Enhancing IFC Models for Circular Design: Validation of Required Information through an IDS Framework

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Abstract -

Given the significant impact of the construction industry on climate change, efforts must focus on reducing energy consumption, emissions, and raw material extraction. Through improved planning and continuous design optimization, building sustainability and circularity can be enhanced. Significant progress has been made in the fields of Building Information Modeling (BIM) and Life Cycle Assessment (LCA). However, it is still necessary to meet the diverse BIM model requirements defined by LCA software vendors, whose proprietary Property Sets (PSets) must be enriched with information in the BIM model for accurate assessments. However, there are also open developments that have agreed on a common information requirement for sustainability assessment and circularity assessment available as datasets in the buildingSMART Data Dictionary (bSDD). This paper presents the development of an Information Delivery Specification (IDS) that combines the information requirements of two LCA software and two bSDDs. The IDS is successfully validated on two BIM models and will be further developed in an ongoing research project.

Keywords -

Circularity, Construction domain, LCA, BIM, IDS, bSDD

1 Introduction

The construction industry is crucial for efficient energy and resource use, because it accounts for an estimated 37 % of global operational energy and process-related CO_2 emissions [1]. The circular economy paradigm emphasizes the importance of reuse over recycling, advocating for the reuse of complete elements as a more sustainable approach than simply recycling materials. To achieve circularity in the construction domain, it is crucial to have a detailed knowledge of the installed elements.

Building Information Modeling (BIM) is a digital planning method that captures extensive planning information, but its application in terms of circular value creation and energy optimization is still limited [2]. To strengthen the connection between sustainable and digital engineering, it is necessary to ensure a consistent data flow between design and assessment, including the circularity potential of elements. Currently, the circularity assessment is based on proprietary information requirements that are custom-tailored for certain vendors.

To facilitate the annotation of BIM models in early design phases with information about reusability and allow for optimizing the design, it is important that this information can be defined in vendor-neutral schemes with open standards.

This paper explores the potential of the Information Delivery Specification (IDS) standard for enhancing information requirement management in circularity assessments. To this end, current requirements from software vendors and publicly available specifications from the buildingSMART Data Dictionary (bSDD) are analyzed and integrated into a unified IDS for validating models in the Industry Foundation Classes (IFC).

Given that various software solutions for Life Cycle Assesment (LCA) are already available, it must be ensured in construction planning that the BIM models used are also suitable for use as input files. The software manufacturers agree on the established IFC standard. For purely geometric and technical planning, the model does not need to be enriched with all the information required for a sustainability and circularity assessment. In particular, the reuse of components is becoming increasingly important. Thus, it must be stored in the data if components originate from reuse or are designed for reuse. Incomplete input data would lead to an incorrect LCA. Assuming that the respective software manufacturers have drawn up modeling guidelines and have either used IFC Property Sets (PSets) for all the required information or have developed their own custom PSets, the following research questions arise:

1. *How can it be ensured that all required information is available in order to carry out an accurate life cycle assessment for buildings?*
2. *How can different proprietary PSets be unified for a vendor-neutral LCA using open standards?*

Answering these research questions, a resulting unified IDS demonstrates how an open standard for LCA can be established and existing approaches harmonized. Its applicability is validated using two IFC models, with further refinements planned as part of an ongoing research project.

This general objective is addressed in the 'CLUE' research project by the procedure described. This research project aims to develop digital tools that provide feedback on resource-efficient, energy-efficient and circular construction during the planning phase. These tools will evaluate building designs based on energy and resource efficiency and the potential for implementing a circular economy. CLUE is an acronym for the project title '**C**ircu**L**ar b**U**ilding d**E**sign'. The project involves stakeholders from all phases of a building's life cycle, ensuring comprehensive analysis and optimization [3].

2 Background and Related Work

2.1 BIM-based LCA and Circularity Assessment

Life Cycle Assessment (LCA) is pivotal for achieving more sustainable construction practices. Through life cycle analysis, it is possible to evaluate the environmental impacts of an entire building as well as individual components and construction materials, providing guidelines on how planning can be modified to achieve greater sustainability.

