

LEVERAGING CLASSIFICATION KNOWLEDGE FOR IMPROVED DATA ACCESSIBILITY IN DIGITAL CONSTRUCTION

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Abstract

While the prevalent use of complex structures such as Industry Foundation Classes (IFC) in digital building models has good reasons, it also limits the easy accessibility of data and hinders a common understanding of building structures across different projects or companies. This paper presents an approach to how existing classification systems can effectively improve common understanding by representing and collecting classification rules in the machine and human-readable IDS format of buildingSMART. The formally mapped classification rationale serves as a common starting point for stakeholders, capturing and consolidating classification knowledge from project or company-specific models and breaking down technical barriers to using digital models. This initiative contributes to a more collaborative and standardized digital construction industry and promotes better data understanding and knowledge sharing between stakeholders.

Introduction

The digitization wave sweeping across the construction industry necessitates the adoption of highly structured and complex data formats like the Industry Foundation Classes (IFC) to encapsulate the rich, multi-dimensional information inherent in construction projects. (Zhang et al., 2014) However, a significant barrier arises as stakeholders, particularly those with varied disciplinary backgrounds, grapple with these complex data structures. The pressing need is to ensure the most straightforward entry point for all stakeholders into the digital realm, promoting wider adoption and effective utilization of digital methods. (Opoku et al., 2023)

Classification systems stand as a pivotal element in bridging this complexity gap. Essentially, classifications are systematic arrangements in defined categories based on shared characteristics, as ISO 14177 (International Organization for Standardization, 1994) outlines. These systems, utilized across diverse application areas and disciplines within the construction industry, provide a familiar framework for engineers working with them for decades. The essence of classification lies in its ability to streamline information retrieval, enhance communication, and promote standardization, which is fundamental in handling complex data structures inherent in digital construction models.

State of the Art

The evolution of digital construction methodologies, particularly Building Information Modeling (BIM), has catapulted the significance of classifications to a new level.

(Wu and Zhang, 2019) BIM, with its ability to create rich, multi-dimensional digital representations of physical and functional characteristics of assets, necessitates a structured approach to information management. Here, classification systems serve as the backbone for organizing this voluminous data in a structured, accessible, and interoperable manner (Beetz, 2018). In the digital realm, classifications have evolved to serve as a categorization tool and a medium to enhance information flow, accessibility, and collaborative engagement. They are now employed to structure the data within digital models, facilitating more straightforward navigation, interpretation, and utilization of the information. For instance, in terms of model structuring, they aid in structuring digital models. This enables stakeholders to navigate and interact with the model contents through a familiar classification view and simplifies the engagement with complex data structures like the Industry Foundation Classes (IFC). In the context of information retrieval, classifications speed up the retrieval of pertinent information. Organizing data systematically and predictably becomes crucial for decision-making and coordination among various project stakeholders. When considering interoperability, classifications enhance this by offering a standardized framework. This facilitates efficient information exchange amongst numerous software applications and platforms typically employed in a project. Lastly, there's a shift in modern digital construction methodologies towards knowledge capture. More than ever, there's a focus on capturing and formalizing the knowledge of how components are classified. This pivotal change facilitates a shared understanding and consensus on classification standards throughout the industry.

In practice, there are two different ways of classifying components of a digital construction model: (1) Rule-based Classification and (2) Attribute-based Classification.

Attribute-based Classification describes a process in which the model authors manually add attributes to the components to assign the component according to a classification. This pragmatic approach is confirmed by its implementation in industry practices and standards, such as the guidelines of BIM Deutschland (BIM Deutschland, 2024). This initiative makes key recommendations for the use of BIM in Germany. It emphasizes the need for defined attributes to be added and maintained across all service phases for Level of Information (LoI), exemplified by the requirement to add attributes for classification according to DIN 276 manually. This customization provides flexibility in classification as attributes can be tailored to suit specific project

needs. It also facilitates intuitive classification based on observable or measurable characteristics. Despite its practical application and advantages, this method involves significant manual effort, which can be cumbersome, time-consuming, and prone to errors. Additionally, a coherent understanding of the classification scheme among all stakeholders is required to ensure consistency. The manual addition of attributes leaves the underlying rationale for classification with the human operator devoid of formalization. This tacit knowledge remains unshared and unstandardized across the industry, highlighting the necessity of initiatives like BIM Deutschland in guiding the industry toward standardized practices.

