Use case-based evaluation of a standardised product catalogue format for configuration

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Abstract

The absence of a standardised, neutral product catalogue format capable of representing parametric and variable product data poses a challenge in the construction industry. Searching and selecting technical building equipment products remains a laborious and manual task. Using a product example, this paper explores and evaluates the constraints of parametric and variable product representation methods in the catalogue format structure influencing configuration processes. A literature review has identified crucial information for product selection required in configuration. We propose an example configuration process that includes a building model and a product data catalogue as data resources. The result shows that selection hierarchies can only be partially mapped due to a lack of flexibility in addressing individual multi-column table values and missing data control structures. The research intends to support the development of a product catalogue file format to facilitate product decisions with the help of efficient configuration processes.

1. Introduction

Since Mechanical, Electrical and Plumbing engineering (MEP) products are essential for the operation of a building, their careful selection is a challenging and critical task in the Architecture, Engineering, Construction and Operation (AECO) industry. The MEP industry has to handle complex and variable product configurations, leading to a labour-intensive and time-consuming data exchange (Kremer et al., 2023).

Multiple manufacturers offer various product classes with differing properties and characteristics. The variability and flexibility with which product properties can be combined lead to a large number of individual, producible product designs, resulting in many potential optimal solutions for customers to choose from. Due to the wide range of options, the product selection process is a laborious and manual task for customers, who often rely on familiar manufacturers and positive cooperation experiences.

The product information needed for manufacturing differs from those required for planning, installation, and operation in construction projects. To be usable to customers, the data from the manufacturers' Product Information Model (PIM) has to be extracted, simplified and transformed interoperable formats at great expense for manufacturers.

Product information is available to customers via the manufacturer's websites, product data portals such as BIMObject, and interfaces with proprietary software systems (Hoffmann et al., 2018). The formats distributed in this way are machine-readable and can be processed automatically to varying degrees. Currently widely used format approaches for product descriptions and data distribution are: The Portable Document Format (PDF), the German VDI-3805-1, 2011 (available and used in Germany), DWG/DXF, Industry Foundation Classes (IFC) and Revit family objects [1] (Wagner et al., 2022).

The MEP industry's ongoing standardisation work aims to improve and simplify the exchange and processing of product data. The standardisation work contains the structure for a data dictionary and a product catalogue exchange format based on the widely used and well-known IFC format (ISO-16757, 2019). Since the large number of properties and their possible combinations recorded in a catalogue file leads to millions of deliverable product variants, mechanisms are needed to support customer searching and selection. Filters and configurators play a crucial role in the MEP industry, simplifying the product selection process by reducing the number of products to a human-manageable level. These tools are designed to process customer requirements and filter suitable products. When selecting products, a distinction must be made between filtering and configuration. During filtering, information is successively fed in to reduce the selection quantity. During configuration, various parallel existing requirements/components (from different sources and with different weightings) are weighed up. The aim is to derive the best possible combination of requirements/components and thus reduce the selection quantity.

Standardised properties further enhance the customer's selection process by providing predefined dependencies and hierarchies of manufacturer data. However, a product's configuration poses unique challenges that require a flexible format structure for mapping, storing, and accessing product data.

So far, the proposed ISO 16757 product catalogue has only been implemented as an example file for burner products. The catalogue applicability for the configuration process has not yet been implemented practically. The question arises as to whether the structure and entities of the proposed product data catalogue format are sufficiently flexible to enable configurations in addition to filter processes. Thus, this paper presents a prototype configuration implementation with the product data catalogue file format proposed in ISO 16757-5 using a use-case example product. We intend to investigate the catalogue's suggested efforts for property combination and selection in addition to constraining methods on property values.

Our research aims to contribute to the ongoing standardisation work in the MEP industry. By implementing and evaluating a configurator based on the IFC Project Library for product catalogues, we seek to identify the advantages and disadvantages of ISO 16757-supported product configuration. Additionally, we highlight unresolved issues and gaps in the current standardisation efforts and propose components of a more practical configuration process.

2. State of the Art

2.1. Standardisation work

The currently developed ISO standard intends to adopt the German VDI 3805 approach for machine-readable product data catalogues and expand it to an international level (Kremer et al., 2023).

