | Product localization | [6, 8, 10, 11] |
| R7 | Environmental and social information and impact | [6, 13, 10, 11, 15, 12] |
| R8 | Bill of materials (raw material, suppliers, spare parts) | [14, 8, 13, 10, 3, 15, 12] |
| R9 | End-of-life management (e.g., repairability, recyclability) | [14, 13, 16, 10, 11, 15, 12] |
| R10 | Certification and legalization information | [10, 11, 3, 12] |

### 2.2. Asset Administration Shell (AAS)

The alignment with Industry 4.0 requires digitalization, interoperability and availability of the information. This aligns with the well-established concept of the *Digital Twin* and its implementation via Asset Administration Shell (AAS) [20], the information model framework introduced by the working group known as Industrial Digital Twin Association e. V. (IDTA)[1], who is in close collaboration with Platform Industrie 4.0[2]. Based on the specification of AAS, every valuable object in manufacturing can be defined as an *Asset* and the information related to that asset should be modelled with the standardized meta-model of AAS. A product is considered as one of the most valuable objects in the manufacturing field. All the related information of a product during its whole life cycle can be modelled using AAS and can be presented as a DPP [21, 22]. The semantic aspect of AAS is described as the possibility of creating a connection between each model element to existing and available ontologies, such as ECLASS[3], IEC CDD[4], or any newly developed ones, via an attribute called "SemanticId". In this case, an agent is required to semantically retrieve the information and perform the necessary reasoning task. Another approach is to translate the AAS metamodel to ontological languages and develop an ontology for AAS that can be used for reasoning tasks, as it investigated in the survey by Beden et al. [23]. However, due to space and time constraints, the connection between the AAS and the developed DPP ontology is regarded as future work in this paper. Yet, there are a few standardized submodels[5], introduced by IDTA, that are relevant to the DPP concept, DPP4.0 – The Digital Product Passport for Industry 4.0[6], which each can be modeled as an ODP. This set of submodels includes *Hierarchical Structures enabling Bills of Material*, *Handover Documentation*, *Carbon Footprint*, *Generic Frame for Technical Data*, *Contact Information* and *Digital Nameplate*.

### 2.3. Ontology Design Patterns (ODP)

Due to the complexity and huge size of existing ontologies, reuse of them becomes a difficulty. The common approach nowadays is to reuse relevant parts of an ontology already developed for another domain or use case. However, in reality, in most cases, users will end up building their own ontology, or existing ontologies are used as a mere 'inspiration' and guideline for creating new ontologies, which is not optimal. This is where the concept of Ontology Design Patterns (ODPs)[7] [24, 25] becomes crucial. ODPs are reusable building blocks for ontology modelling; they mostly use OWL as the formal pattern encoding. OPPL [26] and OTTR [27] are examples of using other

[1] https://industrialdigitaltwin.org/
[2] https://www.plattform-i40.de/IP/Navigation
[3] www.eclass.eu
[4] https://cdd.iec.ch/cdd/iec61360/iec61360.nsf/TreeFrameset
[5] https://industrialdigitaltwin.org/content-hub/teilmodelle
[6] https://dpp40.eu/
[7] www.ontologydesignpatterns.org

Table 2. List of applied criteria on related work regarding DPP ontology

| Related Work | C1: DPP requirements coverage (cf. Table 1) | C2: DPP Metadata | C3: ODP-based Modular approach | C4: Link to AAS | C5: Usage of existing Standards | C6: Available support |
|---|---|---|---|---|---|---|
| Kebede et al. [17, 18] | R1, R2, R4, R5, R6, R7, R8, R9, R10 | – | ✔ | – | ✔ | ✔ |
| Kurteva et al. [19] | R2, R3, R6, R8, R9 | – | ✔ | – | ✔ | ✔ |
| Jansen et al. [13] | R1, R2, R3, R4, R8, R10 | – | ✔ | – | ✔ | ✔ |

languages for representing ontology modelling patterns. ODPs can be of several types, but the focus in this paper is on Content ODPs (CPs). CPs can be understood as ontology snippets, or parts, which inherently are introduced as a modular structure. Reuse of ODPs requires comprehensive documentation. Karima et al. [28] ran 3 surveys to find out which aspects of an ODP are important for the documentation. The surveys' results showed that the key ODP documentation fields consistently considered most important include *Graphical Illustration* or *(UML) Diagram*, *Examples of ODP Use*, and *Competency Questions*. In this paper we cover all three.

