Use case based implementation of a standardised exchange process for configurable and parametric product data

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Abstract. Currently, the ISO 16757 standard for creating electronic product catalogues for building services is being developed. It aims to improve the laborious process of product data exchange between manufacturers and end users by offering a uniform process/framework based on a data dictionary (DD) for property management and the IFC format for serialising the catalogues. This paper illustrates remaining unresolved issues and weaknesses employing a prototypical implementation of the ISO 16757 workflow for the product class *burner*. A central point of criticism is the high complexity of the DD and IFC structure, caused by the fact that the formats are supposed to represent complex relations and configuration logic in addition to actual product information. Hence, we propose integrating Product Data Templates (PDTs) into the workflow. The PDTs can manage the relationships and assignments of the properties, allowing the DD to focus on the efficient management of property definitions.

1. Introduction

The exchange of configurable, variable and parametrically dependent product data is challenging the Architecture, Engineering, Construction and Operation (AECO) industry. There is a lack of a uniform, neutral data format that can represent parametric and variant management.

The Mechanical, Electrical and Plumbing engineering (MEP) industry is currently working on standardising this exchange data format and process. The MEP industry has to handle highly complex product configurations, which currently lead to a labour-intensive and time-consuming data exchange.

Since the product information needed for manufacturing significantly differs from the information requirements needed to plan and configure the product in a construction project, the data from the manufacturers' product information model (PIM) must be translated, simplified, and restructured into specified data packages and interoperable formats.

Common formats and data sources for planning include conventional product catalogues, the manufacturer's website (online catalogue), integrations into MEP software and the upload to various online data portals. Each of these resources has different requirements for presenting, processing, and formatting product data.

The transfer process from the PIM to each format is strongly customised to the respective company and is mainly done manually. Therefore, it can take several months for each product and data format. In addition to the numerous formats, products can be delivered in millions of variants, and the data can evolve and change over time.

Thus, the current method is error-prone, causes many media discontinuities, impedes straightforward data updating and creates an immense administrative effort.

To streamline and improve the exchange process for all participants, the ISO 16757 working group is currently developing a standard exchange data model and format for product catalogues of building services (BS) based on a central data dictionary (DD) and the IFC format (ISO-16757, 2019). The dictionary contains the class, property (set), and value range definitions, which are then referenced in an IFC Project Library file (the product catalogue) containing the actual value assignments, valid property combinations, and parametric property-value dependencies of the respective manufacturer.

However, the proposed workflow of ISO 16757 has only been worked out theoretically (respectively, is still in progress) and has not yet been implemented practically. Thus, this paper presents a prototypical implementation of the ISO 16757 workflow, applying the proposed data model and formats to a use case example. This approach was conducted with leading industry partners of the BS sector.

With the workflow implementation and evaluation of the use case example, we want to support the standardisation work by highlighting the advantages and disadvantages of the proposed methods, outlining unresolved issues, suggesting possible improvements, and reflecting on feedback and demands from the industry.

2. State of the Art

2.1. Standardisation Work

In Germany, a product data exchange format has been standardised at the national level. The VDI-3805 (2011) standard defines uniform properties and possible values for each product class. At the instance level, manufacturers use these specifications as a template to create compliant product catalogue files in a custom format defined in the VDI standard.

ISO 16757

The ISO standard ISO-16757 (2019), currently under development, aims to adopt the VDI 3805 approach and expand it to an international level. However, the standard is not intended to invent new schemes and formats but to rely on existing data standards and concepts.

General parts of the standard are concerned with defining the data model for the semantics and geometry of product data and the technical implementation of the exchange format. Based on these definitions, specific standard parts are to be created for each MEP product class (e.g. heat generators, drinking water fittings, burners, ventilations, etc.), which define the necessary semantic and geometric properties to describe the respective products.

The semantic meta-model specifies the MEP domain specific types of classes, properties, relations and features for selecting and creating valid products. The properties are categorised according to the domain (do they describe the catalogue, a product, or the installation system), function (selection or technical property), and dependency (static and dynamic property). The properties can be grouped and assigned to product (sub) classes connected by inheritance relationships. Dynamic properties represent the parametric nature of products and, thus, are related to other properties (their input parameters) and have a function body.

