2024 European Conference on Computing in Construction
Chania, Crete, Greece
July 15-17, 2024

BRIDGING INFORMATION GAPS IN AECO INDUSTRY: A PROTOTYPE FRAMEWORK FOR STANDARDIZED PRODUCT DATA PROVISION

Jakob Martin[1,2], Klaus Linhard[2], Kai Oberste-Ufer[3], Cornelius Preidel[1,2]
[1]Munich University of Applied Sciences, Germany
[2]Institute of Applied Building Informatics (iabi), Munich, Germany
[3]dormakaba Deutschland GmbH, Ennepetal, Germany

Abstract

In response to the EU's Green Deal and its emphasis on sustainable construction, this study introduces an innovative framework for the AECO industry aimed at overcoming the prevalent challenge of fragmented and non-standardized product data exchange processes. By integrating Information Delivery Specification (IDS) and buildingSMART Data Dictionary (bSDD), the proposed framework enhances the accuracy and efficiency of product data exchange. This approach addresses current inefficiencies in the sector and aligns with sustainable objectives by ensuring consistent, up-to-date information, thereby facilitating better adherence to safety, budget, and regulatory standards.

Introduction

The Architecture, Engineering, Construction, and Operations (AECO) sector critically relies on accurate and timely product data, from design specifications to material properties (Tulke and Schumann, 2018). This data is essential to ensure projects are executed smoothly, remain within budget, and comply with safety and regulatory standards. However, the sector faces significant challenges:

Fragmentation of Product Data: Varied and non-standardized data from manufacturers often lead to delays and inaccuracies in project execution.

Lack of Standardization: The absence of a unified approach in data provision hampers efficient data retrieval and application.

These challenges become more pronounced with the implementation of the European Union's Green Deal, which underscores the need for sustainable construction and stringent environmental standards (European Commission, 2023; Schunz, 2022). The Deal necessitates immediate access to detailed, accurate product data to ensure compliance. Moreover, the push towards a circular economy emphasizes the importance of understanding building materials' origin, composition, and recyclability, where data discrepancies can result in non-compliance and potential legal or reputational damage. This context sets the stage for our research, highlighting the need for a standardized and efficient method to query and retrieve product data, a crucial element for operational efficiency and reliability in the AECO sector. At the same time, a persistent challenge within the sector has been the non-uniform manner in which product data is provided by manufacturers, owing to a lack of industry-wide standardization (Kebede et al., 2022; Lucky et al., 2019). This fragmentation obstructs efficient data retrieval and utilization, inevitably leading to delays and inaccuracies in project execution. The research gap thus emerges from the necessity of a streamlined, standardized method for querying and retrieving product data from manufacturers.

State of the Art

In the dynamic domain of digital construction, the seamless exchange of product information between manufacturers and core stakeholders such as contractors, designers, and engineers is fundamental. This exchange profoundly influences various stages of the construction process, facilitating informed decision-making, accurate cost estimation, and adherence to compliance norms, among other critical facets (Aranda-Mena and Wakefield, 2006). The information regarding products is especially crucial during distinct phases such as the planning and design, tendering, procurement, construction, and operational maintenance phases. During the planning and design phase, engineers and architects heavily rely on product information to make critical design decisions, ensuring that the selected products align with the project's objectives and compliance requirements (Yogana and Latief, 2021). The data aids in evaluating the compatibility of products with the design intent and making necessary adjustments to the design. As the project transitions to the tendering stage, acquiring precise product data is indispensable, empowering contractors and planners to craft accurate bids. They necessitate detailed specifications, pricing, and the availability of products to devise competitive yet realistic tenders. A significant aspect of the tendering process is the comparative analysis of products from different manufacturers. This step helps ascertain the most suitable options in terms of cost and functionality. Procurement is the next critical phase, where accurate product data is vital for making informed purchasing decisions. At this juncture, a bulk of comparison between different manufacturers' products is carried out to secure the best value and ensure project continuity. Once the construction phase commences, access to product information is essential to ensure that suitable materials are utilized per the specifications. It also aids in addressing any on-site challenges that may arise related to product installations. Post-construction, during the operational maintenance phase, having a repository of product information proves invaluable for facility management and maintenance activities. It aids in ensuring that the products used are serviced or replaced following the manufacturer's guidelines. Traditionally, obtaining product information has been a manual process, relying on product data descriptions typically provided in PDF format by manufacturers due to industry norms. Although functional, this method is time-consuming and prone to data inconsistencies, mainly when product specifications are updated.