### 2.4. Related DPP Ontologies

In recent years, significant research has been conducted in the field of the Circular Economy, focusing on semantic information modeling and developing ontologies. Li, Huanyu, et al. [29] did a survey on existing ontologies in related domains, such as Circular Economy Ontology Network (CEON) [30], Building Circularity Assessment Ontology (BCAO) [31], Circular Materials and Activities Ontology (CAMO) and Circular Exchange Ontology (CEO) [32], BiOnto ontology [33]. However, as Jansen et al. [13] observed, none of the existing ontologies are fully suitable for use in the DPP. Nonetheless, ongoing efforts, summarized in Table 2, have focused on developing a dedicated ontology for the DPP. These efforts adopt a modular approach, leveraging existing ontologies and standards to build a framework that facilitates interoperability. However, a critical aspect – the significance of the Asset Administration Shell (AAS) (see Section 2.2) and its employment in the DPP concept – is not addressed in these works. Moreover, the importance of modelling DPP metadata is also not considered in these efforts. To evaluate these existing works, a list of criteria (C1-C6) is defined, which is then applied to each approach. Table 2 shows the result of the evaluation.

### 2.5. Related Ontology Engineering Methodologies (OEMs)

There are existing methodological approaches that aim to facilitate ontology development. As Spoladore et al. [34] clarified, there are three groups of Ontology Engineering Methodologies (OEMs): *Waterfall*, *Lifecycle approach* and *Agile approach*. They evaluate most of the OEMs based on the set of criteria they defined. They also introduced *AgiSCOnt* [35], a novel Agile OEM that meets all their criteria while effectively leveraging existing ODPs. However, their approach emphasizes reusing current ODPs rather than developing new ones.

Although the combination of existing methodologies, as Yang explained [4], can be handy for ontology development, the goal of this paper is to present a set of ODPs that offer the flexibility to develop larger, more comprehensive ontologies. The eXtreme Design methodology (XD) [36] appears to be a better fit to fulfill this purpose, as it was introduced specifically for ODP-based ontology design and modular ontologies. The so-called Modular ontology modeling (MOMo) methodology [37] is another ODP-based OEM which is an extension of XD methodology, which with its supporting tooling infrastructure, Comprehensive Modular Ontology IDE (CoModIDE) [8] plug-in to Protégé[9], the open-source ontology framework, emphasizes modular development and design pattern reuse. Despite the fact that the MOMo methodology is not defined to develop a DPP ontology or DPP ODPs, it can be taken into account in future work.

## 3. Ontology Design Methodology

Ontology modularization is crucial for managing large and complex ontologies, especially if only specific parts of an ontology are relevant for a particular task. By applying modularization to early steps of ontology engineering, instead of building a huge ontology, data and their meaning are modelled as a set of modules. This directly addresses concerns about scalability and interoperability of ontologies. It also brings the benefits of reusability, extensibility and maintainability, access rights manageability, performance improvement of ontology-driven systems, etc. to the semantic web community [38]. For the development of ODPs in this paper, existing concepts were reused, e.g., the Carbon Footprint defined by the IDTA and the Open Energy Ontology. These are depicted with their logos in Figure 1.