The semantic data model has to be implemented as an online data dictionary (DD) storing class and property definitions. The dictionary is based on the meta-model for dictionary creation of ISO-12006-3 (2017) and the property management system of ISO-23386 (2020). Each property is stored with meta data defining a unique identifier, a data type and unit, predefined values, value constraints, etc. The product classes and sub-classes should also be stored in the dictionary. The types of relationships between the different dictionary entities (hasParent, hasParameter, hasPart, etc.) are also defined in the ISO 16757 based on the 12006-3 meta-model.

The actual exchange of manufacturer-specific product data for one product class will be conducted via an IFC Project Library file. This file represents the electronic product catalogue, which references the predefined properties of the DD and then assigns the manufacturer-specific values to them.

The IFC Project Library is a Model View Definition (MVD) of the IFC schema defined in ISO-17549-2 (2021). An *IfcBuildingElementProxyType* represents the product class, and the properties are created as *IfcPropertySingleValues* and grouped by *IfcPropertySets*. All entities refer to the DD by a URL-based *IfcLibraryReference* entity. However, manufacturers can also add custom properties which are not part of the shared DD.

To enable the selection process and the determination of valid property combinations, ISO 16757 proposes to use the *IfcConstraint* entity storing the values as an *IfcTable* or as an *IfcAppliedValue*. A multi-column table can store the valid value combinations in one table row, while the applied value entity can capture a calculated value based on a logical restriction formula. Conventional database operations can then combine separate IfcTables.

The dynamic properties have to be represented by an *IfcPropertyDependencyRelationship* containing the function expression as JavaScript Code. Upcoming software that can read this electronic catalogue must execute this code and implement a selection process based on the logic expressed by IFC constraints.

So far, only the ISO 16757 parts about the semantic and geometric meta-model have been published. Thus, the presented DD and exchange format specifications reflect the current standardisation work status and are subject to ongoing development.

Product Data Template

Another standardisation work in the context of product data is the development of Product Data Templates (PDTs) (ISO-23387, 2020)). They define properties and property sets and assign them to specific construction objects, which serve as templates for products in IFC.

The PDT standard offers a taxonomy for expressing these definitions and relations, which should be serialised as eXtensible Markup Language (XML) files. The primary entity is the *DataTemplate* that connects the so-called *SetOfProperties* with a *ConstructionObject* that represents, e.g. a specific product class. The properties inside the sets and relating entities like units, data types, value enumerations, reference documents etc., can also be initially defined in the PDT. However, in this research, we focus on the linking/assigning features of the PDT standard and only reference already externally defined properties.

2.2. Related Research

Processing and integrating product data into BIM data is the subject of several research and development efforts. Kebede et al. (2022) present an approach of semantically representing product data linked with the CEB 17623:2021 standard for lighting, luminaires and sensing devices properties. They developed a visual programming language-based process for integrating product data into BIM authoring tools applying semantic web technologies. However, the product data used in this research is already pre-structured in a static table form and recorded for each individual product.

Niknam et al. (2019) present research focusing on connecting IFC model data and product data by converting them into ontologies. Another approach by Hoffmann et al. (2018) presents a system that can replace centralised data storage by describing a network of manufacturer data services. The network focuses on standardising and simplifying access to product data for the user.

Research on representing building product catalogues on the semantic web is provided by Beetz and de Vries (2009). They propose instantiating actual products through an instance-of relation enabled by four layers of hierarchical meta-modelling.

These research efforts are based on Linked Data technologies, each focusing on different product data creation and exchange aspects. However, research on the whole process chain from the manufacturer's PIM to a uniform product catalogue exchange format based on a central data dictionary has not been considered so far.

3. Method

In this research approach, the workflow proposed in ISO 16757 for the provision and processing of product data is investigated and exemplified. The approach aims to test the workflow with actual product data to validate the practicality of the approach.

We have chosen the product class *burner* (part of a boiler) as a use-case example. For this product class, the corresponding part of ISO 16757 is already in progress, to which we got access from the ISO working group. As this part of the standard is based on the specifications made for burners in the German VDI-3805 2011 (Sheet 8), we could rely on the legacy standard for taking some currently missing information.

The overlapping content and structure enabled us also to work with existing product catalogues of burner manufacturers that follow the VDI 3805 structure. Moreover, we got a sample file of a product catalogue as IFC Project Library from the working group that displays how the proposed structure could be implemented as an IFC file.

