Product Data Provision from Manufacturers to the Construction Industry: A Scoping Literature Review and Case Study Analysis

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Abstract. Increasing use of Building Information Management (BIM) requires solutions for sharing Product Data (PD), generated and governed by manufacturers, across applications and actors of the architecture, engineering, construction and operation industry. The needed PD, generated and governed by manufacturers, must be available in a machine-interpretable way to facilitate digital processing. However, it is usually provided in proprietary data formats, such as software specific BIM objects accompanied by PDF documents. The aim of this study is to analyse the current approach to PD provision by the manufacturers to the construction industry and the role of BIM models in sharing the data. A scoping literature review was conducted, supported by a case study of a database providing BIM objects in the IFC file format for compound elements such as walls and floors. Furthermore, the possibility to represent compound elements and their incorporated products using Linked Data was investigated. Findings suggest that PD provision and exchange is limited for several reasons that can span from lack of expertise to data management issues. While the possibility to represent PD in IFC BIM objects as well as with Linked Data was concluded to be possible with currently available means, it has yet to be adopted by the industry. This hinders the efficient implementation of PD into building models. While both approaches can be refined, the entirety of PD transferred to one BIM model via BIM objects might not be needed for every use case in its life cycle. Therefore, the author argues linking the BIM model to PD in a database, rather than the implementation of all PD into BIM objects, facilitating access to the information required by the individual use case.

Keywords: BIM, product data, PIM, AECO industry, manufacturing industry.

1 Introduction

The life cycle of a building begins with the construction process, encompassing the pre-design, design, production, and maintenance processes, before concluding with deconstruction when reaching the building's end-of-life phase [1]. Throughout this time, a vast amount of Product Data (PD) can be associated with the building's various elements, which consist of products supplied by manufacturers. Those manufacturers consequently also provide respective PD to stakeholders such as designers, owners, or operators. ISO 2006-2 defines *construction product* as any product intended to be used as construction resource [1]. In this study, the term 'product' will be used aligned to said standard, with the limitation of being a direct resource to the construction process, meaning being supplied by a manufacturer without further decomposition.

1.1 Need for Information

Potential needs for PD can be derived from the BIM uses as defined by the University of Pennsylvania's College of Engineering, which have been proposed to be extended to encompass a building's end-of-life phase [2, 3]. Possible information needs throughout the whole life cycle are also documented in the European standard ISO 19650-1:2019 [4]. During the planning phase, for example, architects and engineers may propose specific products to satisfy defined requirements, based on the products' performance as documented in respective product specifications. PD is also needed to satisfy the rising demand to predict a design's impact on factors such as cost, carbon emissions, energy demand, waste, water consumption or other environmental effects, which is common object of simulations. Throughout the operation phase, the operating party may need to have access to information on incorporated products regarding tasks and schedules for preventive maintenance, or general product specifications when replacement is needed [2]. At the end of a building's life or in case of replacement of individual components, the availability of PD may facilitate decisions on reuse, recycling, or disposal of used components, paving the way for circularity in the building industry [3].

Since PD does not only define the specifications and performance of a product, but also captures its value and possible advantage compared offerings of the competition, manufacturers have an inherent need to document and communicate PD [5]. The described stakeholders in the construction industry rely on having access to PD, in a way that enables their desired actions. It can thus be inferred that the provision of PD is of major interest to the building industry.

1.2 Information Flow

To support an unrestricted information flow between manufacturers and stakeholders of the building industry, PD must be shareable between organisations, personas, and software applications. As pointed out by Kebede et al. [6], not only digital availability but also machine-interpretability of data becomes increasingly important in light of progressing digitalisation.

Traditionally, manufacturers document the specifications of their products in PDF-documents, made available on the company's website [7]. Catering to the use in specific design software, BIM-objects in the software's proprietary file format can be offered. Alternatively, to enable the use of BIM-objects with a broader range of software applications, those can also be stored in the standardised and non-proprietary IFC file format [5]. When available in a machine-interpretable form online, pieces of information can also be shared using Linked Data (LD) technology [8], meaning that rather than transferring data, the source of the information is shared for retrieval when needed.