This paper follows the XD methodology of applying modularity to ontology design based on the idea of ODPs. First, a set of small building blocks (modules) are defined to be developed based on the general DPP requirements listed in Table 1, which are the abstraction of DPP metadata and product-related information. Modules are divided and assigned to *module owners*, who are responsible to develop their modules by following the XD methodology steps. Afterwards, based on a specific use case adapted from a CircThread project deliverable [39], a set of ODPs are specified and selected from the list of developed

[8] https://comodide.com/tutorial.html
[9] https://protege.stanford.edu/

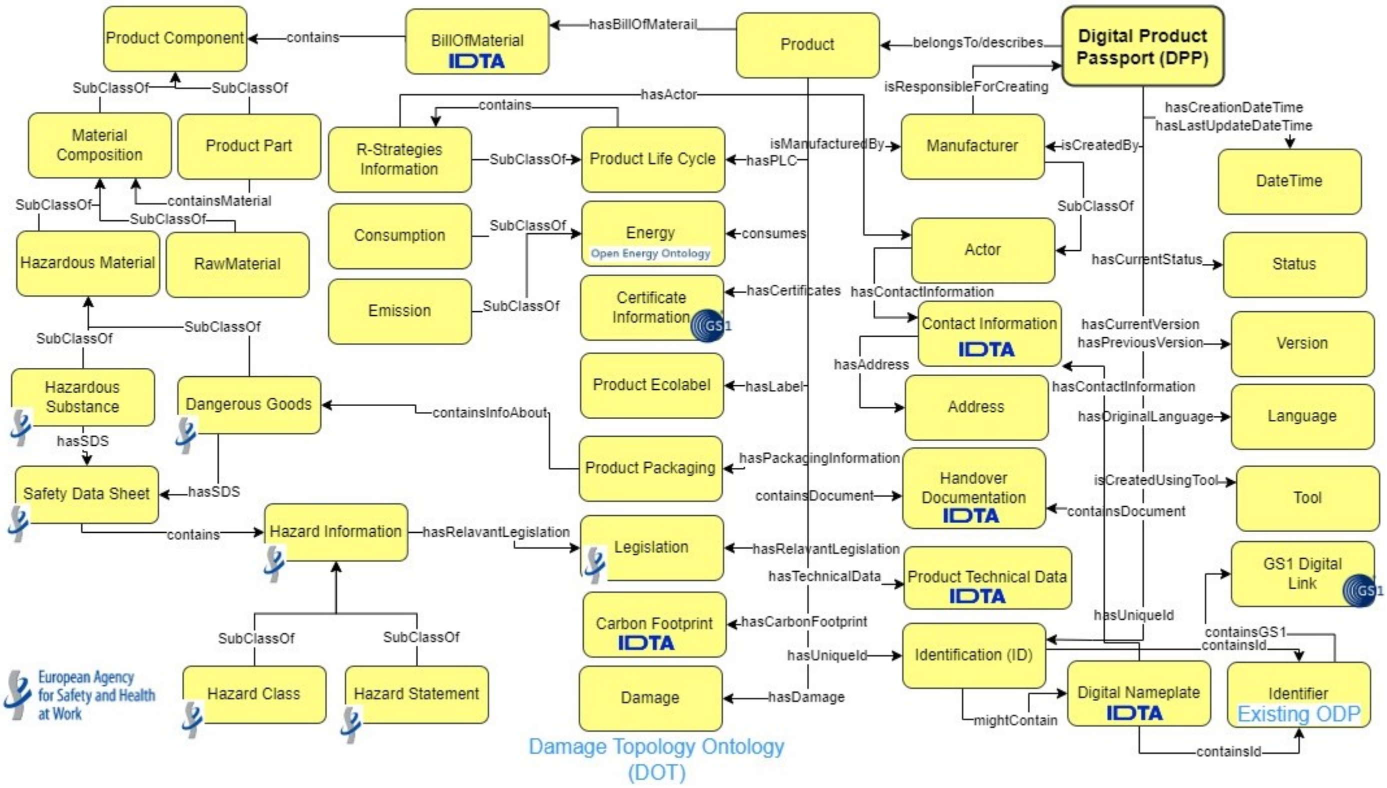


Fig. 1. Overview of the Digital Product Passport (DPP) ontology

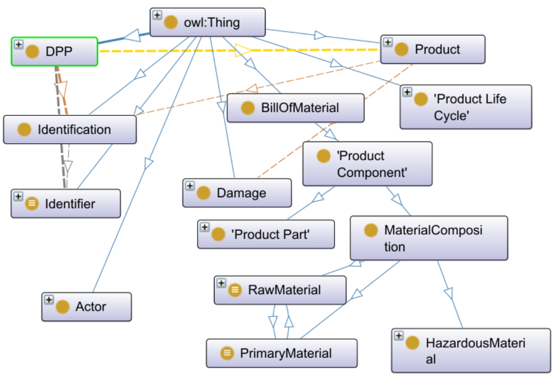


Fig. 2. Overview of resulting DPP ontology for the use case in Section 4

ODPs. The selected ODPs then are merged together to create the resulting DPP ontology in order to fulfill the requirements of the use case. Figure 1 shows the general list of developed ODPs and Figure 2 depicts the selected ODPs to form the resulting ontology.

## 4. Use Case

The use case is required to be simple to evaluate the resulting ontology of the DPP, which is a merged ontology from the developed ODPs. The DPP is meant to be used throughout the whole product life cycle to bring transparency and provide relevant information to a wide range of stakeholders. The use case presented in this paper is a simpler version of the use case described in CircThread project deliverable 6.3 [39]. The use case aims to support end-of-life (EOL) stakeholders and organizations – such as repair shops, original manufacturers, resellers, B-stock managers, and collection operators – in evaluating damaged products to promote and enhance their circularity. The stakeholder, in this case B-stock manager or collection operator, receives household electronic products, for instance washing machines, along with their DPPs. The products are labelled as damaged. The DPP should act as a collection of information about the product and the damages it sustained. The goal is to aid the stakeholders in the decision task of how to proceed with the product, either send it to *Repair* or *Reuse*, or *Disassemble* and *Recycle* the product. Based on the use case above and according to the needs of the stakeholder, a list of Competency Questions (CQ) is defined. Table 3 includes only a few CQs due to limited space. A table containing a more comprehensive list of CQs is available on the GitHub page[10].