On this basis, we simulated the proposed process, outlined schematic information flows, and developed sample files. These generated files are accessible on GitHub [1]. Figure 1 illustrates the product data exchange framework we developed based on ISO 16757. In the following subsections, the separate steps of the workflow are discussed in detail and demonstrated on the use case data.

[1] https://github.com/Design-Computation-RWTH/iso16757exampleFiles

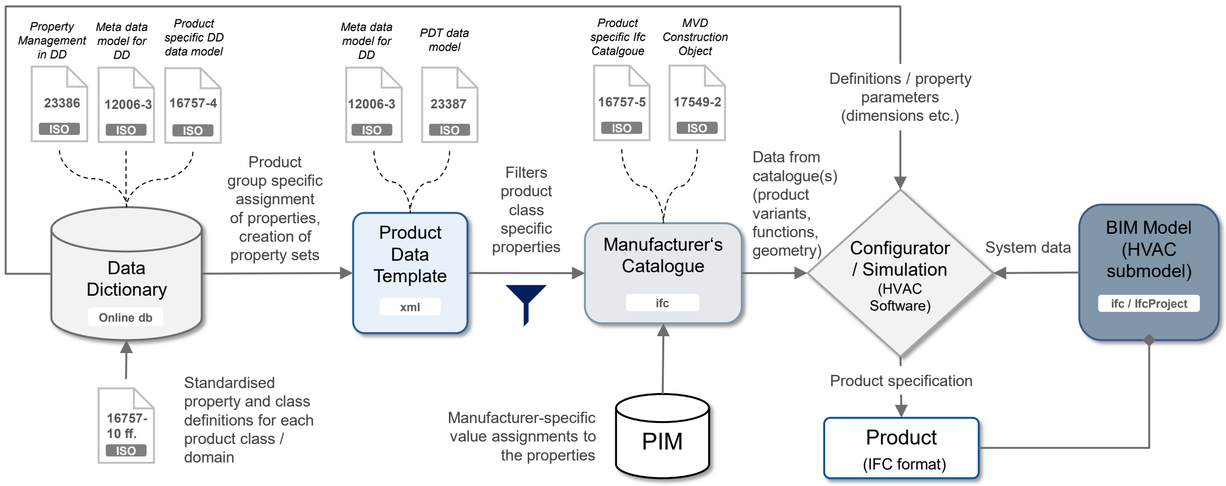

Figure 1: Proposed ISO 16757 workflow with integrated PDT

3.1. Data Dictionary

As explained in section 2.1, the data dictionary stores the classes, properties and relations needed to describe the semantic product data uniformly. The provided preliminary ISO 16757 part for burners contains these data, stored recently in a spreadsheet that represents the property (meta) data structure according to ISO 23386 as separate columns. It is not clarified yet which technical solution/provider will realise the DD for product data in future. For our exemplary process implementation, we assumed the spreadsheet as a preliminary DD for the time being and used a placeholder web address.

Nevertheless, we have mapped the burner data at the diagram level according to the proposed dictionary structure. Even with the graphical implementation, we noticed that the proposed DD structure filled with actual data quickly becomes complex and challenging to handle. The specially defined relationships such as *hasParameter*, *hasProperty*, *hasParent*, etc. and their technical consequences (dynamic dependencies, inheritances, etc.) also need to be technically feasible.

Thus, we propose a slightly simplified DD structure, also concerning the complexity that a request and response of a real online DD would have to cover. In the approach presented here, we attempt to integrate a PDT in the information exchange process between the DD and the IFC catalogue file (see Fig. 1). The PDT standard (ISO 23387) already offers features to group properties and assign property groups to construction objects (product classes).

Thus, these relations do not have to be reinvented and integrated into the DD but can be outsourced to a PDT. Therefore, the DD *only* contains unassigned and ungrouped property definitions, which leads to a simpler structure and easier reuse of single properties. However, some product-specific relations, such as *hasParameter* for dynamic properties and predefined value enumerations, must still be solved inside the DD.

3.2. Product Data Template

Despite the full functionality of a PDT (see section 2.1), we use the PDT in our approach only as a grouping and filtering tool. Thus, we use the PDT to create sets of properties (according to the template/table provided) and assign them to classes (resp. in PDT terms: *construction objects*), but we only reference the needed properties and classes by a name and a URL pointing to the DD. Thus, no new content is created, and the size of the PDT is kept to a minimum. To implement this linking feature, we used the XLink syntax for XML files, which the PDT standardisation group has recently proposed.