ISO 16757 Parts 1 and 2 have been published, while parts 4 and 5 are currently under

[1] Autodesk Revit Families

development and revision. Product class-specific ISO 16757 sheets have yet only been considered and not developed. Kremer et al., 2023 examined and evaluated the theoretically implemented ISO process and its formats using the product class *burner* and two subclasses, oil burner and gas burner.

The first general parts of the ISO standard relate to defining the semantic data model, the structure for representing product data geometry, and the technical implementation of exchange formats. Based on these definitions, further parts of the ISO standard are created for each MEP product class (e.g. heat generators, ventilation, etc.).

The semantic meta-model specifies the MEP domain's classes, properties, relations and features for creating and selecting valid products and value constraints (Kremer et al., 2023). Properties are defined according to ISO-23386, 2020 and categorised according to the domain (description of the catalogue, a product, or the installation system), function (selection or technical property), and dependency (static and dynamic property). Inheritance relationships enable properties to be grouped and assigned to product classes and their subclasses.

Part of the ISO 16757 is the structure definition of a data model for BIM-related dictionaries for storing the semantic data model based on the ISO-12006-3, 2017 for organising construction work information and ISO 23386 for describing properties using attributes in interconnected dictionaries. The data model specifies the different properties categorised according to their relationship (dependent or independent) and allocation (external, system or environment describing property) (Kremer et al., 2023).

The product catalogue exchange format is a Model View Definition (MVD) of the IFC schema called IFC Project Library and defined in ISO-17549-2, 2021 to describe the exchange of product catalogue data for building services (bS) products. A product catalogue is subdivided into a metadata section (including edition and manufacturer data) and product structure elements (including classes, series, properties, and values). The content of a product catalogue consists of `IfcBuildingElementProxyType` representing the product class; a property is created as `IfcPropertySingleValue` and grouped by `IfcPropertySet`. These entities refer to the predefined classes and definitions stored in a data dictionary using URL-based `IfcLibraryReference`. If required, the manufacturer's PIM system provides and adds manufacturer-specific entities and values without a data dictionary reference.

ISO-16757, 2019 suggests two different configuration mechanisms for identifying valid products. The first mechanism is the product index, where an object (product index) refers to the values of selection features that together represent a single product. The second mechanism is the rule-based valid combination of characteristics, where the manufacturer provides the necessary function for application. The function's input parameter is an incomplete product index and its return value is either a complete product index or an empty value (ISO-16757, 2019).

A selection process is required to costume a product from a product class. Manufacturer-managed products are characterised by their combination of valid property values. To obtain these combination and selection options in an `IfcProjectLibrary`, `IfcObjective`, `IfcMetric`, and `IfcTable` entities are used to restrict property values and combinations.

Depending properties, where the value of one property is used to calculate the value of another property, is represented using the `IfcPropertyDependencyRelationship`, which embodies a JavaScript function specification for calculating a temporary result based on depending property values.

2.2. Configuration

The configuration of products provides product variety and is a critical objective in mass configuration and mass production. However, up to date, there is not yet a generally accepted definition for configuration existing (Haug et al., 2012). Cao et al., 2021 defines a configurator as a decision support system automating the efficient and rapid generation of product variety through a combination of kit-of-parts using predefined rules. The generation process results in a valid manufacturable product meeting the customer's desired product properties. The configurator as a simulation for an expert system, supporting users in creating product specifications while restricting component and property combinations, is outlined by Haug et al., 2012.

2.3. Related Research

Bac et al., 2021 comprehensively evaluate Heating, Ventilation, and Air Conditioning (HVAC) systems for an industrial building use case using a hybrid multi-criteria decision method. Their evaluation included eleven HVAC systems based on previously determined twenty-seven criteria intensified through a literature review and categorised in *economic*, *cost*, *technical properties*, *physical properties*, *flexibility*, and *reliability*. Their research did not depict the process of selecting or configuring the eleven products from various manufacturers; however, they focused on the best choice determination according to BIM-based simulation and a criteria weighting system out of the preselected product pool.

Beetz and de Vries, 2009 outline a semantic web-based method for heterogenous, distributed catalogues of building-related products. They focused on retrieving product data from distributed resources using a four-layer approach. While the research outlines the concepts of classes, super and subclasses relation and property and value assignment, the mapping of functions and value dependencies has not been approached.