## 5. DPP Ontology

### 5.1. Development of the ODP-based DPP Ontology

To satisfy the use case, the following set of ODPs from Figure 2 are selected: DPP, Product, Identification, Product BillOfMaterial. Additionally, the Damage Topology Ontology (DOT)

[10] https://github.com/CircThreadH2020/Ontology-design-Pattern-for-Digital-Product-Passport

Table 3. Evaluation of the DPP ontology with Competency Questions (CQ) from the perspective of an end-of-life actor

| No. | Competency Questions (CQ) | dppOnto Class | Object Properties | Data Properties |
|---|---|---|---|---|
| 1 | What is the unique identifier of the product - based on the given DPP unique id? (see Figures 3 & 4) | DPP, Product, Identification, Identifier | :hasId, :containsId, :belongsTo | :hasIdentifierAsText |
| 2 | Is the product damaged? What is the damage type? | Product, Damage, FaultCode | :hasDamage, :hasFaultCode | :CodeMeaning |
| 3 | Can the damaged parts be disassembled? | Product, Damage, FaultCode, Product Part | :hasDamage, :hasFaultCode, isRelatedTo | :canBeDisassembled |
| 4 | Does the device contain valuable materials? | Product, Damage, RawMaterial, Metal | :hasDamage, :hasRawMaterial | :isValuable, :WeightComposition |
| 5 | Does the device contain hazardous substances? | Product, Damage, Hazardous Substance | :hasDamage, :hasHazardousSubstances | – |

```
SELECT ?dpp ?dppUniqueId ?product ?productUniqueId
        WHERE {       { ?dpp rdf:type dpp121:DPP .
                ?dpp dpp121:hasId ?identification .
                ?identification dppOnto:containsId ?idL1 .
                ?idL1 dpp144:hasIdentifierAsText ?dppUniqueId .
        FILTER ( str(?uniqueId) ||
                "dfki.sfkllab/dpp/dppwm/id/c6bb13b0-0aa3-4fb9-9b40-f14ddb7263cd" ) .
        }
        ?dpp dpp121:belongsTo ?product .
        ?product dpp121:hasId ?identificationP .
        ?identificationP dppOnto:containsId ?idL1P .
        ?idL1P dpp144:hasIdentifierAsText ?productUniqueId .
        }
```

Fig. 3. SPARQL Query for CQ No.1 in Table 3

[40] is reused and imported to model the damage to the product or its parts. The Actor module and the Life cycle module are reused directly from the ontology that has been developed in the CircThread project[11]. The Identifier module is an existing ODP that is used to model the unique identifier of both DPP and Product. The BillOfMaterial module developed based on the AAS BillOfMaterial submodel contains information about the Product Parts and its Material Composition, which contains Raw Material and Hazardous Substances of a product.