Rule-based Classification is a methodology that leverages static filter-like rules within native software tools. Users implement rule logic to filter components based on inherent information. This mechanism automates the classification process, ensuring consistency and efficiency while reducing the manual effort required. However, it presents limited flexibility in adapting to varying classification needs, and the logic may become complex and challenging to manage with evolving project requirements. (Bloch and Sacks, 2018) A notable short-fall of this approach is the lack of formalization of the underlying rationale for classification, making it difficult to capture and share classification knowledge across the industry. This mechanism can also be used to harmonize different types of content from other authoring tools. For example, exterior walls that have different characteristics (e.g., name or specific property) in various models can be identified as such. Prominent examples of rule-based classification in practice are seen in tools like *Solibri Office* and *BIMcollab Zoom* (Solibri, 2023; BIMcollab, 2023) (see Figure 2). In *Solibri Office*, classifications are facilitated through predefined rules, allowing users to filter and organize model components efficiently. Similarly, Smart Views in *BIMcollab Zoom* enable users to create custom views based on rule logic, aiding in the classification and visualization of model components. Figure 1 shows how users can define these rule-based classifications within *Solibri Office*. These examples showcase the practical utility of rule-based classification but also underline the inherent limitations in flexibility and formalization of classification rationale, underscoring the necessity for exploring alternative or supplementary methods to encapsulate classification knowledge in a more standardized, shareable format.

When examining the two prevalent classification methods, each brings distinct advantages. Rule-based classification stands out for its automation and consistency, offering a quicker and more standardized way of categorizing items. Conversely, attribute-based classification shines in its flexibility and intuitiveness, enabling more customized classifications.

Delving into the disadvantages, rule-based classification reveals certain limitations. Its adaptability to varying clas-

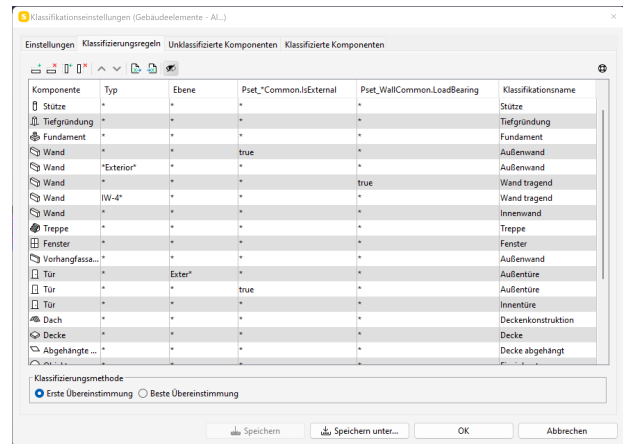


Figure 1: User interface in *Solibri Office*, in which a user can build up classification rules line by line

sification needs is initially restricted, posing a challenge in dynamic projects. As these projects evolve, the rule logic might become complex, cumbersome to manage, and potentially decelerating the classification process. Most notably, the absence of clarity in the rationale behind classifications obstructs the sharing and standardization of classification logic across different projects or teams, impeding collaborative endeavors and industry-wide learning.

On the flip side, attribute-based classification carries its own set of hurdles. It demands manual effort in classifying items, which can be time-intensive and error-prone, particularly in large-scale projects. Additionally, a coherent understanding of the classification scheme among all stakeholders is requisite to maintain consistency, a demand that could be challenging in diverse teams or multi-stakeholder projects. Like its rule-based counterpart, attribute-based classification falls short in elucidating the reasoning behind classifications, leaving the understanding of classification logic unshared and unstandardized across the industry. This shortfall again hinders knowledge sharing and collaborative efforts.