1.3 Product Data Provision

This study addresses the Building Industry and its supplying manufacturers. More specifically, it discusses means of providing PD in a digital way, facilitating integration into BIM models, as well as allowing open access by other software applications.

In scientific research, PD is being discussed in terms of its uses within construction processes, as well as its communication between different industries, stakeholders and software applications relevant to the building sector. The handling of PD throughout a building's life cycle is sometimes summarised by the term Product Information Management (PIM) [5, 6, 9-12]. The field of related topics encompasses traceability [13], BIM objects, Digital Product Passports (DPP) [10, 11, 13-15], as well as data transfer using Semantic Web (SW) and LD technologies.

Playing a key role for manufacturers in the diffusion of their products, different platforms for BIM objects have been investigated [5]. Linked Data technologies have been demonstrated to enable incorporation of PD into BIM models [6]. Both IFC BIM objects and LD are therefore feasible approaches for a digital provision of PD to a wide range of BIM applications [6, 12]. To the best of the author's knowledge, however, no case study on the current practices of PD provision in the building industry, combined with a comparison of the alternative methods of using IFC BIM objects or LD, has been conducted so far. Based on the established research field and gap, the research questions for this study have been formulated as follows:

RQ1: What are the current approaches of PD provision?
RQ2: How can PD provision be realised with IFC and LD, respectively?
RQ3: For providing PD, how does using IFC BIM objects compare to using LD?

By addressing those questions, this study aims to explore possible means of creating a digital connection between both parties instead of relying on proprietary data formats. The results are hoped to enhance the availability and currentness of data, as well as its implementation into building models.

1.4 Outline

The theoretical background to this research, as gained through the conducted scoping literature review, will be presented in the second chapter of this study (see chapter 2). The methods that were followed in said literature review, as well as the aforementioned case studies, are described in the third chapter (see chapter 3), with the results being presented in the fourth chapter (see chapter 4). This will be followed by a discussion, including interpretation of the obtained results, as well as implications and limitations of this study (see chapter 5). Conclusions will be provided in the last chapter (see chapter 6).

2 Theoretical Background

As a tool for the exchange of digital information, BIM offers new opportunities for processing information on products incorporated in buildings. While PIM has the potential to facilitate processes throughout all life phases, it demands an unrestricted information flow between applications and stakeholders [15]. This, in turn, necessitates the use of open data formats such as IFC and the existence of standards in regard to product specifications.

2.1 Hindrances of Product Data Provision

The availability, interoperability, and quality of data are commonly described to be problematic in the usage of PD [5-12, 14-18]. More specifically, Wagner et al. [19] and Kebede et al. [6] state that digital PD is often provided by the manufacturers in proprietary formats, such as BIM objects in file formats of specific design software. Consequently, the accessibility and interoperability of information is limited. Moreover, the information delivered in BIM objects on common platforms was observed to lack completeness or even correctness [5, 6, 12]. The fact that manufacturers mostly rely on product documentations in PDF format poses a general problem for data availability: Although being digital, the information cannot be imported to any software tool, rendering it effectively inaccessible [7].

2.2 Information Quality

The quality of any given information is difficult to assess, considering the multidimensionality and context-dependency of the concept [20]. Synthesising existing literature on data quality and adapting it to the context of BIM objects, however, Bahrami et al. [5] has extracted the following indicators for the value of BIM objects: compatibility, functionality, accessibility, accuracy, adequacy, comprehensibility, currency, applicability, and reliability.

As pointed out by Halttula [21], good data quality over the whole life cycle also necessitates data management and maintenance. Consequently, a framework for data governance is presented based on Wende and Weber et al. [22, 23], including the roles of data steward, data owner, data manager and data user. Practicing data governance is meant to ensure the quality, consistency, usability, security, and availability of data over its whole life cycle.