Platforms for the distribution of product data

In the evolving landscape of the AECO industry, the emergence of platform providers for product data has become notable. Acting as intermediaries, these platforms house various manufacturers' product data, providing a centralized hub for stakeholders to efficiently access and compare product information. Such platforms include BIMobject (BIMobject AB, 2023) and Cadenas (CADENAS GmbH, 2023).

These providers endeavor to bridge the gap between product manufacturers and various industry stakeholders, including contractors and designers, positioning themselves as intermediaries that provide access to product data that is more about availability than immediate, customizable retrieval. Such platforms are particularly valuable during phases like tendering and cost calculation, where precise product specifications are paramount. However, the adoption of these platforms presents significant challenges. The utility of such a platform is contingent upon its widespread acceptance by multiple product manufacturers, as navigating various platforms not only complicates the workflow but also introduces inefficiencies. Therefore, for contractors and other stakeholders to reap the full benefits, a unified system is essential to streamline processes and enhance efficiency across the board.

A more pressing concern is the redundancy inherent in these systems. Product manufacturers, in their typical operations, maintain detailed specifications within their proprietary databases or systems. The introduction of intermediary platforms necessitates the replication of this data onto the new platform. This duplication poses several risks:

Inconsistencies: There's always the potential for discrepancies between the data in the manufacturer's primary system and those copied onto the intermediary platform.

Data Asynchronicity: The delay between updates in the manufacturer's system and their replication on the platform can result in stakeholders accessing outdated information.

Maintenance Overhead: For manufacturers, managing and updating product data in two places can be resource-intensive and error-prone.

While these platform providers aim to streamline processes and enhance accessibility to product data, they inadvertently introduce complexities and potential data integrity issues. It underscores the need for more integrated solutions to address these challenges, ensuring stakeholders have access to consistent, up-to-date product information without the pitfalls of redundancy.

Digital labeling and classification systems

In contrast to dedicated platforms that aim to host all the information, other approaches aim to link the connections between the required data and the manufacturers' data and manage these links. A prominent example is the *UniversalTypes*, developed and owned by *ProMaterial* under the aegis of buildingSMART International (buildingSMART International, 2023c). This initiative was developed to standardize and harmonize the characteristics and properties of products in a catalog and thus significantly improve the real-time sale of building products and materials.

Initially published as a publicly available specification in the buildingSMART Data Dictionary (bSDD), the language of UniversalTypes is envisioned to be standardized and maintained for general use. Unlike previous systems that were confined to proprietary platforms, UniversalTypes is integrated with the bSDD, enabling it to leverage a wider industry acceptance and providing a robust foundation for data harmonization across the construction sector. This integration is illustrated in our study's Figure 2, where UniversalTypes are referenced as a classification system within the bSDD framework (buildingSMART International, 2024).

ProMaterial offers a dedicated platform that utilizes UniversalTypes to streamline online sales processes. Within this platform, products can be explored using specific properties defined as UniversalTypes, such as the manufacturer's product number, Data-provider product ID, and various product dimensions and material properties. These properties are essential for designers during the design phase, allowing for an in-depth analysis and comparison of products from different manufacturers.

Moreover, ProMaterial extends its functionality by providing developer documentation for API development, facilitating advanced queries and interactions with the UniversalType Center for more customized workflows. This integration enhances the efficiency and accuracy in data retrieval and analysis, making it a valuable tool for planners' workflows and embodying modern digital construction industry processes.

In summary, the classification part of UniversalTypes represents a robust approach that not only uniquely identifies individual features but also complements other classification systems. It is showcased by its integration into the bSDD, enhancing its utility and reach. However, the reliance on a dedicated platform for providing this information highlights a business case that inherits the limitations of proprietary platforms, posing challenges for achieving a truly open, vendor-neutral solution.