According to Feng et al. [4], the adaptive reuse of precast concrete and timber can significantly reduce carbon emissions and concludes that secondary materials should replace virgin materials wherever possible. Reuse of materials leads to a greater reduction in carbon emissions than recycling. Minunno et al. [5] have demonstrated that the positive environmental impacts of reuse far exceed those of recycling, as evidenced by a modular building designed for dismantling and reuse. Specifically, a reduction in greenhouse gas emissions of 88% was achieved with reuse compared to recycling. Prefabricated elements have a higher reuse potential than in-situ and ready-mixed concrete [4]. The comparison shows that wood and metals have high recyclability because they can be easily recycled or reused, unlike concrete which usually has to be crushed. According to Feng et al. [4], maximizing the reuse of materials should be a key strategy for planners when selecting material resources.

Based on the growing demand for sustainable buildings, Azhar et al. [6] reviewed three building performance software solutions in 2009 and described how they work when embedded in BIM. However, the topic of BIM lacks any reference to the IFC standard that has been developed in recent years and this study is concerned with the operation of buildings. Nevertheless, it is found that the greatest influence on the subsequent environmental impact of a building takes place in the early planning phases. Therefore, the environmental impact of the construction project can be analyzed as early as possible during the planning stage. Backes and Traverso [7] include the social and economic impact of buildings in addition to their ecological impact and make a proposal for such an evaluation system. These two aspects should also not be neglected during construction, but it is questionable to what extent they can be analyzed using BIM data or whether it makes more sense to consider them outside of BIM planning. This aspect is, therefore, not considered in this paper. Carvalho et al. [8] have developed a workflow of BIM-based LCA for the portuguese market. They further parameters that are based on the portuguese SBTool^{PT}-H method and could be used in Revit to optimize building sustainability assessment [9]. Based on the fact that circularity research has identified decisive parameters for the LCA of buildings, these must be annotated in the BIM model. Fenz et al. [10] show how PSets can be developed for the sustainability context, compare them with third-party sources and integrate the results into an ontology. This shows how the sustainability parameters can be processed in the BIM context. In addition to the question of how the information required for the LCA gets into the BIM model, it is also crucial that the information in the BIM model is correctly compared with the material databases in order to determine the environmental impact. There is already research in this area, for example, by Forth et al. [11].

There are several software solutions on the market for implementing an LCA (see overview by [12]): The Madaster platform is a well-known LCA software that uses IFC data to analyze the circularity of a building and is also used in scientific publications (see Rieke et al. [13] and Theißen et al. [14]). Madaster can also be used to compare variants of different construction methods. Concular has already been successfully used by Gordon et al. [15] in the field of stocktaking for circularity assessment.

The concept of reuse is inherently connected to urban mining, which emphasizes the importance of establishing a comprehensive knowledge base on potential sources of reusable components and building materials. Additionally, considerations such as minimizing transportation distances and optimizing interim storage durations are critical. Akbarieh et al. [16] present relevant approaches addressing these aspects.

2.2 Open BIM Standards

BIM as a central planning method is established in the construction sector. Open BIM has an open orientation that enables various manufacturers to use the IFC data standard to foster interoperability.

IFC enables the exchange of construction data between different software in the planning process. IFC4 is the current standard of the IFC format as an 'open international standard'[17] and offers, among other things, broader support for infrastructure projects. Version 4 is registered as an ISO standard [18] and has existed since 2014 [19].

In the current IFC4x3 format, geometric, semantic, and alphanumeric information about buildings can be stored. For instance, this can be data that is used for a sustainability assessment. However, the IFC standard only contains the types of information that are industry standard. Other data used by specific software manufacturers can be stored in additional custom property sets (custom PSets). These can be developed and made available by the manufacturers so that full compatibility of the manufacturer's software with a file in IFC format is achieved.

Furthermore, IDS (Information Delivery Specification) defines information requirements in a machine-readable XML format closely related to the IFC format. It is a newly introduced buildingSMART standard that enables the automatic checking of IFC models to verify that all requirements are met [20]. Thus, the IDS file can be transmitted to any stakeholder, that prepares an IFC model for any following purposes. In this context, IDS thus also replaces Model View Definitions (MVDs), which were previously used in part to define information requirements, although the filtering of information is their actual benefit. The IDS format is now recommended by buildingSMART for the definition of information exchange requirements [21].The complete documentation of the IDS schema and the user manual can be found in the buildingSMART Github repository [1].