2.3 Exchange of Information

To tackle the problems of PD provision from manufacturers to the Building Industry, different and partly contradicting solutions are being proposed. Ramaji and Memari [18], as well as Ma et al. [24] both suggest the enrichment of IFC files with the necessary information to guarantee interoperability in the context of cost calculation and structural analysis, respectively. An opposing approach is the use of a centralised database. Again, propositions differ whether this should provide pure PD [7, 9, 14, 25] or host a library of quality-ensured BIM objects in the non-proprietary IFC file format, acting as information carriers [5, 17, 26]. Lastly, use of Semantic Web technologies, as suggested by Kebede et al. [6] and Pauwels et al. [8], would make PD - non-centrally hosted on manufacturers' websites – not only available to software but also machine interpretable and queryable by providing the necessary meta-data inherent to data modelled after the Resource Description Framework (RDF).

Independent of the means of data exchange, researchers widely agree on the necessity of standardised property sets, possibly defined by Product Data Templates (PDT) or Digital Product Passports (DPP), to ensure interoperability by consistently describing products [10, 11, 13-15, 17, 27].

3 Methods

The theoretical background to this study was established through a scoping literature review. It was then complemented by a case study, further investigating the provision of PD via IFC BIM objects on the example of objects obtained from a public database. As an alternative approach, the use of SW technologies was explored. Based on the gained insights, a Use Case was formulated.

3.1 Scoping Literature Review

To assess the state of the industry, a scoping literature review was conducted. Starting by using the PICOC framework, the field of research was established as indicated in Table 1. PICOC is an acronym standing for Population and their problem, Intervention and issue, Comparative intervention, Outcomes, and Context. The use of this method facilitates the identification of important keywords for, as well as the scope of the research, while considering different aspects of the subject. Thus, guaranteeing a both holistic and yet focused approach to the topic [28].

Table 1: Establishing the research field using the PICOC framework.

Population	-	Manufacturers and the Building Industry
and their problem	-	Integration of PD into BIM models
Intervention	-	Digital connection
and issue	-	Availability of data, implementation
Comparative intervention	-	Technical specification in proprietary data formats
Outcome or themes	-	Currentness, direct integration
Context	-	Building Industry

Subsequently, the search was carried out in the scientific database SCOPUS, yielding 114 results. By condensing the obtained papers following the PRISMA strategy [29], 30 papers were deemed relevant for full-text analysis, of which 19 were included in this paper. Additionally, 5 papers were added through snowballing, resulting in a total of 24 papers that were synthesised in the literature review.

3.2 Case Study

The database dataholz.eu[1] is a project of the Austrian Forest Products Research Society, aiming to serve as a reference work fulfilling requirements of both users and building regulations by providing certified data on wooden construction products [30]. It offers not only BIM objects in the non-proprietary IFC file format, but also supplies data sheets specifying the individual products listed on the website. Those data sheets are issued by independent testing and research institutes, guaranteeing correctness of the provided data. For its unique combination of offering BIM objects as well as supplementary certificates, as well as being industry-based, dataholz.eu was considered to be an interesting example to be studied in further detail.

The conducted case study was comprised of four parts: clarification of practical purpose through formulation of a Use Case, assessment of quality of the data provided on dataholz.eu, investigation of the used IFC BIM objects as carriers for PD in general, as well as an investigation of PD provision using Linked Data as an alternative approach.

Use Case. To clarify the purpose and scope of the envisioned information exchange, the case study was begun with the definition of a formal Use Case. BuildingSMART International (bSI), with their Use Case Management (UCM) initiative[2], offers a framework for defining Use Cases along with a platform for publishing them. However, bSI demands a Use Case to capture the whole life cycle, defining not only purpose and scope of the information exchange, but also the definition of the exact set of attributes that is to be exchanged (Exchange Requirements). Since the objective of this study is not to delineate a procedure in one specific scenario, but rather to explore general means of information exchange applicable to various scenarios, the Use Case developed in this study does not strictly follow the exact framework of bSI but adapts it to its objectives. This Use Case defines the purpose

[1] https://www.dataholz.eu/
[2] https://ucm.buildingsmart.org/

and scope of PD provision in, respectively, IFC and triple-store format, as well as objectives and limitations of the information delivery.