Product Data Templates (PDT)

A Product Data Template (PDT) is a standardized format that outlines essential and optional product attributes, such as fire rating and color, according to established product standards. PDTs offer a unified method for handling construction product data, simplifying the process for manufacturers to keep product details up-to-date. The ISO standard 23387:2020 establishes guidelines for data structures that describe construction-related entities, promoting efficient digital information exchange and operational enhancement (International Organization for Standardization, 2020b). ISO 23387:2020 is a consistent further step after ISO 23386:2020 that includes a definition of characteristic structures (International Organization for Standardization, 2020a). PDTs are supposed to maintain data consistency across a product's lifecycle and are designed to be machine-readable for easy data exchange.

A Product Data Sheet (PDS) is created when manufacturers input data into a PDT using specialized software, detailing a construction product's technical and performance characteristics according to various regulations and requirements. As a product's identifiable document, a PDS ensures the supply chain can access up-to-date and accurate information from a trusted source. Unlike static formats like PDFs, PDSs support automation by integrating with various manufacturer systems, such as Product Information Management (PIM), Digital Asset Management (DAM), or Enterprise Resource Planning (ERP), to keep data fresh. They can act as a single source of truth for automatic updates across these systems.

PDTs can potentially improve data management in construction, but they come with challenges. The complexity of PDTs, particularly their integration with the IFC schema, creates a steep learning curve that can discourage smaller firms or those without technical expertise. The specificity of PDTs to IfcTypes can also be restrictive, lacking the flexibility to handle unique data needs and sometimes leading to inaccuracies requiring manual correction. Moreover, PDTs' reliance on the IFC schema can be limiting if the IFC schema has no prominent role in the project or undergoes changes, necessitating updates to the PDTs. Integrating PDTs into existing systems not designed for them can be complex and costly. PDSs, while designed to be a standardized source of information, face issues with data consistency, mainly when multiple parties contribute to project-specific PDSs.

Filling out PDSs can be time-consuming for manufacturers, particularly for those with a wide range of products or frequent updates. Despite these obstacles, the industry is working towards improving these systems to leverage their benefits in the digitally evolving construction sector fully. The transition involves overcoming the initial difficulties associated with adopting new technologies.

Formulating requirements for successful and efficient product data exchange

The AECO sector is at a pivotal juncture where the need for accurate product data intersects with the drive for sustainable construction mandated by the EU's Green Deal. Despite the potential of existing systems like native Product Data Platforms or Product Data Templates (PDTs), their adoption faces significant hurdles. The complexity of these systems, their integration challenges, and the need for consistent, up-to-date data underscore the necessity for a more streamlined approach to product data exchange. The industry's reliance on fragmented and non-standardized data hinders project efficiency and poses risks to compliance with emerging sustainability regulations. As the sector grapples with these challenges, it becomes clear that a new paradigm is needed to address the limitations of current methodologies and set clear, actionable requirements for a robust data exchange framework. To transition from the current state of disparate data practices to a future of streamlined and standardized data exchange, the following requirements must be met: Firstly, it is imperative to have a standardized data format. A universally accepted data format ensures seamless product data integration into the myriad software tools and platforms employed across the sector. Moreover, the systems utilized by various stakeholders, be they architects, engineers, or contractors, must be interoperable. This interoperability ensures smooth data exchange devoid of any compatibility hiccups. The integration of open APIs and dedicated tools can further smoothen this process. For widespread adoption, platforms or tools designed for data exchange must feature an intuitive user experience, easing the transition for all involved parties. Additionally, these platforms should allow stakeholders to retrieve specific data subsets efficiently, negating the need to sift through entire datasets. Another cornerstone of this endeavor is real-time data access. Stakeholders should always be working with the most recent information available.

Approach & Methodology

To enable the information orderer and provider to communicate information and requirements directly, this study proposes using the newly introduced Information Delivery Specification (IDS) standard from buildingSMART in conjunction with data dictionary services, e.g., buildingSMART Data Dictionary. The main objective of this study is to optimize the information exchange between the two main stakeholders in this process, especially in phases such as the tender: the information receiver and the sender. Therefore, the central idea is to rely on existing standards and describe a process as simply as possible, allowing as few obstacles as possible between these stakeholders.

buildingSMART Data Dictionary (bSDD)

The buildingSMART Data Dictionary (bSDD) serves as a fundamental source for ensuring data consistency and interoperability between different software platforms and actors in the AECO industry. Although there are several organizations that see establishing such sources as their task (see, e.g., the BIM Portal of the Federal Government (BIM Deutschland, 2023)), in our approach, bSDD provides the standardized terminology and data structures. These structures can be referenced in the Information Delivery Specification (IDS) to effectively communicate the data requirements and ensure that the exchanged product data is correct and commonly and uniformly understood within the industry, particularly between the purchaser and supplier.