Our use case has the class *burner* and two subclasses, *oil burner* and *gas burner*. The superclass *burner* has the property set *Basic Product Data*, and the two subclasses have additional fuel type-specific property sets. In the PDT, all of them are *construction objects*. The PDT first defines all *Set of Properties* and then uses the Product Data Template entity to relate the *Burner* with the property set *Basic Product Data* (see Fig. 2), the *Oil Burner* with the property sets *Basic Product Data* and *Oil Specifications*, and the *Gas Burner* with the property sets *Basic Product Data* and *Gas Specifications*.

Thus, without duplication and invention of new relationships inside the DD, the class assigning, property grouping and class/property inheritance are solved with minimal effort, using a standardised schema.

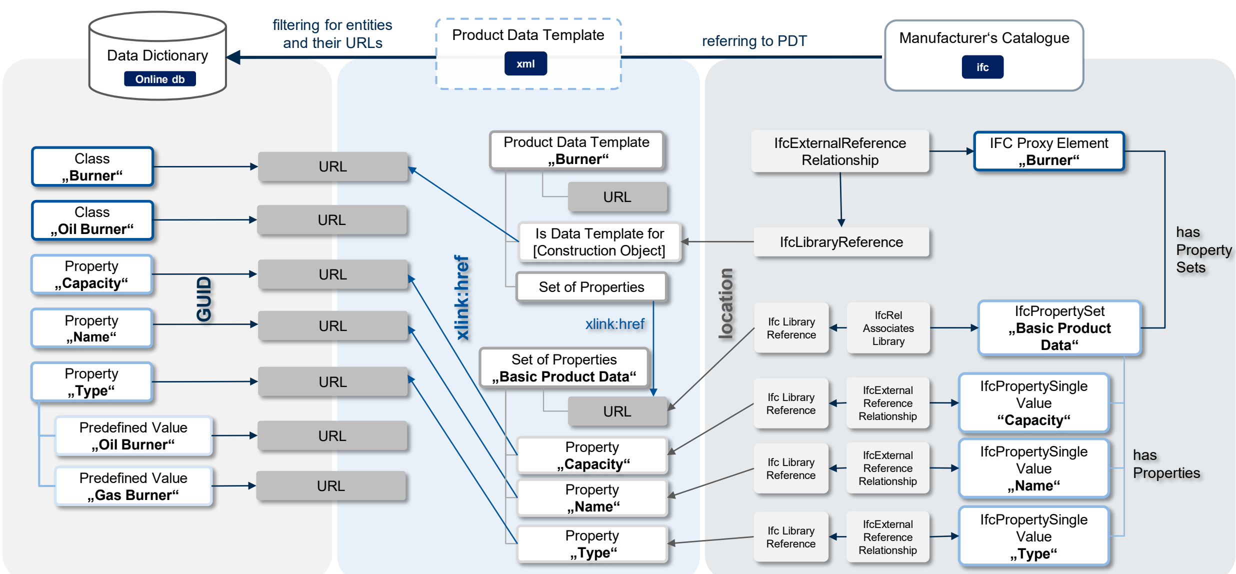

Figure 2: Interaction of the DD, the PDT and the IFC Project Library at object level.

3.3. Manufacturer's Product Catalogue – IFC Project Library

Based on the ISO working group's IFC Project Library example file and the specifications of ISO 16757, we created an IFC catalogue file for the product class *burner*. The classes, property sets and properties listed in the PDT were transferred to the IFC structure as IfcProxyElement, IfcPropertySet and IfcPropertySingleValue entities that reference back to the DD by an IfcLibraryReference.

The required unit and datatype definitions for each IfcProperty are queried from the DD and translated into IfcUnits and their related entities.

Utilising an existing burner catalogue (based on VDI 3805, therefore broadly compatible with the ISO 16757 properties of the spreadsheet), we were able to implement the proposed solution for mapping, respectively, selecting valid product variants in IFC as IfcTables exemplarily.

Figure 3 shows a graphical view of three IfcTables containing the valid value combinations for three (simplified) property sets of burners. Each row of each table represents a different product variant related to the queried property (here: type, capacity and fuel type).