Both methods share a common pitfall: the ambiguity in the reasoning behind classifications. This ambiguity stifles the sharing and understanding of classification logic across the industry, pinpointing an area ripe for further exploration. In summation, while each classification method boasts its unique strengths, they both encounter significant challenges, chiefly in elucidating the reasoning behind classifications to foster knowledge sharing and industry-wide standardization. This exposition underscores the need for a refined classification approach that combines the strengths of rule-based and attribute-based classifications while alleviating their weaknesses, paving the way for enhanced sharing and understanding across the digital construction domain.

Approach

The potential benefits of formalizing this classification knowledge in a shareable, neutral format are manifold.

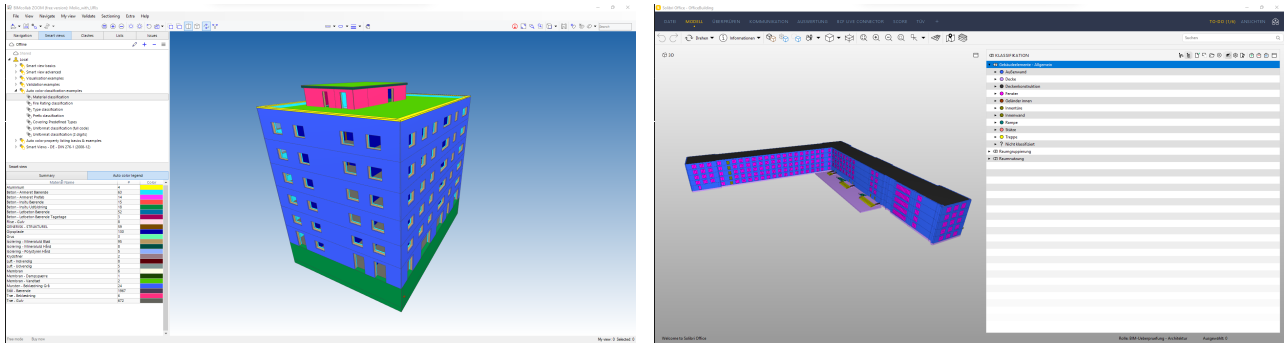


Figure 2: Showing Smart Views in BIMcollab Zoom (left) and Classifications in Solibri (right)

Firstly, it provides stakeholders with valuable insights, enabling a more comprehensive understanding and agreement on classifying components. This mutual understanding is crucial for harmonizing different stakeholders' perspectives. Additionally, a significant benefit is the reduction of manual work. By utilizing existing information about components for automated classification, the process becomes more efficient and consistent, minimizing the chances of errors that come with manual classification. A key advantage is the encapsulation of rule logic into a standardized format. This encapsulation creates a common language that explains the reasoning behind each classification, making it much easier to manage and share across various projects and teams. Overcoming the typical constraints associated with traditional classification methods, this approach fosters better collaborative engagement. A standardized format serves as a common ground, encouraging dialogue and cooperation among stakeholders, which is vital for the success of digital construction projects. Moreover, streamlined data management is a significant outcome of this approach. It simplifies the classification process and creates a more organized digital environment, making navigating and interacting with digital models easier. Often, the rationale behind a component's classification is inherently depicted by the existing information about the component. The prevalent constraints can be overcome by identifying and encapsulating this rule logic into a standardized format, paving the way for enhanced collaborative engagement and streamlined data management in digital construction. By extracting and formalizing this rule logic into a standardized form, we can transcend the current limitations, unlocking a new horizon of collaborative engagement and streamlined data management in digital construction. Through this endeavor, we aspire to intertwine the existing classification systems with complex data structures, simplifying the digital landscape for all stakeholders and nurturing a more collaborative, efficient, and user-centric digital construction ecosystem.