As demonstrated in Figure 2, we explicitly utilize references from bSDD to establish this connection and ensure uniformity across the data exchanged. This us-

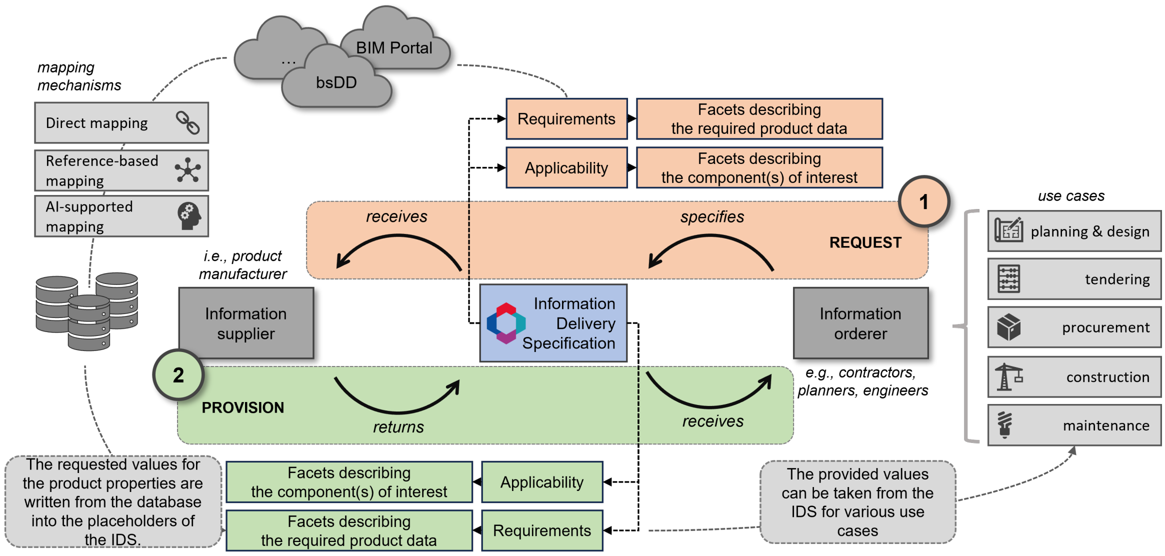


Figure 1: Schematic representation of the suggested methodology and process between the actor that orders and that provides the information

age highlights how bSDD's standardized terminology and data structures are critical in supporting the IDS's role in enhancing interoperability and clarity in communication among stakeholders.

Information Delivery Specification (IDS)

Information Delivery Specification (IDS) (buildingSMART International, 2023b; Tomczak et al., 2022) is a rather newly introduced XML-based tool to specify a construction project's information delivery requirements. It serves as a blueprint, outlining the nature, format, and extent of semantic information to be exchanged amongst stakeholders at various stages of a project lifecycle. By doing so, IDS augments the clarity, consistency, and efficiency of information exchange, minimizing misunderstandings and errors that could potentially derail a project. The primary intent of IDS is to facilitate the precise articulation and fulfillment of information requirements. It acts as a bridge, ensuring that the information generated and consumed across different phases of a construction project is aligned with the defined standards, thereby promoting interoperability and collaborative engagement. However, the structure of the format itself offers a variety of possibilities for further application areas that the introduction can open up. In addition, the format is getting a lot of attention, and many software vendors are implementing the standard. This momentum can be used to exploit the widest possible application of the format.