Kebede et al., 2022 present an approach to semantically representing product data linked with the CEB 17623:2021 standard for lighting, luminaires, and sensing device properties. Using a visual programming language, the implemented process intends to integrate product data into BIM authoring tools by applying semantic web technologies. However, the product data is pre-structured in a static table format and recorded for each product. The user manually selects the required properties in a hierarchised sequence.

3. Method

In this research, the IFC Project Library catalogue exchange format is examined, tested and evaluated for configuration processes using actual product data to validate the practicality of the format structure. The proposed implemented configuration process used and investigated in this paper is based on the configuration options, product selection structures and property combinations suggested in ISO-16757, 2019 and VDI-3805-22, 2019.

We have selected the heat pump product class as a use-case example. Heat pumps are a significant part of the sustainability debate, particularly in the MEP sector. Their properties, values, and combinations are complex; however, in this use case, they are limited and scoped to the flexibility and extensiveness of a product, excluding the complexity of a product system.

Our research involves collecting data from manufacturers' released heat pump product catalogues. For instance, we used a Viessmann VDI 3805 catalogue specification for heat pumps [2]. We generated an IFC Project Library sample file using the sample catalogue as

[2] Viessmann catalogue heat pump 2029

a basis for information. This IFC file contains a reduced subset of properties, focusing on selection properties and covering the IFC-provided entities for value constraining.
We have supplemented the properties and structures for heat pump product selection covered in VDI 3805 and ISO16757 with the results of literature research. The heat output was added as an important requirement for customised heat pump selection. The literature research includes scientific papers, manufacturer websites, and general information websites for potential customers and interested parties.
In the following section, we investigated the IFC Project Library entities and outlined the information flow by simulating a configuration process.

4. Use case implementation

As shown in Figure 1, a generalised selection process for a heat pump includes information from the building model and customer preferences. In addition, product selection can be influenced by restrictions in the form of standards or applicable law, as well as the product file format structure. The information requirements depend partly on the area of application for which a heat pump will be used (heating and/ or hot water providence).

4.1. Selection process and configuration

The customer defines and provides the area of application information. After selecting the area of installation and application, the decisive influencing variables (heating load and flow temperature) of the future operating environment are calculated for the heat pump's dimensioning. The dimensioning process is sensitive, as an oversized and undersized heat pump leads to inefficient operation.
The heating load of a building is determined by information from the building model (e.g. square meters of building structural components, material composition, insulation information, and the amount and size of radiators). The heat load calculation for dimensioning a heat pump is standardised in Germany through the DIN-EN-12831-1, 2017. In addition to the building model data, customer information about the building's usage, the heat pump's mode of operation (monovalent or bivalent), and usage restrictions are included in the calculation.
Functional components for customer selection include the heat pump's application and type, the heat source (soil-water, water-water, air, etc.), the additional backup heat/ energy source, its design, the installation location, the heat pump drive energy and its functional principle. In addition, the manufacturer's own properties can extend the predefined selection properties and must be filled and regulated with the manufacturer-specific values.
The described heat pump selection process is presented as a linear process; however, it is not. Individual building details are adjusted over time, and selection choices are adapted to balance the product requirements and performance, identifying a pool of possible applicable variants that fit the building's performance.

4.2. IFC Project Library

Based on the IFC Project Library structure defined in DIN EN 17549-1 and the specifications of VDI 3805, a (reduced) IFC catalogue file for the product class *heat pump* was developed.
Since no existing heat pump product catalogue is represented as Ifc Project Library, we utilise the existing VDI 3805-22 (broadly compatible with the ISO 16757 properties of the example decision tree structure and content). Restrictions and constraints on valid property and value combinations are implemented to map parts of the sample catalogue and display manufacturable products. These constraints are created using single- or