Data Quality. The quality of the provided data was assessed following concepts extracted from the literature review. That means the value of the BIM objects was evaluated based on nine indicators defined by Bahrami et al. [5]: *compatibility, functionality, accessibility, accuracy, adequacy, comprehensibility, currency, applicability of content, reliability*. Fulfilment of the criteria for quality was assessed based on objective characteristics of the investigated BIM objects. A systematic qualitative analysis, however, as conducted by the referred researchers, was prevented by a lack of objective data. For those indicators that could not be evaluated based on objective evidence, a set of questions was addressed to a representative of the database. In addition to the remaining indicators regarding the quality of the provided BIM objects, the formulated questions also addressed management and maintenance of the provided data, aiming to establish whether the operators of the database follow a data governance framework as or comparable to the one presented by Halttula et al. [21] (see chapter 2).

Data Provision using IFC BIM Objects. Based on the quality assessment of data carried by the IFC BIM objects provided on dataholz.eu, a general investigation of PD provision using IFC BIM objects was conducted. Since data on the product level was found to be missing in the modelled wall assembly, the obtained IFC file was enriched with PD. This was done selecting only the core layer as an example, using data from a matching product listed on dataholz.eu. Following the documentation on IFC 4, the information from the product's specification sheet was added to the original IFC BIM object, while referencing entries of the data dictionary *industry-dictionary for products in wood*[3], created by the European Woodworking Industry Confederation (CEI-Bois), to define the added properties.

Data Provision using Linked Data. To investigate the possibility of sharing PD using Linked Data based on Semantic Web technologies, the investigated wall assembly, as presented on the database dataholz.eu, was modelled using the existing Building Product Ontology[4] (BPO). This ontology facilitates a semantic description of building products, offering methods to represent assembly structures as well as properties connected to incorporated products, having template-driven product descriptions in mind [19].

Using the BPO, the specification sheet of the used product was translated according to the Resource Description Framework (RDF). In a separate file, the wall assembly was then described using the BPO, referring to the previously created RDF description of the incorporated product. Thus, demonstrating the use of Linked Data in a model of a building element.

4 Results

With the scoping literature review delivering the base for the theoretical background to this work, its results were presented in the previous section (see chapter 2). Hence, the following section describes the results of the conducted case study. Links to investigated files are provided upon mention. Developed files, as well as the created Use Case are made available in a GitHub repository[5].

As a preliminary point, it should be mentioned that the investigated BIM object represents a compound wall element that will be assembled on site, with the individual product being a subpart of said assembly. In the IFC schema, such a wall is represented as a singular element (*IfcBuiltElement*) with multiple layers (*IfcMaterialLayer*), and its constituting products are described as materials (instances of *IfcMaterial*). The term 'material level' will be used to describe the assembly level in which *IfcMaterial*'s are allocated, '(material) layer' corresponds to the *IfcMaterialLayer*. Consequently, PD is being carried on the material level of the IFC wall element.

[3] https://search.bsdd.buildingsmart.org/uri/cei-bois.org/wood
[4] https://www.projekt-scope.de/ontologies/bpo/
[5] https://github.com/jochembe/pdpExamples

4.1 Use Case

The scope of the Use Case "Product Provision from Manufacturers to the Construction Industry" is the description of means of PD provision that could be applied to realise information exchanges envisioned by existing Use Cases such as *Materialpass mit Produktklassifizierung*[6] (material pass with product classification). It is the objective of this description to satisfy information needs defined in the related use case. The described means constitute two possible approaches how product information can be stored and shared between actors and applications, realising a traceable, digital, and machine-interpretable information flow throughout a building's life cycle.

The Use Case describes the representation of PD using the IFC and RDF format, respectively. For both approaches, a schema defining leveraged methods and concepts is proposed.

4.2 Data Quality

Since dataholz.eu hosts a library of products next to its IFC BIM objects of standard wall assemblies, those objects were expected to include the data specifying incorporated products. However, the BIM objects were observed to only carry properties associated with the whole wall assembly. On the material level, where each layer represents one product constituting the assembly, no product specific attributes exist. The quality of the contained information, evaluated based on the indicators defined in subchapter 3.2 and in the context of this study, are displayed in Table 2.

Table 2: Quality of information in BIM object, evaluated based on indicators defined by Bahrami et al. [5].