The following methodology has been proposed to achieve this objective and is shown schematically in figure 1:

1. Information Request

To begin with, the required product information must be collected using the IDS format. For this purpose, the features of IDS are used as follows:

- The *Applicability* elucidates which components need certain information and why. It specifically identifies which components are affected and should be considered. In this section, additional facets can add more details to describe the components, and some settings can be established as defaults. Additional design specifications could need to be set in advance during the planning phase. A more detailed description of the affected component could help identify it during the operating phase.
- The *Requirement* section further refines this by detailing the exact nature of the information needed. This can be an attribute according to the IFC schema or a user-defined property, i.e., a property in a property set with its required data type.

For the definition of the different pieces of information, a special characteristic of IDS can be used to give more robustness and reliability to the whole process: Each piece of information can be additionally provided with a URI, which refers to an external resource, e.g., to the bSDD. Similarly, other sources can be used as reference systems for attributes and properties, such as the BIM Portal in Germany (BIM Deutschland, 2023). The BIM Portal in Germany, managed by BIM Deutschland as of 2023, functions as a central resource for promoting BIM standards and practices. It offers detailed guidelines, best practices, and tools to streamline BIM adoption, supporting governmental and industry-wide efforts to enhance interoperability and efficiency in construction projects through digitization. In this way, a reference to a source can be established, which can be used for a common understanding of the same information if required. This could involve mapping to national classifications, UniversalTypes, and other standards recorded in the bSDD or any other source of information. An example of an IDS capturing requested information for external doors is shown in figure 2.

```xml
<ids>
  <specification name="Example for doors" description="Requesting Door Properties" ifcVersion="IFC2X3 IFC4">
    <applicability>
      <entity name="IfcDoor"/>
      <property name="IsExternal" datatype="IfcBoolean" value="TRUE" propertySet="Pset_WallCommon"/>
    </applicability>
    <requirements>
        <property propertySet="Pset_DoorCommon" name="AcousticRating"
        ↪ uri="https://identifier.buildingsmart.org/uri/buildingsmart/ifc/4.3/prop/AcousticRating"/>
        <property propertySet="Pset_DoorCommon" name="FireRating"
        ↪ uri="https://identifier.buildingsmart.org/uri/.../Pset_DoorCommon/FireRating"/>
        <property propertySet="Pset_DoorCommon" name="DurabilityRating"
        ↪ uri="https://identifier.buildingsmart.org/uri/.../Pset_DoorCommon/DurabilityRating"/>
        <property name="Türschließerfunktionen"
        ↪ uri="https://identifier.buildingsmart.org/uri/promaterial/universaltypes/1.0/prop/ST08-HODV">
            <propertySet>
                <xs:restriction base="xs:string">
                    <xs:pattern value="." />
                </xs:restriction>
            </propertySet>
        </property>
        <property name="Türflügelbreite"
        ↪ uri="https://identifier.buildingsmart.org/uri/promaterial/universaltypes/1.0/prop/ST05-WWDO">
            <propertySet>
                <xs:restriction base="xs:string">
                    <xs:pattern value="." />
                </xs:restriction>
            </propertySet>
        </property>
    </requirements>
  </specification>
</ids>
```

Figure 2: Example IDS file containing an information request for product manufacturer data for doors - for illustration purposes, the IDS has been greatly simplified and can therefore not be directly used as such

This formulated IDS can now be used as an information request and, as such, be sent to one or more information providers - i.e., product manufacturers eligible to deliver the requested information. This can happen precisely when the information is imperative, for instance, during the tendering phase.

2. Information Provision

Upon receiving the IDS-based query, a manufacturer deciphers the request, mapping it to their specific product specifications. The bSDD and, where needed, other standards like UniversalTypes aid this mapping. By doing so, the manufacturer can access its databases, where the most recent and reliable data about products is maintained. This prevents inconsistent or outdated data from being returned, and no middleman is required, which is a great help regarding liability issues. Subsequently, the manufacturer responds with the solicited information formatted in IDS. This returned IDS, while preserving its original format, now contains the values for each piece of requested data.

The planner, upon receiving the populated IDS along with the requirement specifications, has two potential courses of action:

- Manually incorporate the provided data. Given that the IDS already dictates applicability, the planner is guided on where to position the product data.
- Opt for a fully automated data integration in the model.