Standardized Formats for Formalizing Classification Knowledge

It is worth investigating existing standards that can efficiently encapsulate and share classification rule logic to

formalize classification knowledge within the digital construction domain. Among the many available formats, mvdXML and Information Delivery Specification (IDS), both by buildingSMART International, emerge as suitable candidates owing to their structured frameworks and widespread recognition in the industry (Tomczak et al., 2022). A summary of the different pros and cons for our use case is shown in Table 1.

mvdXML (buildingSMART, 2016) is a technical schema accompanying Model View Definition (MVD) to formalize and validate data exchanges in construction projects. MVD is used to specify subsets of the Industry Foundation Classes (IFC) schema to facilitate interoperability in specific use cases. It can also be leveraged to formalize classification knowledge, aligning it with established industry standards. mvdXML provides a structured framework with an added validation layer, ensuring the encapsulated classification rule logic adheres to the predefined standards. Employing mvdXML to formalize classification knowledge could align the classification logic with established industry standards, promoting consistency and interoperability. Furthermore, the validation feature of mvdXML could be instrumental in maintaining the integrity of classification logic over time.

Information Delivery Specification (IDS) (buildingSMART International, 2023a) is a relatively newly introduced schema specifying a construction project's information delivery requirements. It serves as a blueprint, outlining the nature, format, and extent of 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.

Suggested Methodology

mvdXML offers a broad framework for formalizing and validating data exchanges in construction projects across

Table 1: Comparison of mvdXML and IDS for Formalizing Classification Knowledge

	mvdXML	IDS
Pros	<ul style="list-style-type: none"> + Powerful, structured framework for formalizing data exchanges. + Supports detailed specification of data subsets in IFC for interoperability. + Built-in validation ensuring adherence to industry standards. + Potential for aligning classification logic with established standards. 	<ul style="list-style-type: none"> + Simplified and straightforward encapsulation of classification rule logic. + Quickly adopted standard by buildingSMART, ensuring industry recognition. + Compatible with existing IDS editors for authoring and editing. + Facilitates interactive exploration and application of classification logic. + Supports regular expressions (Regex) for the specification of values
Cons	<ul style="list-style-type: none"> - Complexity and detailed structure may challenge users. - Many features may be redundant for classification, adding to the complexity. - Low market penetration given that it was introduced years ago. 	<ul style="list-style-type: none"> - Lacks built-in validation mechanism. - May require additional effort to capture more complex classification logic. - No existing tools for interpreting IDS in the proposed manner (before demonstrator development).

various use cases of the IFC schema. In contrast, the Information Delivery Specification (IDS) is limited to specific aspects of mvdXML, focusing on clearly articulating information delivery requirements throughout a construction project’s lifecycle. While mvdXML is versatile enough to encompass the functionalities of IDS, the latter’s targeted approach promises to be more user-friendly and streamlined for its intended purpose.

Despite its robustness and comprehensive technical schema, the mvdXML standard has specific challenges that could hinder its prompt adoption of our suggested approach. A primary concern is its current market penetration, which is not as widespread as desired, potentially limiting its immediate usability and acceptance for formalizing classification logic. Furthermore, the high complexity of mvdXML poses a steep learning curve for stakeholders, especially those new to digital construction standards, which could deter them from adopting this standard for classification logic formalization. On the other hand, the IDS standard, with its simplified approach, presents a lower barrier to entry, making it a more attractive option. Despite these concerns, the potential of mvdXML in this domain is acknowledged, and a comparative analysis with IDS in future studies could provide a nuanced understanding of their respective merits and limitations in formalizing classification knowledge.

Our proposed method utilizes the Information Delivery Specification (IDS) format without altering or extending its existing structure. The key idea is to employ a slightly different interpretation of certain aspects of the IDS for a distinct, constructive purpose.