The documentation of ODPs is crucial; it must not only be accessible but also facilitate their reuse by making it easier for ontology engineers to understand them [28]. One way is to submit the ODPs to the community catalogue available on the website, Concept OPs catalogue[12]. However, at the time of writing this paper, unfortunately the website is not available. Therefore, the ODPs and the resulting DPP ontology are uploaded on the GitHub page[10] which is dedicated for this paper.

### 5.2. *Evaluation of the DPP ontology*

The evaluation of the DPP ontology is achieved by executing the SPARQL queries associated with the CQs to show the fulfilment of the defined requirements and logical correctness of axioms, relations, and instances of the DPP ontology. As an example of performed SPARQL queries, Figures 3 and 4, which are screenshots from the Protégé Tool[9], show the SPARQL query of the CQ no. 1 in Table 3 and its query result, respectively. All queries and their results are available on the GitHub page[10], along with the resulting DPP ontology and its UML diagram. However, providing a proper documentation of it via the WIDOCO[13] tool is a task for future work.

## 6. Conclusion and Future Work

The DPP can facilitate the transition from the linear economy to the Circular Economy (CE). It should provide interoperability as well as transparency of product-related information during the entire product life cycle for a wide range of stakeholders. In this paper, modeling such information in an ontological language is proposed to ensure that this goal is achieved. This work lays the groundwork for a broader goal: the development of a more extensive set of ODPs, which can be integrated to fully meet DPP requirements. This approach aims to enhance the flexibility of the DPP ontology, enabling it to address a wider range of CE use cases. For example, future work could focus on calculating the CO2 footprint associated with energy consumption throughout the product life cycle.

The DPP is itself a Digital Twin (DT), and one of the most common representations of the DT in Industry 4.0 is the AAS. One of the future works of this paper is to develop an ontology-based AAS for the DPP and build the connection between them to be in line with Industrie 4.0. Furthermore, improvement of the developed ODPs based on industrial standards is also part of future work. This paper follows the Ontological Requirement of defining *Competency Questions (CQ)* and running queries to evaluate the developed ontology. There are two more Ontological Requirements, *Contextual Statements* and *Reasoning Requirements*, which are considered as future work to improve the validity of the DPP ontology.

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[11] https://circthread.com/
[12] http://ontologydesignpatterns.org/wiki/
[13] https://dgarijo.github.io/Widoco

| dpp | dppUniqueId | product | productUniqueId |
|---|---|---|---|
| DPPwm | "dfki.sfkllab/dpp/dppwm/id/c6bb13b0-0aa3-4fb9-9b40-f14ddb7263cd" | Washing Machine | "dfki.sfkllab/product/wm/id/690af76e-efe7-4e5b-a745-545e33c870ae" |