Using the BCF API Standard to foster the workflow

Applying the BCF API specification, as outlined by (buildingSMART International, 2023a), is recommended to facilitate prompt data exchange. Particularly, the BIMsnippet object within the BCF API framework is optimally designed for exchanging subsets of information, utilizing a harmonized schema. Particularly, the BIMsnippet object within the BCF API framework is optimally designed for exchanging subsets of information, utilizing a harmonized schema. A BIM snippet is a partial model referencing a schema, ensuring structured standards for its content. The Information Delivery Specification (IDS) XML schema is integrated with our proposed methodology. The IDS XML schema is integrated with our proposed methodology. Moreover, the pertinent attributes defined in the BCF standard are selectively employed for initiating and

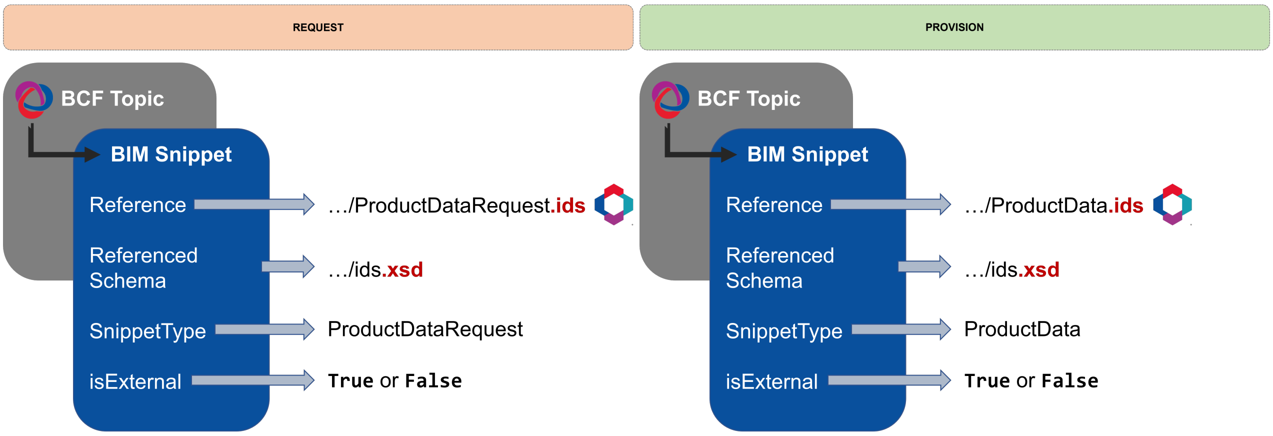


Figure 3: Schematic representation for the use of the BIMSnippet object for the BCF API for the mapping of the data request (left) and the data provision (right)

fulfilling data requests. Figure 3 illustrates the foundational principle for requesting and providing entities. The widespread adoption of the BCF API across software vendors significantly attests to its efficacy in streamlining this workflow. By employing this proposed workflow, a product manufacturer can establish a BCF API server as an access point for stakeholders seeking information. In this process, an information requester initiates a new BCF topic, embedding the request details as IDS within the BIMSnippet objects. Conversely, the supplier responds to the request by filling the same BCF topic with a BIMSnippet object that holds the information provision as IDS. This way, the request workflow can be largely automated and scaled if needed.

As an example, if multiple manufacturers are queried simultaneously via the BCF API, a mechanism for multiple suggestions could be conceived. This would allow planners to receive and compare various data samples simultaneously. Based on this comparison, the planner could decide what product to choose. To confirm that all data have been received and entered in the model as required, it can be checked very easily with the original IDS that was used for the request at the beginning - according to the original purpose of IDS, it also serves for model checking and can also be used for this purpose.

Adopting this methodology is anticipated to engender a more seamless and efficient data exchange within the AECO sector, thereby enhancing collaborative efforts and augmenting the quality of project outcomes.