To facilitate the sharing of standardized definitions for describing the built environment in IFC models, the buildingSMART Data Dictionary (bSDD) is a service provided by buildingSMART [22]. This service aims to ensure the use of consistent and agreed-upon terminology across various software solutions. bSDD comprises a collection of interconnected data dictionaries, each containing definitions of classes and properties relevant to the built environment. These dictionaries are published by independent organizations and researchers and encompass international classifications, national standards, and company-specific agreements. Additionally, bSDD can store relationships between definitions, map between classifications, and provide translations, so that different interpretations of terms by different actors or software are prevented. bSDD focuses on the metadata-definitions of terms used to describe products and projects. This makes bSDD a valuable vendor-neutral reference library for shared definitions in IFC and IDS. The content within bSDD is organized into classes, properties, and their interrelations, adhering to the bSDD data model based on international standards. In the bSDD, the properties listed are divided into groups of properties. However, these groups of properties do not necessarily represent a property set as defined in ISO 16739-1 [23]. The prefix 'PSet_' is reserved for the official IFC and not the bSDDs [23].

[1] https://github.com/buildingSMART/IDS/tree/development/Documentation/UserManual. Accessed: 10.03.2025

3 Methodology and Framework

In order to force more sustainable construction methods and increased circularity, the approach shown in Figure 1 is pursued. First, the information requirements for BIM models are investigated and a modeling guideline is developed on this basis. This incorporates the existing requirements of LCA software manufacturers as well as open approaches. This is the aim of this work. With the help of these modeling requirements, BIM models can be enriched with the necessary information. The result is a collection of existing planning alternatives that can be stored as expert knowledge. If this expert knowledge is incorporated into building planning in the form of a software tool, greater sustainability and circularity can be achieved by considering suitable planning alternatives.

The proposed solution is the creation of an IDS with which the information requirements for the IFC model for an LCA can be checked at any point in the planning process. This is a rule-based approach. The proposed workflow with the IDS is shown in Figure 2:

The IFC model can be checked at any time during planning using the IDS to ensure that it contains all the information required by the LCA software (1). The IFC model is then transferred to the LCA software (2). This could also use the IDS to check whether all the required information has been transferred (3). However, the LCA software analysed already has its own functions for checking whether all the required information is available. Depending on the

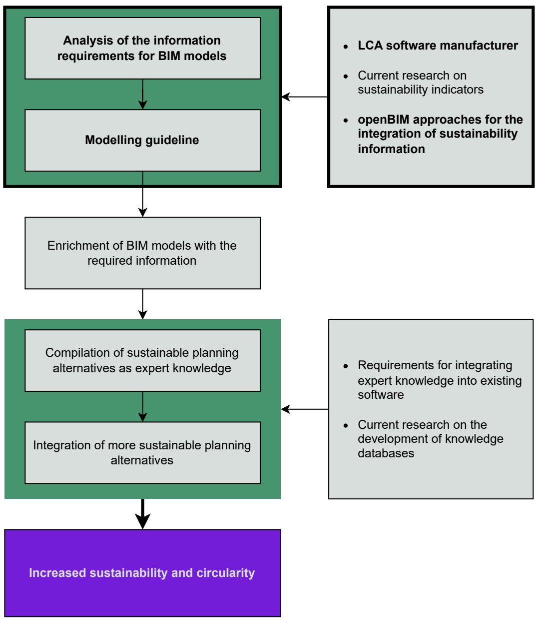

Figure 1. Schematic representation of the overarching research method

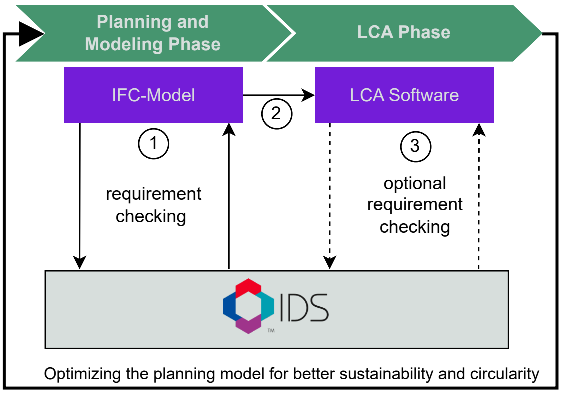

Figure 2. Schematic representation of the proposed workflow for sustainable building planning

assessment by the LCA tool, the design can then be improved in terms of sustainability and circularity. Although Concular and Madaster support both IFC2x3 and IFC4, the IDS created was designed for the current IFC4x3 version, as the different versions each have alternative requirements and no redundant IDS should be set up.