Fig. 4. Query result of SPARQL Query of Figure 3

## References


[1] The European Commission, A new Circular Economy Action Plan For a cleaner and more competitive Europe (2020).
[2] European Commission, Proposal for Ecodesign for Sustainable Products Regulation (2022).
[3] C. Plociennik, M. Pourjafarian, S. Saleh, T. Hagedorn, A. d. Carmo Precci Lopes, M. Vogelgesang, J. Baehr, B. Kellerer, M. Jansen, H. Berg, et al., Requirements for a Digital Product Passport to Boost the Circular Economy, INFORMATIK 2022 (2022).
[4] C. Yang, Y. Zheng, X. Tu, R. Ala-Laurinaho, J. Autiosalo, O. Seppänen, K. Tammi, Ontology-based knowledge representation of industrial production workflow, Advanced Engineering Informatics 58 (2023) 102185.
[5] M. D. Wilkinson, M. Dumontier, I. J. Aalbersberg, G. Appleton, M. Axton, A. Baak, N. Blomberg, J.-W. Boiten, L. B. da Silva Santos, P. E. Bourne, et al., The FAIR Guiding Principles for scientific data management and stewardship, Scientific data 3 (1) (2016) 1–9.
[6] K. Berger, R. J. Baumgartner, M. Weinzerl, J. Bachler, K. Preston, J.-P. Schöggl, Data requirements and availabilities for a digital battery passport–A value chain actor perspective, Cleaner Production Letters 4 (2023).
[7] C. Soufi, T. Mesbahi, A. Samet, Digital Battery Passport as an Enabler of Environmental Impact Assessment in Electric Vehicle Applications, in: IEEE Vehicle Power and Propulsion Conference, 2023.
[8] T. Götz, H. Berg, M. Jansen, T. Adisorn, D. Cembrero, S. Markkanen, T. Chowdhury, Digital product passport: the ticket to achieving a climate neutral and circular european economy? (2022).
[9] A. Neligan, C. Schleicher, B. Engels, T. Kroke, Digitaler Produktpass – Enabler der Circular Economy: Relevanz und Umsetzbarkeit durch Unternehmen, Tech. rep., IW-Report (2023).
[10] L. Saari, J. Heilala, T. Heikkilä, J. Kääriäinen, A. Pulkkinen, T. Rantala, Digital product passport promotes sustainable manufacturing: whitepaper (2022).
[11] L. Stratmann, G. Hoeborn, C. Pahl, G. Schuh, Classification of product data for a digital product passport in the manufacturing industry, in: Proceedings of the Conference on Production Systems and Logistics: CPSL, 2023.
[12] L. Westerlund, Enabling a circular economy with digital product passports: Information requirements and data collection practices (2023).
[13] M. Jansen, E. Blomqvist, R. Keskisärkkä, H. Li, M. Lindecrantz, K. Wannerberg, A. Pomp, T. Meisen, H. Berg, Modelling Digital Product Passports for the Circular Economy, KG4S Workshop (2024).
[14] K. Berger, R. Baumgartner, M. Weinzerl, J. Bachler, J.-P. Schöggl, Digital battery passport information content for end of (first) battery life management support, 2023.
[15] J. Walden, A. Steinbrecher, M. Marinkovic, Digital Product Passports as Enabler of the Circular Economy, Chemie Ingenieur Technik (2021).
[16] R. H. Reich, J. Ayan, L. Alaerts, K. Van Acker, Defining the goals of product passports by circular product strategies, Procedia CIRP 116 (2023) 257–262.
[17] R. Kebede, A. Moscati, H. Tan, P. Johansson, A modular ontology modeling approach to developing digital product passports to promote circular economy in the built environment, Sustainable Production and Consumption 48 (2024) 248–268.
[18] R. Kebede, Ontology and knowledge graph-based product data representation for sustainable buildings: A case of data integration and digital product passport, Ph.D. thesis, Jönköping University (2024).
[19] A. Kurteva, C. van der Valk, K. McMahon, A. Bozzon, R. Balkenende, RePlanIT Ontology for FAIR Digital Product Passports of ICT: Laptops and Data Servers, Semantic Web journal (2024).
[20] IDTA, Specification of the asset administration shell part 1: Metamodel, Specification, Industrial Digital Twin Association (2024).