Test Case: Requesting manufacturer properties of a door

To test the viability of our proposed approach in a simple test use case, we set up a common use case together with a manufacturer of door products as it is often encountered in practice: The correct specification of doors is a crucial element to ensure safe, user-friendly, and efficient buildings. At this, the key factor is the correct definition of requirements at each door aligned with local standards and regulations. Architects and planners often lack the knowledge to do this properly and are often exposed to the risk of missing important security-related features. The process proposed in this paper helps to enhance this task. In collaboration with the door manufacturer, we used our framework so that a planner generates a specification request (IDS) containing the requirement definitions, formulating a typical information request for a set of doors, mirroring common industry practices. The receiver is a domain specialist who adds the specific values to the request and sends it back to the architect. This roundtrip is repeated along the planning stages multiple times with different requirements, data, and stakeholders. The requested and transmitted response information from the product manufacturer is shown here in Table 1, together with the URI for the mapped source, e.g. bSDD:

Table 1: IDS Exchange for Door Specification with iterative planner and manufacturer responses, including URIs

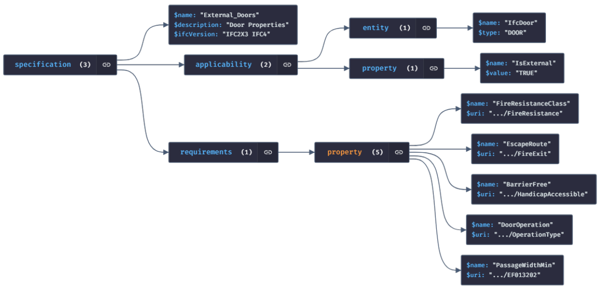
Information	**URI**	**Responses**
FireResistanceClass	🔗	T30
EscapeRoute	🔗	RW DIN 179
BarrierFree	🔗	True
DoorOperation	🔗	A (Automatic)
PassageWidthMin	🔗	900mm

The resulting IDS files for information request and provision are shown in Figure 4 - to enhance understanding further, it is shown as a graph-based illustration.

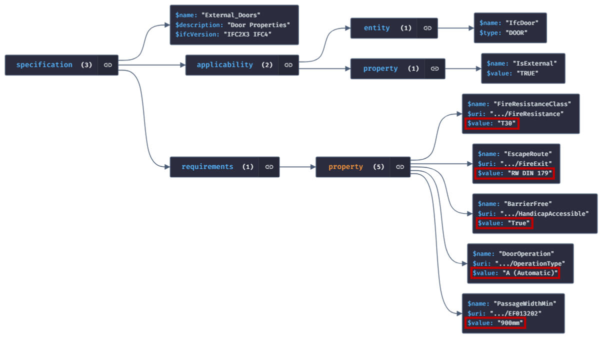
Conclusions & Outlook

The proposed method of utilizing IDS alongside bSDD and other data dictionaries presents a novel pathway toward overcoming the long-standing challenge of standardized product data provision within the AECO industry. This approach promises enhanced data accuracy and availability and fosters a collaborative ecosystem among the various stakeholders, driving the industry toward a more integrated and efficient future.

Building upon the presented research, several avenues emerge for further investigation:



Query of features in an IDS specification



Providing features by assigning values (marked red)

Figure 4: graph-based representation of a (left) query and a (right) response based on IDS-XML

- **Industry Adoption Analysis:** Investigating the barriers to, and facilitators of, widespread adoption of this standardized data provision method within the AECO industry.
- **Integration with Existing Systems:** Exploring this method's compatibility and integration possibilities with existing industry data management and project management tools.
- **Exploratory Prototype Development:** In our study, we have outlined a conceptual framework designed to standardize and streamline product data exchange within the AECO industry. Moving forward, the next phase of our research will focus on evolving this conceptual framework into a more tangible model that can be rigorously tested and validated. This will involve developing an initial prototype for a broader spectrum of product data queries and processes. The prototype will be designed to demonstrate the practical applicability of our framework in real-world scenarios, allowing us to assess its effectiveness and make iterative improvements based on feedback from industry stakeholders. This progression from a conceptual framework to a prototype is crucial for bridging the gap between theoretical research and practical implementation. It will provide valuable insights into the challenges and opportunities associated with deploying such a system on a larger scale, thus paving the way for widespread adoption in the industry.