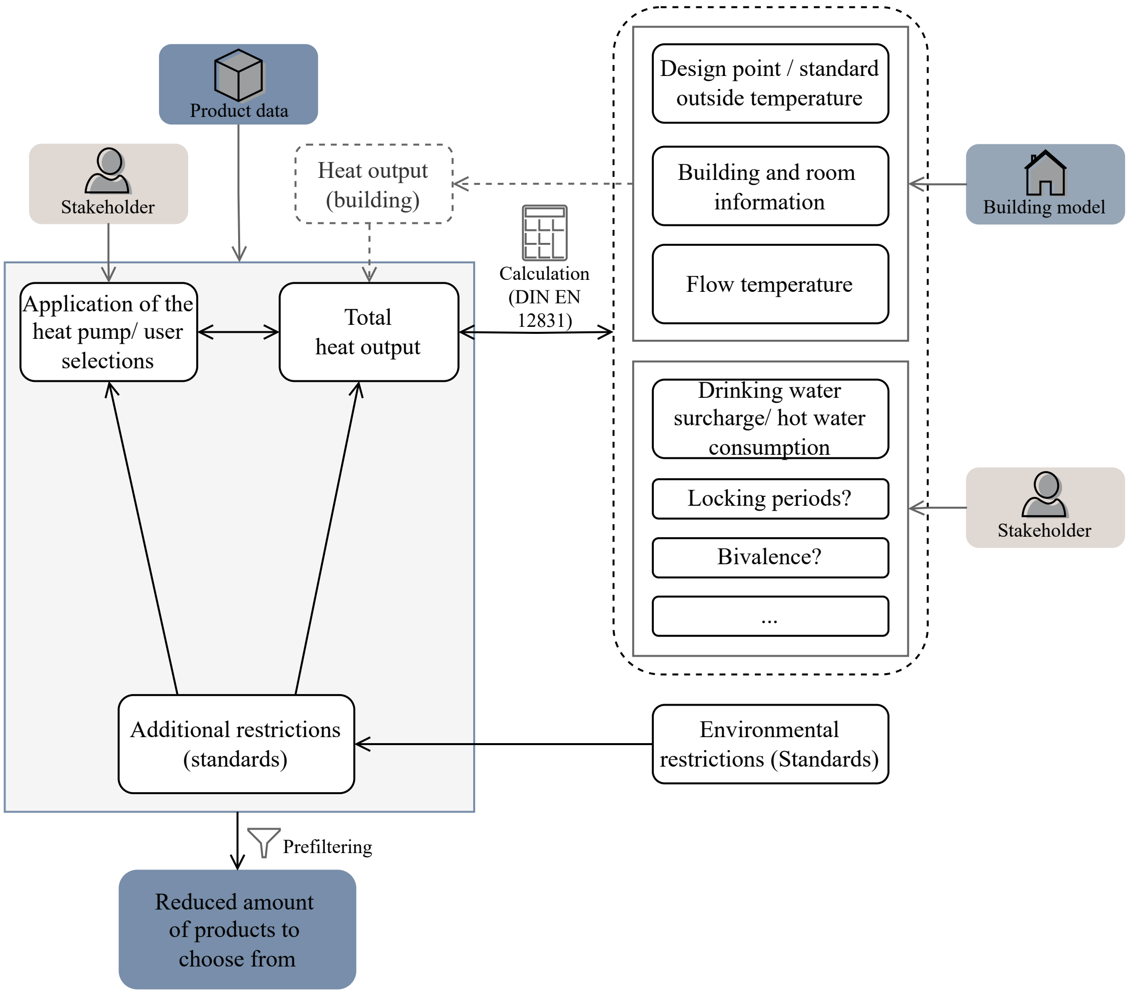

Figure 1: Important information input and source for configuration according to German requirements

multi-column tables and boolean and logical expressions, summarised in Table 1.

4.2.1. One-column table

One-column tables are used for value-storing ranges and enumerations. Therefore, the `IfcTable` entity consists of only one column named after the property, e.g. width, and contains in each row a single value. Together, the individual lines result in the various value options for the *width* property. In a one-column table each individual value can be internally addressed through its IFC local instance identification. Thus, the approach is suitable for mapping selection features for the configuration by compiling a product index.

4.2.2. Multi-column table

The properties defined in ISO 16757-1 are selection and technical, subdivided into dynamic and static properties. The selection properties are particularly important for the customer's product selection. In Figure 2, we have illustrated a selection process for a valid product using the approved combination of property values for heat pumps provided in the example catalogue.