The IDS file format, grounded in a standardized XML schema, is a robust mechanism for detailing information requirements for elements within Industry Foundation

Classes (IFC) files. An IDS file comprises two main sections: a Header containing general metadata about the file and a list of Specifications detailing the information requirements for IFC elements.

Each Specification within an IDS file is divided into three components: Metadata, Applicability, and Requirements. Metadata provides contextual information about the Specification, Applicability defines the scope of elements the Specification applies to, and Requirements outline the actual information requirements for the objects in question. Both the Applicability and Requirements components use a mechanism known as Facets to specify their content. In the context of IDS, Facets describes potential information an element in the IFC model might have. Six precisely defined Facet Parameters are used to make these requirements machine-interpretable, namely:

- Entity Facet
- Attribute Facet
- Classification Facet
- Property Facet
- Material Facet
- PartOf Facet

Traditionally, the IDS specification is divided into two main parts: the ‘Applicability’ part, which outlines the specific components the specification applies to, and the ‘Requirement’ part, which outlines the information requirements for those components. Our methodology retains the conventional use of the ‘Applicability’ part but adopts a different interpretation of the ‘Requirement’ part. Instead of seeing the facets defined in the ‘Requirement’ part as information requirements, we suggest interpreting them as classification logic. This subtle shift in interpretation allows an IDS specification to be seen as one or many applicable classification rules. These rules, encapsulated

in the 'Requirement' part, apply to the components specified in the 'Applicability' part.

Figure 3 shows an example of this. In this example, the characteristics for identifying load-bearing external walls are defined in the 'Applicability' part, and then two classification requirements are listed in the 'Requirement' part. According to the introduced logic, all identified building components in a model should now be classified as "*buitenwanden; niet constructief, massieve wanden*" according to the Dutch NL-SfB 2005 and as "*332 - Nichttragende Außenwände*" according to the German DIN 276 (BIM Locket, 2023; DIN, 2018). Since an entry is stored in the buildingSMART Data Dictionary (bsDD) (buildingSMART International, 2023b) for the Dutch classification, a corresponding URI can also be stored here, which links the resulting classification to the entry.

This novel methodology facilitates the systematic classification of components based on established logic, nurturing a more structured and insightful representation of model data. The transparency of the classification logic further improves understanding and consensus among different stakeholders, fostering a more collaborative and efficient digital construction ecosystem.

Utilizing the existing IDS format in such an innovative way aligns with the industry's ethos of leveraging established standards to foster interoperability and knowledge sharing while paving the way for enhancing the practicality and usability of digital models in construction projects.

Results & Test Cases

This section examines the practical application and feasibility of the proposed methodology using selected test scenarios. The aim is to gain insights into how the approach performs when applied to real cases. For this preliminary investigation, we have focused on the example of the national classification system DIN 276 to assess its applicability and robustness. This decision marks our first effort to validate the proposed method and illustrate its feasibility straightforwardly.

IDS Authoring & Demonstrator

Creating IDS files is a crucial part of this process, and having accessible tools significantly aids in this endeavor. One significant advantage of authoring the IDS according to the suggested approach is the compatibility with existing IDS editors, whether commercial or open-source. As the IDS specification is not changed or expanded, any compatible IDS editor can create, author, or edit the suggested classification logic.

For this research, the open-source *xBIM IDS Editor* (Benghi, 2023) was used to create the IDS files.

Given the absence of existing tools capable of interpreting the IDS as per our suggested methodology, a demonstrator was developed utilizing *ifcopenshell* (Krijnen, 2023) and the *IFC.js* (Viegas, 2023) viewer components. This demonstrator allows stakeholders to interact with IDS files alongside IFC files. In this setup, users can conveniently

load IFC files with one or multiple IDS files, and the encapsulated classification logic is automatically applied. Consequently, users are presented with the classification systems and the corresponding classification items, alongside the count of components identified as classified components according to the rules contained. Users can interactively navigate the model by clicking and highlighting the objects based on their classification.