Limitations and Future Research Directions

While our current framework focuses primarily on model-based workflows typical of the AECO industry, a significant portion of the sector still operates without such models, particularly in managing existing, non-digitized assets. Given this gap, an important question for future research arises: how can the framework we propose be adapted to support non-model-based workflows effectively? This question is crucial as it aims to extend the benefits of standardized product data exchange to broader contexts within the industry, ensuring inclusiveness and broad applicability. Answering this question involves exploring methods to generalize the principles of our framework to support workflows that do not rely on structured digital models, thus expanding the scope of its utility and impact.

Additionally, it is important to note that the current implementation of IDS is limited to alphanumeric information exchanges and does not support the transfer of geometric data. While this is acceptable as an initial step, further investigation is needed since some product information exchange might also rely on geometric data, not just characteristics.

This endeavor lays the groundwork for a series of potential advancements in addressing the product data provision challenge, pushing the frontier of information management within the AECO domain.

Acknowledgments

The authors gratefully acknowledge the support and resources that made this research possible. This work has been carried out mainly within the framework of the openDBL project, which has received funding from the European Union's Horizon Europe research and innovation program under grant agreement No 101092161. We are deeply grateful for this fundamental support. Furthermore, our thanks also go to the NEMETSCHEK Innovation Foundation, whose financial contributions have been an essential basis for the progress of our research and, thus, of crucial importance. Additionally, the authors extend their sincere thanks to dormakaba Deutschland GmbH for their practical contributions to this study.

References

Aranda-Mena, G. and Wakefield, R. (2006). Interoperability of building information — myth of reality? In eWork and eBusiness in Architecture, Engineering and Construction. ECPPM 2006, page 7. CRC Press, 1st edition edition.

BIM Deutschland (2023). BIM Portal des Bundes. https://via.bund.de/bim/infrastruktur/landing. Accessed: 2023-11-02.

BIMobject AB (2023). BIMobject. https://www.bimobject.com/. Accessed: 2023-10-29.

buildingSMART International (2023a). BCF REST API. https://github.com/buildingSMART/BCF-API. Accessed: 2023-10-29.

buildingSMART International (2023b). buildingSMART - information delivery specification (ids). https://technical.buildingsmart.org/projects/information-delivery-specification-ids/. Accessed: 2023-10-08.

buildingSMART International (2023c). Universaltypes. https://www.buildingsmart.org/users/services/universaltypes/. Accessed: 2023-10-29.

buildingSMART International (2024). Türflügelbreite. https://identifier.buildingsmart.org/uri/promaterial/universaltypes/1.0/prop/ST05-WWDO. Accessed: 2024-04-21.

CADENAS GmbH (2023). Cadenas. https://www.cadenas.de/. Accessed: 2023-10-29.

European Commission (2023). The european green deal. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en. Accessed: 2023-10-29.

International Organization for Standardization (2020a). ISO 23386:2020 - Building information modelling and other digital processes used in construction Methodology to describe, author and maintain properties in interconnected data dictionaries. Technical report, International Organization for Standardization.

International Organization for Standardization (2020b). ISO 23387:2020 - Building information modelling (BIM) - Data templates for construction objects used in the life cycle of built assets - Concepts and principles. Technical report, International Organization for Standardization.

Kebede, R., Moscati, A., Tan, H., and Johansson, P. (2022). Integration of manufacturers' product data in BIM platforms using semantic web technologies. Automation in Construction, 144:104630.

Lucky, M. N., Pasini, D., and Spagnolo, S. L. (2019). Product Data Management for Sustainability: An Interoperable Approach for Sharing Product Data in a BIM Environment. IOP Conference Series: Earth and Environmental Science, 296(1):012053.

Schunz, S. (2022). The 'European Green Deal' – a paradigm shift? Transformations in the European Union's sustainability meta-discourse. Political Research Exchange, 4(1).

Tomczak, A., van Berlo, L., Bolpagni, M., Krijnen, T., and Borrmann, A. (2022). A review of methods to specify information requirements in digital construction projects. IOP Conference Series Earth and Environmental Science, 1101.

Tulke, J. and Schumann, R. (2018). BIM-Based Production Systems, chapter 27, pages 447–461. Springer International Publishing, Cham.

Yogana, E. and Latief, Y. (2021). Development of system information of building code checking in planning and permitting phase to improve building code compliance based on work breakdown structure (WBS) using building information modeling (BIM). Journal of Physics: Conference Series, 1858(1):012091.