Valid combinations defined by the manufacturer are summarised in one `IfcTable` entity. Each row in this multi-column table represents a valid combination of values for the *Application*, *Type*, *Design* and *Drive energy* properties. The selection marked in Figure

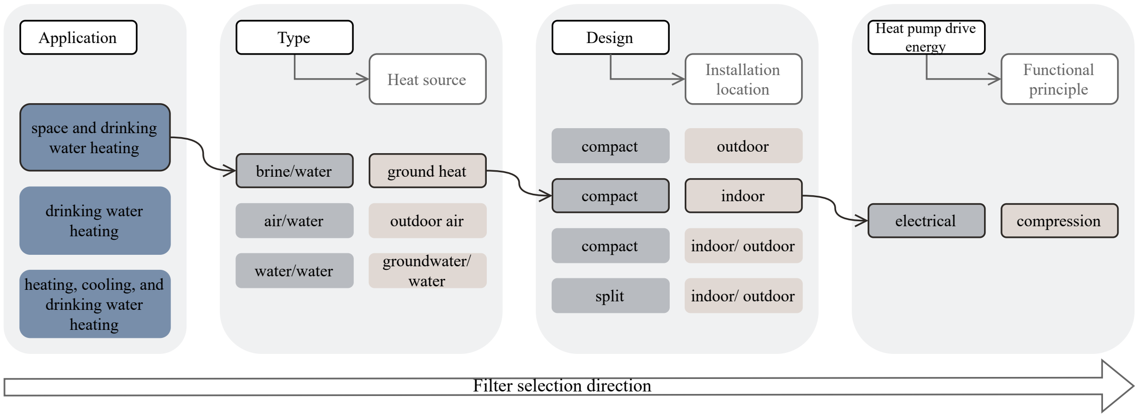

Figure 2: Example selection process structure (excluding operating mode)

2 reduces the product quantity to all space and drinking hot water heat pumps that are brine/ water-based, compact in design and whose drive energy is electrical.

4.2.3. Boolean and logical expression

While tables restrict possible property combinations, logical and boolean expressions restrict property values and their range. Boolean and logical expressions are mapped using the `IfcMetric` and `IfcObjective` entities. The IFC schema allows a nesting arrangement to represent complex expressions, extensive cascading logic, and boolean constraints of values. Logical constraints have been applied to set a general minimum and maximum of the *width* property. Geometric restrictions require heat pump sizes to stay within predefined limits captured by logical expressions. Restrictions are combined in validity using the boolean *AND* connection in the `IfcObjective` entity.

4.2.4. Arithmetic calculation

Basic calculations are implemented through the `IfcAppliedValue` entity deploying arithmetic operators (multiply, subtract, divide and add). Setting up a calculation algorithm requires individual `IfcAppliedValue` entities for each property and each calculation operation. Properties and values are separately declared and combined in a calculation description where their IFC individual identifier references them. All arithmetic calculations we have implemented can be realised using a corresponding JavaScript function since, in both cases, depending values are implemented.

5. Findings

In this paper, we investigated and evaluated the IFC Project Library structure components for selecting, connecting and restricting information to perform configuration processes.

5.1. Configuration

The ISO 16757-1 selection properties assume a static hierarchical structure, levelling down and increasing properties' detailing according to their classified level. This strategy primarily corresponds to the manufacturer's structural mapping of product data. The products are grouped, first according to general information (which corresponds to the selection properties) for categorisation into subclasses and then according to the technical specifications of individual products. This procedure implements a filter process, where a customer enters desired characteristics through his/her choices of properties and design while the software selects the fitting product. However, in configuration, multiple data sources provide information that influences each other. Thus, product

properties should be arranged and addressed flexibly according to their prioritisation for the configuration process.
Given the intricate and integrable nature of the product configuration process, we advocate for a combined process. This process, which can optionally include the building model as an additional data resource for calculating building requirements, is an improving step in managing the configuration process's complexity. However, this integration requires additional process steps and software tools for model validation and precalculating the building heat load.
Given the constant adjustments in the construction process, circular and iterative configurations and comparisons are essential to maintain the selection's fit quality. Configurators operating on product catalogue data formats instead of databases require a high degree of flexibility in the catalogue format structures to achieve equivalent performance characteristics. This adaptability is crucial to responding adequately to constant modelling changes.