[21] M. Pourjafarian, C. Plociennik, M. H. Rimaz, P. Stein, M. Vogelgesang, C. Li, S. Knetsch, S. Bergweiler, M. Ruskowski, A Multi-Stakeholder Digital Product Passport Based on the Asset Administration Shell, in: IEEE 28th International Conference on Emerging Technologies and Factory Automation (ETFA), 2023.
[22] C. Plociennik, A. Nazeri, M. H. Rimaz, S. Knetsch, A. do Carmo Precci Lopes, T. Hagedorn, J. Baehr, M. Vogelgesang, C. Li, W. Benner, B. Kellerer, E. Ionescu, M. Ruskowski, A. Weidenkaff, Connecting Producers and Recyclers: A Digital Product Passport Concept and Implementation Suitable for End-of-Life Management, Procedia CIRP 122 (2024).
[23] S. Beden, Q. Cao, A. Beckmann, Semantic asset administration shells in industry 4.0: A survey, in: 2021 4th IEEE International Conference on Industrial Cyber-Physical Systems (ICPS), IEEE, 2021, pp. 31–38.
[24] A. Gangemi, V. Presutti, Ontology Design Patterns, Springer Berlin Heidelberg, Berlin, Heidelberg, 2009, pp. 221–243.
[25] R. d. A. Falbo, G. Guizzardi, A. Gangemi, V. Presutti, Ontology patterns: clarifying concepts and terminology, in: Proceedings of the 4th Workshop on Ontology and Semantic Web Patterns, Vol. 1188, 2013.
[26] M. Egaña Aranguren, R. Stevens, E. Antezana, Transforming the axiomisation of ontologies: The ontology pre-processor language, Nature Precedings (2009).
[27] M. G. Skjæveland, D. P. Lupp, L. H. Karlsen, H. Forssell, Practical ontology pattern instantiation, discovery, and maintenance with reasonable ontology templates, in: The Semantic Web – ISWC, 2018.
[28] N. Karima, K. Hammar, P. Hitzler, How to document ontology design patterns, in: Advances in Ontology Design and Patterns, IOS Press, 2017, pp. 15–27.
[29] H. Li, M. Abd Nikooie Pour, Y. Li, M. Lindecrantz, E. Blomqvist, P. Lambrix, A survey of general ontologies for the cross-industry domain of circular economy, in: Companion Proceedings of the ACM Web Conference 2023, 2023, pp. 731–741.
[30] E. Blomqvist, H. Li, R. Keskisärkkä, M. Lindecrantz, M. A. N. Pour, Y. Li, P. Lambrix, Cross-domain Modelling – A Network of Core Ontologies for the Circular Economy, in: WOP@ ISWC, 2023, pp. 1–12.
[31] L. Morkunaite, F. H. Al-Naber, E. Petrova, K. Svidt, An open data platform for early-stage building circularity assessment, in: Proceedings of the 38th International Conference of CIB W78, 2021.
[32] E. Sauter, R. Lemmens, P. Pauwels, CEO and CAMO ontologies: a circulation medium for materials in the construction industry, in: 6th International Symposium on Life-Cycle Civil Engineering (IALCCE), 2019.
[33] C. Bicchielli, N. Biancone, F. Ferri, P. Grifoni, BiOnto: An ontology for sustainable bioeconomy and bioproducts, Sustainability 13 (8) (2021) 4265.
[34] D. Spoladore, E. Pessot, An evaluation of agile Ontology Engineering Methodologies for the digital transformation of companies, Computers in Industry 140 (2022) 103690.
[35] D. Spoladore, E. Pessot, A. Trombetta, A novel agile ontology engineering methodology for supporting organizations in collaborative ontology development, Computers in Industry 151 (2023) 103979.
[36] E. Blomqvist, K. Hammar, V. Presutti, Engineering ontologies with patterns–the eXtreme design methodology, in: Ontology Engineering with Ontology Design Patterns, IOS Press, 2016, pp. 23–50.
[37] C. Shimizu, K. Hammar, P. Hitzler, Modular ontology modeling, Semantic Web 14 (3) (2023) 459–489.
[38] C. Parent, S. Spaccapietra, An Overview of Modularity, Springer Berlin Heidelberg, Berlin, Heidelberg, 2009, pp. 5–23.
[39] CircThread Project, Deliverable 6.3: Damaged product circularity assessment tool overview and technical description, Tech. rep. (2024). URL https://circthread.com/publication-results/project-deliverables/
[40] A.-H. Hamdan, M. Bonduel, R. J. Scherer, An ontological model for the representation of damage to constructions, in: LDAC, 2019, pp. 64–77.