Selecting a variant (row) in a table can restrict the subsequent selection. For example, an oil burner has different capacities than a gas burner. The selection hierarchy/sequence is formed from left to right, which must be implemented by a future software solution. The permitted combinations of entire tables can be modelled using standard relational database tools.

The individual columns are assigned to the *IfcProperties* they represent via an *IfcReference* object. Thus, the columns are connected to the DD via this relationship and can be identified across files. However, this technique cannot be implemented for the individual values of each column. Only an entire *IfcRow* with all its values could be referenced to all corresponding DD entries, but the individual assignment would be lost. Therefore, predefined values for specific properties stored in the DD (such as the burner types) cannot be referenced to the values in the table.

The other suggestions of ISO 16757 for mapping product variants and dynamic properties, such as using IfcAppliedValues and the IfcPropertyDependencyRelationship, could not yet be implemented and tested for the product class *Burner* due to missing/ mismatching manufacturer data.

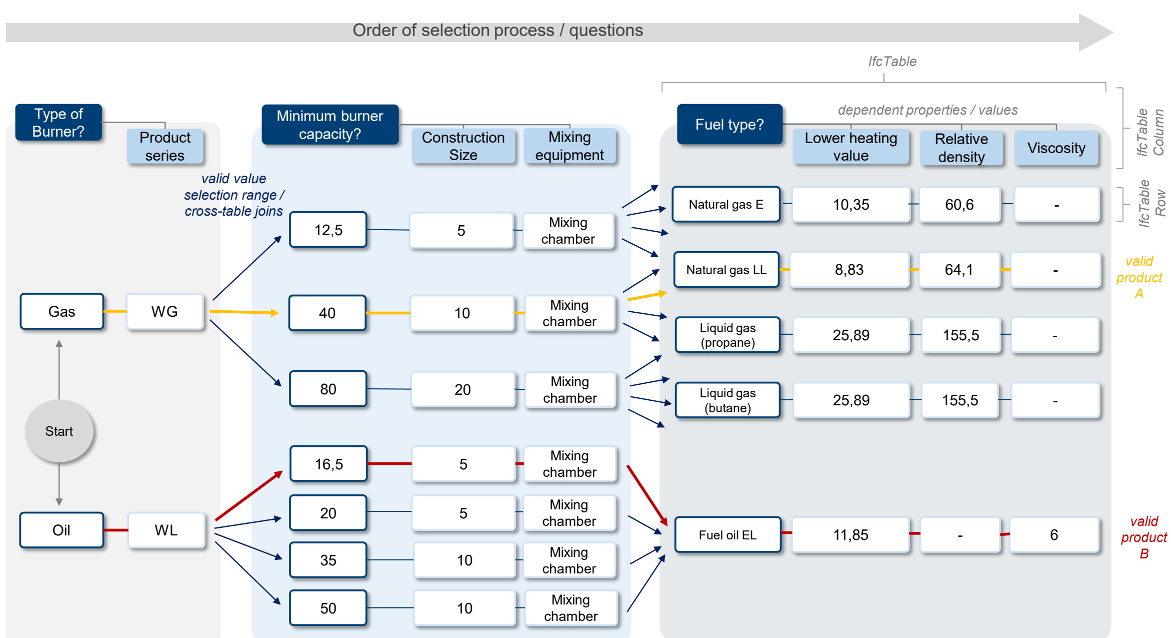

Figure 3: Representing the selection process and property hierarchy using IfcTables

4. Findings

The presented approach outlines and investigates the product information exchange process developed in ISO 16757 using the product example burner. The application example has shown a prototypical implementation of the ISO 16757 workflow using a practice example. The proposed formats are already existing, widespread and accepted by users. However, there are also challenges and unresolved issues which have become apparent during the practical implementation.

4.1. Data Dictionary and PDT

The use of ISO 23386 for structuring the properties in the DD enables uniform and solid data generation and management. However, the required functionalities resulting from the product data characteristics demand a complex dictionary structure that can display, e.g., class assignment, property groupings, inheritances and parametric dependencies.

To reduce this complexity, we propose outsourcing the relations between individual dictionary entries to a PDT wherever possible. The PDT, in turn, should not contain any new definitions of data types, properties or classes but only references to the DD. Thus, the structure and content of the DD can focus entirely on the detailed definition and documentation of the properties and classes, while the PDT is responsible for mapping their interrelations.