4 Implementation

We implemented a generalized IDS, which combines two proprietary solutions (custom PSets) with open approaches (bSDDs). As described in the methodology and related work above, there are various approaches to carrying out LCA. This paper analyzes the requirements of two distinct software solutions which, according to the DGNB's assessment [12], offer a wide range of functions compared to alternatives. However, despite functioning proprietary solutions, the aim is to map all functions using an open solution.

In Figure 3, the idea of the standardization procedure is shown: The two software solutions of Madaster and Concular and two open bSDDs are combined in an IDS. The bSDD dataset *Decommissioning and Reuse (DOR)* by Akbarieh [24] and the dataset *Circularity* by Al-Qazzaz [25] were used as open solutions. It should be noted that the latter is currently a preview version (as of March 2025).

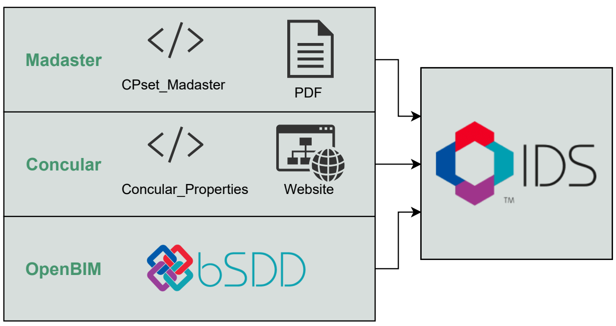

Figure 3. Schematic representation of merging the custom PSets with the *DOR* and the *Circularity* bSDD

Madaster offers a modeling guide in PDF format for preparing IFC models for their LCA platform [26]. The modeling guide contains detailed tables of all property names of their custom PSet. The main disadvantage of a formatted PDF modeling guideline to an IDS is that it is not machine-readable, so there could be some typos included, for example, a false space or a line break. Concular offers their modeling guide on their website [27]. There could be mistakes caused to display errors in the browser or similar. Therefore, all of the property names must be reviewed before transferring them to the IDS.

The respective PSets are also available for download for various BIM software, such as Revit and ArchiCAD [28, 29]. However, the verification of the model to ensure that all information required for the LCA, depending on the specific LCA solution used, is present, takes place within the respective LCA software. Using IDS, this verification can occur without access to the LCA software, allowing it to be integrated into the workflow during the modeling phase and supporting the open BIM approach. This ensures that the planning model being transferred directly meets all requirements, eliminating the need for multiple iterative model adjustments due to missing information.

4.1 Implemented Properties and PSets

For this IDS, parameters of different origins were initially selected to illustrate the standardization approach. The custom PSets of the LCA solutions from Concular and Madaster were selected as well as the mentioned two bSDDs. From these PSets and the bSDDs, parameters were selected that are suitable for describing the reuse case of solid building elements. It is clear from Table 1 that the four approaches partly describe similar element properties, although the property names differ.

4.2 Procedure for Creating the IDS

The IDS was implemented using the IDS web editor by LastBIM [30] as shown in Figure 4.

The main problem in the formulation of a generally valid IDS, in which several approaches are harmonized and which is to check whether the necessary information is available at all elements, is the 'applicability' of the IDS. This must be defined for each requirement. The first significant issue is that only one entity can be employed as applicability (see IDS standard according to buildingSMART [31]). As a result, alternative elements

Table 1. Comparison of PSets [26, 28] and equivalent bSDD [24, 25] - selection of possible properties that could be helpful for the reuse of components and which were saved in the prototype IDS