Indicator	Question	Evaluation
Compatibility	Is the object compatible with common design and calculation software?	Yes: IFC format standardised and widely adopted
Functionality	Is the object sufficient for performing accurate calculations and simulations?	No: (averaged) properties for energy and environmental analysis, but no structural properties available
Accessibility	Can users easily access the information in the content of a selected object?	Yes: properties are displayed in Revit after import
Accuracy	Is the information accurate?	Yes: certified
Adequacy	Is sufficient information included in the BIM objects?	No: no information on individual products
Comprehensibility	Does the information give a clear understanding of the product?	No: no information on individual products
Currency	Is the information up to date?	(not assessed)
Applicability of content	Does the information enable the user to compare different brands and choose the products with better attributes?	No: no information on individual products
Reliability	Has the information been verified or certified?	Yes: certified

No answer from dataholz.eu was received to the questions addressing currency of information and data management, and no information on this subject seems to be publicly available. Hence, this part of data quality could not be assessed.

[6] https://ucm.buildingsmart.org/use-case-details/3097/de

4.3 Data Provision using IFC BIM Objects

The IFC schema, however, accounts for attributes to be defined on the material level of a wall assembly. Following the schema, the IFC BIM object obtained from dataholz.eu was enriched with product specific information. The selected BIM object[7] was chosen for its minimal count of components, consisting of a Cross Laminated Timber (CLT) slab as core layer, followed by one insulative layer and one layer of gypsum board on each side of the core.

The enrichment was conducted exemplarily on the core layer, with information from a suiting CLT product listed in the same database (illustrated in Figure 1). The attributes from the product's Declaration of Performance[8] (DOP) were added to the IFC file as *IfcPropertySingleValue*, grouped into a property list using *IfcMaterialProperties*. Since most added properties are not natively defined by the IFC schema, a reference to a buildingSMART Data Dictionary (bSDD) definition was included, using the *Description* attribute (renamed to *Specification* with IFC 4.3) at the second index of *IfcPropertySingleValue*. The enriched file was subsequently validated using the bSI Validation Service[9], reporting only one error that was inherited from the original file.