5.2. IFC Project Library

One of the key unresolved understandings we identified is the scope of content that can be mapped in an IFC-based product catalogue. Using the example of the selection properties of a heat pump, it is essential to consider whether the selection hierarchy is implemented externally (e.g. in the configurator) and the catalogue format only provides the calculation parameters or whether it is contained in the IFC catalogue structure.
Since the number of possible combinations is high, a corresponding table specifying one valid combination of characteristics per row would become extensive. A more flexible solution is to split the table into several tables, which can be linked in multiple combinations by links and relations not defined as part of the file, similar to using one-column tables. Since only an entire `IfcRow` entity can be addressed, not its specific field entries/values, individual predefined data dictionary value entries can not be referenced.
Selection hierarchies and mappings of sequences and dependencies require control structures. However, the IFC format lacks control structures in the form of conditional statements (if-then) and prioritisation declarations. In addition, the lack of conditional statements affects the possibilities of logical and boolean expressions. Although we could set a minimum and maximum value, we could not link this restriction to the condition that the product is a brine-to-water heat pump.
Furthermore, during the implementation process, we encountered a limited ability to identify, address, and reference individual table entries directly in multi-column tables. They lack a unique identifier since they are not specified as individual IFC entities. In addition, a table field can not contain enumeration or range elements. Thus, we could define value ranges in a one-column `IfcTable` entity, but we could not reference these tables to provide input for another table field.
While including arithmetic functions in the IFC Project Library structure allows for the mapping and executing mathematical operations, their implementation is challenging. The process needs additional cumbersome references since already defined `IfcPropertySingleValue` are redefined as `IfcAppliedValue` entities. We propose to consider a more streamlined approach, suggesting the direct reference of properties to an `IfcAppliedValue` element as an input parameter.
The structure and assumption of possible selection properties are developed from the perspective of the manufacturer and software developer. For iterative configuration processes, the format structure has to adapt to changing and levelling processes, including equivalence transformation, instead of a linear assumed progression, supporting the customer with feedback.

Table 1: Overview of IFC entities restricting combinations and constraining values (ISO-17549-2, 2021)

Name	IFC representation	(Possible) usage
One-column table	IfcTable	Value range of a property
Multi-column table	IfcTable	Selection and combination constraint
Logical and Boolean expression	IfcObjective, IfcMetric	Property value constraint
Arithmetic expression	IfcAppliedValue	Integrating arithmetic operations
JavaScript	IfcProperty DependencyRelationship	Connecting depending property (values) for calculation

6. Conclusion

In this paper, we investigated limits and gaps concerning using IFC Project Library files for product configuration. Therefore, we operated on the example heat pump product catalogue.

Since users require varying levels of information from a product's catalogue after configuration, future research should investigate the Level of Information Needs (LOIN) and their representation in IFC project libraries and configuration outputs. The creation and file exchange process has yet to be clarified.

The IFC format structure is complex due to the definition of each individual IFC entity, which is characterised by a vast amount of subcomponents and attributes. Combining this complexity with additional complex product data will likely lead to extensive files.

The integration of JavaScript offers the potential for parametric features in IFC. Determining whether the JavaScript function declaration and implementation are within the IFC product catalogue file is crucial. Alternatively, only the declaration is part of the catalogue, and the manufacturer supplies the implementation externally. Software manufacturers must react to this hybrid format version, implement additional reading and processing methods and guarantee the secure use of integrated code snippets.

Currently, only specific product-related selection criteria are considered. Future research should incorporate more general requirements, such as efficiency and sustainability, and examine how these can be mapped at the product data level. Emphasis should be placed on identifying the product characteristics and properties that influence and support customer decisions on suitable products.

In addition, geometry aspects, contextualisation of product components within the product/ building system, and accessory components were out of scope. These yet excluded topics should be included in further research approaches and activities to reveal unresolved issues and impacts.

However, the IFC Project Library approach used in ISO 16757 provides major improvements and future possibilities since parametric components and structures are now implemented and tested in the IFC file format. The parametric extension allows highly modular and parametric product data to be mapped in IFC. It increases the versatility of the IFC file format's applicability to continuous changes in modelling tasks and project developments.

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