	Madaster CPSet_Madaster	**Concular PSet_Concular**	**DOR bSDD**	**Circularity bSDD (preview)**
1	DetachabilityConnectionType		Connection Type	Type of Connection
2		CpxReusability	Circular Potential	
3	DetachabilityConnectionTypeDetail	CpxDeconstructability		
4	DetachabilityAccessibility			Accessibility to Connection
5	DetachabilityIntersection	CpxSeparability		
6	DetachabilityProductEdge			Geometry of Product Edge
7		CpxPreuse	Current Reuse Count	
8				Probable Outlet
9			Total Reuse Count	

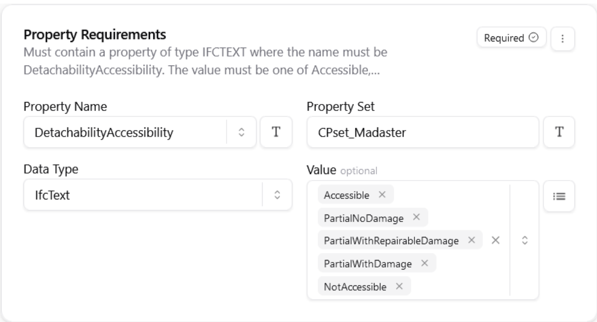

Figure 4. Setting up the IDS with the LastBIM IDS editor [30]

cannot be evaluated, and it must be explicitly clear which elements are present in the IFC model under examination to ensure that the requirement rules are applied precisely to these elements. Another challenge is that abstract IFC classes, which do not have instances themselves but only contain other classes, cannot be checked by the current IDS standard v1.0. This limitation makes it difficult to design the IDS to be as universally applicable as possible.

Therefore, the following approach is used, as shown in Figure 5: First, the IDS was created as shown in Figure 4. The requirements were formulated in general terms and no applicabilities were defined yet. The rules should be applied to all components. The entities for which these rules are to be applied were taken from the IFC documentation as a list [18]. A Python script was then used to manipulate the IDS document in XML format in order to duplicate the requirements, which were only available in one specification and only applied to the placeholder entity, into several new specifications and assign an entity from the list of instantiable entities in the IFC schema to each specification. The newly created IDS is, therefore, the basis for the model check and contains the properties shown in Table 1, which originate from Concular, Madaster, and the bSDDs.

5 Validation

Two existing IFC building models were used to validate the developed IDS. One is a residential building provided by the Institute for Automation and Applied Informatics (IAI) at Karlsruhe Institute of Technology (KIT) [32] as an IFC4 test file, and the other is an office building belonging to the Ruhr University Bochum (RUB). The IDS is validated in the open-source software Blender with these two models, as shown in Figure 6. Blender [33] is known as a 3D-modeling software with roots in video production and special effects. In Blender, the BIM-add-on Bonsai [34]