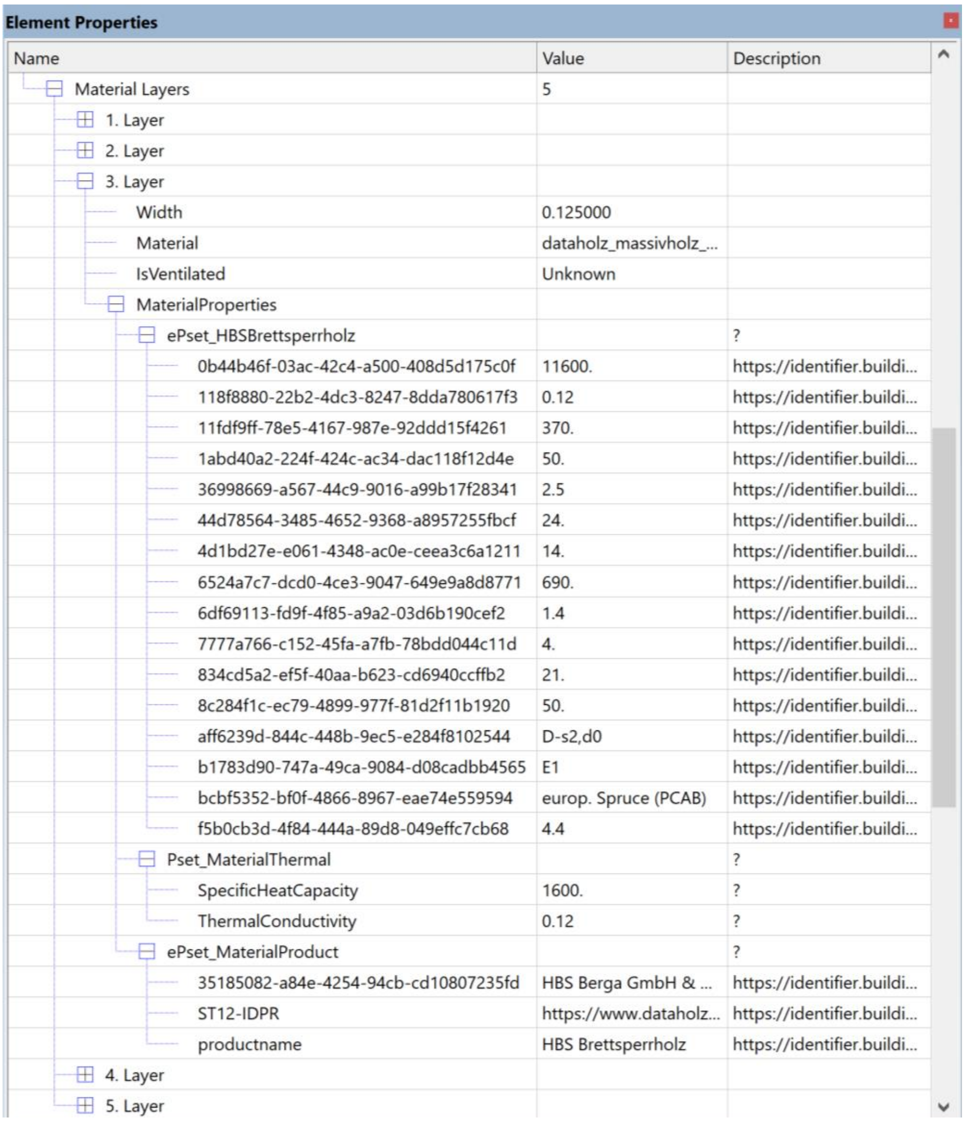

Figure 1: Added Product Data as seen in an IFC viewer.

[7] https://www.dataholz.eu/bauteile/trennwand/variante/kz/twmxxo02a/nr/01.htm
[8] https://www.dataholz.eu/fileadmin/dataholz/media/baustoffe/DoPs/dop_hbs-berga-bsp_de_en.pdf
[9] https://technical.buildingsmart.org/services/validation-service/

4.4 Data Provision using Linked Data

In a similar process as described in the previous section, the specification sheet of the same CLT product was translated into RDF data representing the properties obtained from the DOP. This was done using the BPO, with every property referring to the same bSDD definitions used in the enrichment of the IFC file.

After translating the product specification, the wall assembly was modelled in a separate file. Each material layer was represented as a *bpo:Product*, together constituting the wall assembly represented using *bpo:Assembly*. The core layer references the previously modelled product using the predicate *bpo:realisesObject*, thereby linking the defined properties to the respective component of the assembly (illustrated in Figure 2).

Figure 2: Representation of a wall assembly as RDF data, with a specific layer referencing product data from a different source (own illustration).

5 Discussion

While both concepts of IFC BIM objects and LD were proven suitable to be used to facilitate digital PD provision, the presented results leave room for discussion and optimisation. Therefore, the following section offers a reflection upon the conducted work and gained insights.

5.1 Case Study

The enrichment of the obtained IFC BIM object with the attributes from the product specification was complicated by the lack of corresponding attributes predefined in the used IFC 4 schema. To comply with the desired result of a machine-interpretable information flow, a standardised use of attributes is obligatory, in turn demanding definition of custom properties by referencing a data dictionary. The IFC 4 schema allows this by mapping the bSDD *PropertyCode* (of *ClassProperty*) to *IfcPropertySingleValue.Name*, and *uri* (of *ClassProperty*) to *IfcPropertySingleValue.Description*. Notably, this means that the human-readable bSDD *Name* is not reflected in the IFC file. A BIM application will only show the *PropertyCode*, unless it is able to access and retrieve the *Name* from bSDD [31]. While necessary to keep consistency in datasets, this could significantly impair user-friendliness. However, IFC 4.3 already expanded on the predefined properties to include most of the attributes that were missed during this enrichment.

During this study, the correct mapping of mechanical properties from the product specification to bSDD properties was found to be particularly troublesome. The measured mechanical resistances are distinct in their direction compared to the orientation of the grain, combined with the orientation of the whole panel, and used names and descriptions are not always unambiguous. This problem seems to prevail with IFC 4.3, where direction of resistance compared to the direction of the grain seems to remain unspecified in the newly introduced properties.