Implementing the use case has shown that this division of functionality can contribute to an efficient data exchange process. Although the PDT lacks structures that can manage superclass-subclass relationships (property inheritance), the direct assignment of property sets of the superclass to the different subclasses (basic product properties to sub-classes Oil and Gas Burner) represents a feasible workaround.

However, in the current implementation, the *has-parameter* relationship of dynamic properties and the referencing of predefined values to specific properties had to remain in DD, as these cannot be mapped in PDT. Thus, a future extension of the PDT structure, including more complex relationships, would be desirable to simplify the DD structure further.

Another approach that can lead to an improved DD structure is to define and store data types and units as individual DD entries that each property can reference. This way, data redundancies and inconsistent specifications of meta-information could be prevented.

4.2. IFC Project Library

The proposed application of IFC as the exchange format of the product catalogues has the advantage of utilising an already standardised, accepted and interoperable format. Thus, future software solutions for creating/reading/integrating the catalogues can be based on existing IFC interfaces. Since product data are highly complex regarding configuration logic and property dependencies, the ISO 16757 standard presents methods to integrate these requirements into the IFC format using tables, logical functions and JavaScript code.

The use case has shown that the use of IfcTables for mapping valid product variants generally works. However, creating a property in IFC, including the reference to the DD and the storage of possible values in an IfcTable, requires generating at least ten IFC entities plus one IfcRow for each value (combination).

Extrapolated to the complexity and variance of a real product catalogue (up to a billion variants) and concerning additional complexity of dynamic properties and logical functions, this approach can lead to unmanageable file sizes resulting in poor processing performance. Thus, saving, sending, processing, and revising the catalogues can be impaired.

Another drawback of the IFC format noticed during the use case implementation is the limited ability to identify entities externally. For example, specific table entries cannot be addressed and referenced directly. Often, only file-internal IFC-specific identifiers exist, which also may change depending on the file version. The file-independent / central managing and revision of data are thus made more laborious and challenging to automate.

In addition, there is the problem of the selection hierarchies defined in ISO 16757 Part 1, which cannot be mapped in an IFC file. These dependencies and conditions are not mapped in an IFC project library, and hierarchical if-then relationships are not yet foreseen.

Linked data technology, also used in other product-related research, could be an option to address some of the problems mentioned above. Using existing tools, the IFC format can be converted into the Linked Data format. This format can be read and queried with standardised tools that are specialised for large amounts of data. Meta-information can also be created more easily and managed on an object-related basis.

5. Conclusion

In this paper, we investigated and evaluated the proposed product information exchange workflow of ISO 16757. Based on applying the workflow to the use case *burner*, unresolved issues and shortcomings of the process were identified, and suggestions for improvement were introduced.

As a recurring problem, the complexity of the data structures of the dictionary and the catalogue was identified. The introduction of the Product Data Templates illustrates how the complexity could be reduced on the side of the Data Dictionary.

Since the IFC format is complex, the combination with complex product data will likely result in large, unmanageable files. Therefore, in the upcoming standard section on the IFC catalogue, consideration should be given to how the complexity and size of the created catalogues can be reduced to a minimum. Furthermore, the creation/editing/reading of the catalogue files should be made efficient.

This paper does not address the associated question of software requirements and implementation guidelines. This topic includes the definition of software functionalities, providers, and interfaces to existing BIM/planning tools. Significantly, creating and exchanging a product instance file (configured/selected from the catalogue) must be clarified.

Other essential aspects that were out of scope for this work are the geometry and the contextualisation of individual products within modules, including accessory components or whole building systems. Also, the versioning of data dictionary entries and the individual product catalogues were not discussed in detail in this paper. In future, these currently disregarded topics should be included in implementing a use case example, as they can majorly impact the required data structures and may reveal further unresolved issues.

Despite the open issues remaining in the current state that have been illustrated in this paper, the approach of ISO 16757 is an improvement for product data exchange since uniform and already standardised formats are used. Following this approach, manufacturers do not have to serve several formats simultaneously. Attention should be paid to balancing the needed complexity for representing the product data and an efficient data management. Otherwise, the advantages of the ISO 16757 workflow will be lost due to a high implementation effort.

We advocate for reusable reference implementations to assist both manufacturers and software vendors incorporate these powerful and versatile means to model parametric product data in building models.

Acknowledgements

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