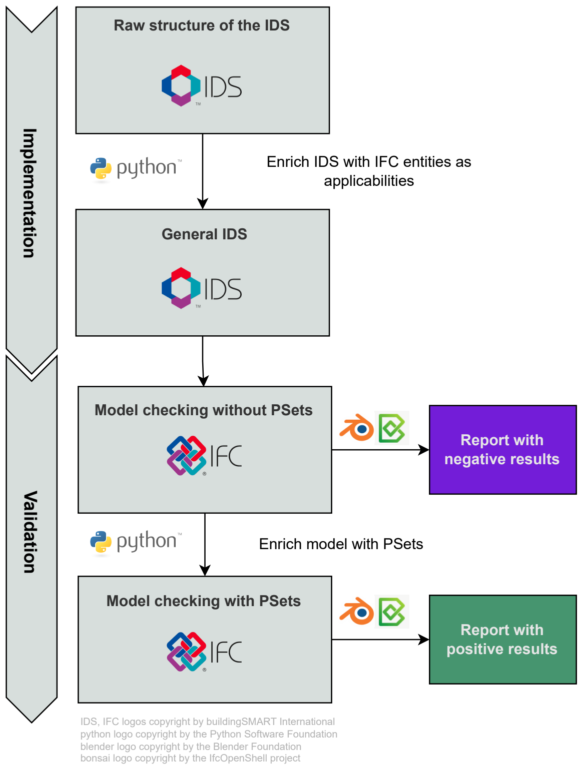

Figure 5. IDS creation and validation workflow

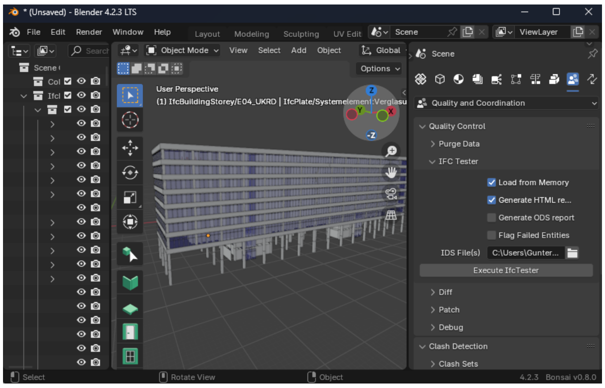

Figure 6. Validation of the IFC model of the RUB office building via Blender and the add-on Bonsai; screenshot of [33], [34]

is used to ensure the open BIM approach and check IDS requirements. An advantage of Bonsai is, that it is based on IfcOpenShell, so it works with native IFC and does not convert it to a proprietary format. The software generates a report after validation, which outlines which requirements are met or violated. This makes it possible to validate that the IDS is working properly. First, the models are checked in which the required PSets and bSDDs are not annotated. This control check, therefore, only resulted in unfulfilled requirements and thus in a negative report (see Figure 5).

Second, both IFC models were edited, and the properties were filled in accordingly with IfcOpenShell [35]. The focus was not on plausible values from an engineering perspective but only on ensuring that all properties were assigned a value. During the audit of the model enriched with sustainability information, the IDS audit rules were fulfilled, and positive results were reported by the IDS checker in Blender. This indicates that the PSets entered were accurately reported as present by the IDS. The IDS model checker displays the results in the program window and generates an HTML report, as well as a detailed ODS report. Based on the entities employed as applicabilities and the selection of PSets implemented (see Table 1), the IDS generated 889 specifications in which a total of 4,318 requirements were checked. Subsequent to this, 2,788 checks were conducted for the IAI building and 497,896 checks for the RUB office building due to the higher number of applicable building elements.

Overall, the IDS standard, as a recently developed standard, necessitates further refinement to ensure its more robust establishment. In this paper, the absence of reference from abstract classes to subordinate classes was of particular significance, as numerous component properties pertaining to reuse must be queried for nearly all solid components. Fischer et al. [36] have previously identified the absence of a reference to related elements, and Kremer and Beetz [37] have demonstrated the integration of geometric and topological checks with semantic information checks, for example, in the simulation of building energy models. The solution provided by the Python script for generalizing the information requirements in this paper could be replaced by a more advanced IDS standard in the long term.

6 Conclusion and Outlook

This paper has reviewed current practices in information requirements management for LCA and circularity assessment and proposed a unified method using IDS. A prototype IDS has been developed and demonstrated to meet the specified requirements for an accurate life cycle assessment for buildings. The proposed method can be utilized in an open BIM environment to ascertain the presence of the requisite LCA data within the IFC model.

The proposed workflow, which involves the implementation of an IDS to verify the requirements stemming from LCA for an IFC model, is thus proven to be a rational approach. However, the current IDS standard v1.0 has applicability limitations that required the use of the Python script to create it. Given the highly diverse requirements and the varying designations of the same model properties across different software, the creation of a universal IDS for LCA necessitates either the standardization of the LCA software solutions to function with the same PSets or an extensive compilation of all prevalent PSets. The latter option is less practical in application, as software manufacturers can continuously evolve their PSets, resulting in the IDS becoming obsolete rapidly. In this regard, software manufacturers could consider the option of automated creation or updating of an IDS. Achieving the greatest conformity with the open BIM working method could be achieved by several participants agreeing on a common bSDD, which is further developed and could be based, among other things, on the four originating sources analyzed. A potential avenue for advancement could be the generalization of the requirements, accompanied by the incorporation of informative reuse data, which could be a by-product in the form of an updated IDS of the CLUE research project. For further validation, a larger study with additional IFC models would be necessary so that all IFC entities used as applicability are validated. The next step is to develop a design-for-reuse, that can be validated using the IDS and assessed for optimizing the reusability potential of a structure.

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