This demonstrator serves as a practical illustration of the utility and effectiveness of our proposed approach, facilitating an interactive exploration of classification systems and the underlying classification logic within the digital construction models. In its current form, the viewer implemented acts more like a substitute, given the lack of existing implementations capable of interpreting the IDS as per our methodology. However, a far more impactful use case for the resulting IDS would be its integration into any platform users utilize to visualize, create, or edit digital building models. Such integration would significantly enhance the user experience by allowing the contents to be immediately structured according to the classification logic represented in the IDS files. This showcases the potential of integrating the existing IDS format for classification purposes and demonstrates a path toward fostering a more collaborative and insightful interaction with digital construction data among stakeholders. Through this hands-on evaluation, the proposed methodology has showcased promise in bridging the complexity associated with digital construction models, paving the way for broader adoption and effective utilization of digital methods in the construction industry. The resulting demonstrator is shown in Figure 4.

At this point, it should be added that the resulting classification results can also be fed back into an IFC model, as the IFC schema provides explicitly for this. However, it should be noted that this content only reflects the classification results but not the classification logic itself. If there are changes in the IFC model, the logic stored in the IDS would have to be applied again, and the classification contents stored within the IFC model would have to be updated. The resulting classification data can also be added to the IFC file on demand as part of the prototype development. For example, these contents can be displayed with Solibri Office as shown in figure 5.

The entire development of the Prototype Framework and the generated IDS files are open source and can be reused (iabi, 2023).

Use Case: DIN 276

The German DIN 276 standard is a vital guideline in the construction industry for structuring and managing costs in construction projects (DIN, 2018). It categorizes costs systematically, aiding in accurate budget planning and risk reduction by standardizing cost estimation and allocation. This standard ensures financial discipline, transparency, and effective communication among stakeholders in German construction projects. We have translated significant