Although attributes were matched to the best of the author's knowledge in the enrichment of the IFC BIM object as well as the creation of the RDF representation, uncertainties in referencing bSDD properties accompanied both parts of the case study.

Since SW and LD technologies rely on extending modules rather than one inherent schema, referencing varying sources in the same graph comes more naturally. This, with the BPO providing the necessary concepts, made the translation of the product specification into an RDF graph rather straightforward. A possible conclusion is that smaller, specialised modules ease their application, whereas one all-encompassing schema becomes difficult to navigate with increasing complexity.

5.2 Comparison of Approaches

IFC BIM Objects. As pointed out in chapter 4, PD of the building element represented by the investigated BIM object is carried on the material level of the corresponding IFC wall element. Taking the 3D modelling software Autodesk Revit as example for a popular BIM application, a direct import of information on the material level would require import of a material library. These use a file format proprietary to Autodesk software, rather than IFC. A possible workaround would be the import of an element featuring the material as IFC BIM object. The material would then be available for further use in the Revit project's material library.

In the case of dataholz.eu, the offered BIM objects are already an assembly of product types. While dataholz.eu currently stops at the definition of product types, this or a similar database could provide the function to select specific products listed in the database. The corresponding BIM object could then be created to include product specific information on the material level, facilitating the transfer of actual PD. The platform hereby acts as an intermediary between manufacturers and BIM application. This process is necessary whenever the products to be represented are modelled as components of an assembly in the design software, and would, similarly, affect roofs and slabs.

Linked Data. The question arises how such a platform would retrieve the PD from manufacturers in this scenario. Unless it is stored in the platform's database, which in turn necessitates proper management of the provided data, there is still a need to digitally access PD from the manufacturer on demand.

Provision of PD in form of RDF graphs directly by the manufacturer can facilitate not only that, but also allows working with generic building elements in the design software and specifying the exact product by linking to said RDF graph. The subsequent integration of PD from an RDF database into the design software Revit was successfully demonstrated by Kebede et al. [6]. This way of sharing PD negates the need for an intermediary, as well as for the management of a centralised database. Moreover, retrieving information directly from the manufacturer whenever needed ensures currentness of the information, and avoids clustering complex BIM models with large amounts of data.

However, this approach also relies on the individual manufacturer to adopt new technology, potentially hampering the implementation of the concept. If information is hosted outside of the BIM model itself, continuous accessibility of the information throughout the whole life cycle of a building, using the same URI, must also be ensured. Notably, the importance of availability of PD and traceability of materials across life cycles was pointed out by Davari et al. [13] as well as Bellini and Bang [10].

6 Conclusions

The building industry's transformation towards an increasingly digital and sustainable future relies on innovative solutions for handling data connected to building products.

This study established that manufacturers still heavily rely on the use of barely digital PDF files for providing Product Data (PD) to the industry. BIM objects, especially when available in the non-proprietary IFC format rather than being software specific, represent a more innovative mean of integrating PD into BIM models and sharing across software applications. However, the investigated BIM objects did not display the same information content as in respective product specification sheets. To address this shortcoming, existing concepts of the IFC schema that allow referencing property definitions from a data dictionary were used to enrich said IFC BIM object with attributes representing data of a constituting product. Similarly, concepts of the existing Building Product Ontology combined with open property definitions were used to translate the product specification into RDF data, complying with principles of Linked Data technology. While the validity of using both BIM objects in the standardised IFC file format as well as Linked Data technology to leverage the provision of PD in the desired traceable and machine-interpretable way was demonstrated, only the latter allows referencing information directly from the manufacturer, rather than storing the data within the BIM model. Furthermore, Linked Data negates the need for an intermediary platform to provide BIM objects including products of several manufacturers.

Future research into sharing data between industries relevant to the building sector should focus on the development of a framework on the location of storage and its format for sharing across applications. This will need to be accompanied by respective standards, and possibly regulations regarding the long-term availability of data.

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