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1 <ids>
2 <specification name="LoadBearing External Walls" ifcVersion="IFC2X3 IFC4">
3 <applicability>
4 <entity>
5 <name pattern="IFCWALL|IFCWALLSTANDARDCASE"/>
6 </entity>
7 <property name="IsExternal" datatype="IfcBoolean" value="TRUE" propertySet="Pset_WallCommon"/>
8 <property name="LoadBearing" datatype="IfcBoolean" value="FALSE" propertySet="Pset_WallCommon"/>
9 </applicability>
10 <requirements>
11 <classification uri="https://identifier.buildingsmart.org/uri/nlsfb/nlsfb2005/2.2/class/21.11"
12 value="buitenwanden; niet constructief, massieve wanden"
13 system="NL-SfB 2005"/>
14 <classification value="332 - Nichttragende Außenwände"
15 system="DIN 276"/>
16 </requirements>
17 </specification>
18 </ids>

```

Figure 3: Example IDS File containing classification logic - this example is for illustration purposes and is not directly usable as IDS because it was simplified

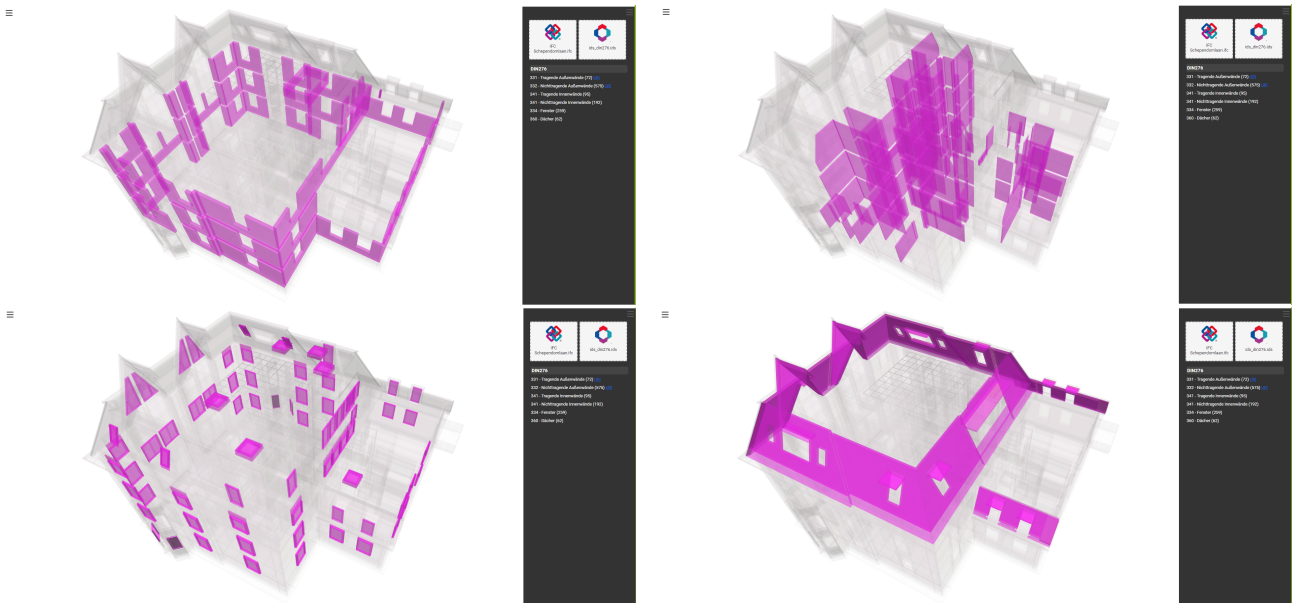


Figure 4: Resulting framework Demonstrator showing different resulting classifications processed using the IDS-representation of the German DIN 276

parts of the DIN 276 structure into IDS for demonstration purposes using the approach presented in this paper.

The resulting IDS can be used in the prototype framework to classify and structure any IFC model, showing the resulting structure on the fly. Figure 4 shows different classification results that have been successfully applied using the rules contained in the IDS. On-demand, the resulting classification can also be written back into the IFC file as references *IfcClassificationReference* objects.

Conclusions & Outlook

The exploration into formalizing classification knowledge via the IDS format reveals a promising avenue toward

bridging the intricacies of digital construction data with the practical necessities of industry stakeholders. This methodology not only leverages an established standard but also proposes a nuanced interpretation that aligns classification logic with the inherent structure of construction components. The resultant framework demonstrates a tangible step towards a more collaborative, efficient, and user-centric digital construction ecosystem. The success of the applied test cases underscores the methodology's potential to facilitate more intuitive interaction with complex data structures, thereby fostering a broader understanding and engagement across disciplinary bounds.

However, our approach is only a first step and has a whole

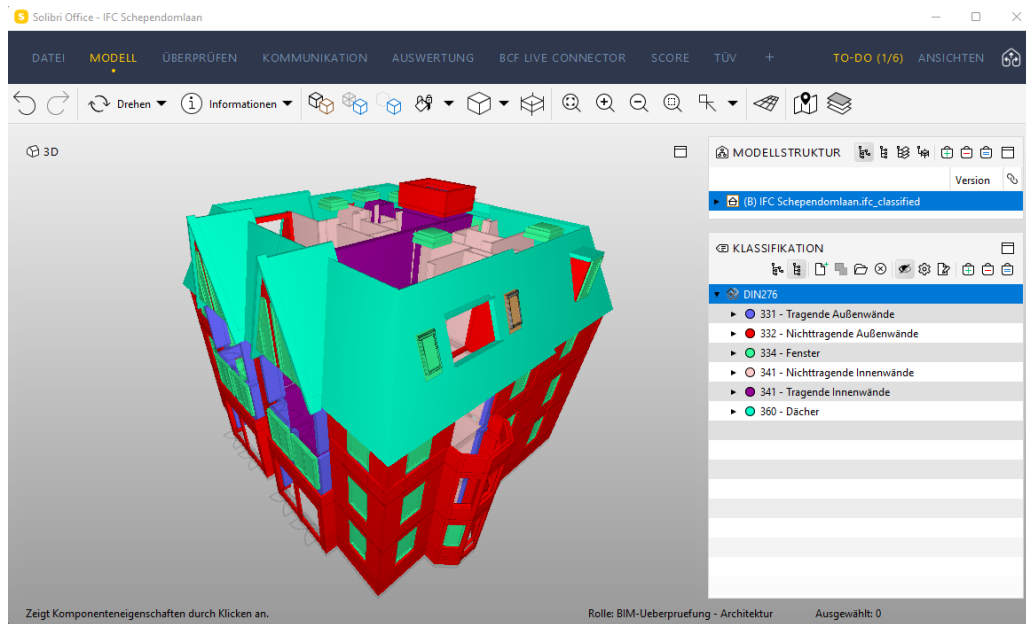


Figure 5: Resulting classification shown in Solibri Office

series of limitations that require consistent further development and refinement:

Exploration of Complex Classification Systems: In

our contribution, we have initially converted elementary parts of DIN 276 as a first step to test the basic concept. Of course, there are other national or specialized classification systems worth translating into IDS to make them easily applicable to the masses. Our future research will examine more complex classification systems such as Uniclass and Omniclass. These systems are designed for more complicated and global classification requirements and will be essential for expanding the scope of our study.

Dependence on correct model content: The accuracy and precision of model content remain critical to the successful application of any classification system, underscoring the need to improve modeling procedures continuously. The effectiveness of classification systems depends mainly on users' consistent and accurate maintenance of attribute data. Our approach does not change this, but this is not the intention because, at this point, it is the task of model quality assessment and assurance mechanisms to ensure the appropriate quality.

Conversion of Native Classifications: Regardless of official classification systems, a lot of valuable classification knowledge is deeply embedded in native software solutions and remains inaccessible without targeted and sometimes laborious extraction processes. This represents a significant obstacle to using this knowledge across different systems. Classification knowledge currently only contained in systems such as Solibri Classifications and BIMcollab Smart Views needs to be extracted and converted into an open format such as IDS.

This will enable wider sharing and application of this knowledge, overcoming the limitations of proprietary systems and improving interoperability and collaboration across digital construction platforms.

Our work represents an initial step towards potential improvements as we explore automated classification and model validation. It introduces possibilities for further research in model semantics, knowledge extraction, and sharing classification knowledge. Future efforts can focus on refining these methods to enhance their practicality and efficiency:

Automatic Derivation of Classification Logic: A

proactive examination of existing models with classification attributes could be undertaken to derive classification logic from these models automatically. Utilizing Artificial Intelligence (AI) and Machine Learning (ML) techniques, the underlying classification logic within these models could be extracted and formalized into IDS files. This automated extraction of classification knowledge could potentially unveil a rich repository of classification logic, making it available for users across different platforms.

Model Validation: The established classification logic can be employed in its original intent, as per IDS, for validating models. This validation ensures that models adhere to defined classification schemes, enhancing the quality and consistency of digital construction data.

Semantic Enrichment of Models: The classification logic could also serve as a mechanism for semantically enriching models. When a component is identified under a specific classification, this logic could provide instructions on the data placeholders or specific values the component should possess. This semantic enrichment facilitates a more detailed and nuanced

representation of construction components, enriching the digital construction model.

Community-Driven Evolution: Encouraging a community-driven evolution of this methodology could foster a collaborative environment for continuously refining and expanding the classification logic. Engaging with industry experts, academia, and software developers could collectively advance this approach, aligning it more closely with real-world needs and emerging industry standards.

The envisioned enhancements and the community-driven evolution of this methodology highlight the potential of this approach in addressing the present challenges and adapting to the evolving needs of the digital construction landscape. Building upon the established standards and engaging with the broader community could significantly contribute to the ongoing digitization efforts within the construction industry, making digital construction models more accessible, understandable, and usable for all stakeholders involved.

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