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Research article

Requiring Circularity Data in Bim With Information Delivery Specification

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Abstract

Implementing the circular economy model in the built environment demands high-quality information about the building stock and products. Building Information Modeling (BIM) is considered vital to capturing relevant information. This study uses a constructive research method to assess BIM support for effectively capturing circularity-related information. We identified circularity needs and transcribed them into actionable, machine-interpretable form, applying the novel Information Delivery Specification (IDS) standard. Considered use cases include material composition, quality and identity, environmental impacts, and disassembly aspects. We discuss the benefits, challenges, and suitability of modelling such information based on the Industry Foundation Classes (IFC) schema. The developed IDS specification allows for semi-automated compliance checking of BIM content. Most considered aspects can be expressed in BIM but often lack consistent terminology. Difficult to document are disassembly instructions and elements' connections. Discussed technical limitations help rationalise the amount of information reasonable to capture in BIM. The study bridges the gap between sustainability expert demand for data and BIM deliverables. Resultant knowledge enables practitioners to increase the availability of quality data relevant for future building disassembly, reuse or adaptation.

Keywords: Circular Economy, Design for Disassembly (DfD), Building Information Modeling (BIM), Information Delivery Specification (IDS), Industry Foundation Classes (IFC), Life Cycle Assessment (LCA), Compliance Checking, Legal Reasoning, Information Requirements.

List of Abbreviations: Automated compliance checking (AAC), Building Information Modeling (BIM), buildingSMART Data Dictionary (bSDD), design for disassembly and adaptability (DfD/A), Environmental Product Declaration (EPD), Information Delivery Specification (IDS), Industry Foundation Classes (IFC), Life-Cycle Assessment (LCA), Extensible Markup Language (XML)

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1. INTRODUCTION

Globally, the construction sector contributes to almost a quarter of the CO_2 emissions from all global economic activities (Huang et al., 2018). One of the remedies to lessen the environmental impact is circular economy (CE), covering activities aiming to slow, close and narrow the material loops by using products longer, multiple times or less (Bocken et al., 2016).

Europe is experiencing an advent of initiatives and certification schemes trying to capture digital data useful to the circularity of building products. Among others, the European Taxonomy (European Commission, 2020) calls for circular practices and recommends following the ISO20887 standard on design for disassembly and adaptability (DfD/A) (International Organization for Standardization, 2020).

The standard provides general design guidelines for creating adaptable, versatile or extendible buildings containing components that are easy to reuse or replace. Regarding the digital implementation of the relevant information, the DFD/A standard (International Organization for Standardization, 2020) recommends using BIM to capture and transfer information, evaluate designs, and better understand the data. However, defining how this information should be captured in BIM is outside of its scope.

Çetin et al. (Çetin et al., 2023) identified relevant data needs through interviews with industry representatives. The results show discrepancies between information needs and data availability. Building professionals want data to be available in BIM models or drawings. Bellini and Bang (Bellini & Bang, 2022) identified data-related barriers to the circular economy: low data availability and unwillingness to share, low quality and interoperability, and lack of competencies.

The study aims to assess BIM support for effectively capturing circularity-related information. Through the development of IDS specification, we demonstrate opportunities, technical limitations, and challenges of transforming plain text circularity needs into machine-interpretable form and evaluate the difficulty of capturing the information.

1.1 Background

Previous studies on capturing environmental data in BIM show the modelling approaches are inconsistent, case-specific, limited in scope and often apply ad-hoc solutions and unique terminology (Akbarieh et al., 2020; Nawrocka et al., 2023; Soust-Verdaguer et al., 2017). They emphasise the importance of accurate BIM data for environmental analysis and decision-making (Nawrocka et al., 2023; Röck et al., 2018; Soust-Verdaguer et al., 2017). Automating LCA calculation with BIM offers great potential but is hindered by low interoperability of tools and data sources (Meex et al., 2018; Röck et al., 2018; Shadram et al., 2016; Soust-Verdaguer et al., 2017). Research by Santos et al. (Santos et al., 2019) on IFC schema (Industry Foundation Classes) support for environmental data found it suitable but incomplete for expressing all LCA-relevant aspects.

To quantify circularity using methods like the Material Circularity Indicators (MCI) or the derivative version for buildings (BCI), knowledge about the content, composition and source of the building products is required (Cottafava & Ritzen, 2021; Goddin et al., 2019; Mestre et al., 2023). Case studies demonstrate that BIM can provide such information if sufficiently specified (Mestre et al., 2023).

Automated compliance checking (ACC) in the design process can significantly impact the quality of the data, ultimately leading to increased data trustworthiness. Eastman (Eastman et al., 2009) divided the BIM rule-checking process into four phases: (1) rule interpretation and logical structuring; (2) building model preparation, where the necessary information required for checking is prepared; (3) the rule execution phase, where the data is validated, and (4) the reporting of the checking results. Solihin et al. (Solihin et al., 2017) highlight the need to understand semantic concepts with underpinning relations and spatial operations, often not explicitly modelled. Amor and Dimyadi (Amor & Dimyadi, 2021) reviewed decades of research on ACC to find three key components: openBIM standards, such as IFC, that enable sourcing the relevant information; knowledge representation standards for capturing requirements uniformly, and the development of solvers capable of checking the models against requirements. The same authors list the human inability to interpret information consistently and the insufficient quality of BIM as key hindrances to ACC (Amor & Dimyadi, 2021).

Legal reasoning is a methodology for interpreting natural language regulations. Studies in legal informatics by Schartum (Schartum, 2018) confirm that it can help increase the number of requirements to check automatically. The Tx3 framework from Hjelseth (Hjelseth, 2012) distinguishes between three categories of requirements: Transcribable – those that can be immediately put into machine-interpretable form, usually quantitative; Transformable – usually qualitative, possible to put in an actionable form making certain assumptions; Transferable – where understanding is very context-dependent or requires checking external information, therefore needing to be processed by an expert.

There are many approaches to requiring information in BIM, differing in scope, complexity, expressiveness, and dependency (Tomczak et al., 2022). Information Delivery Specification (IDS), a recent technical standard from buildingSMART, allows specifying and validating if the information is delivered accordingly. It defines the schema for capturing requirements for exchanging digital information in human-readable and machine-interpretable forms (buildingSMART International, 2023a; Tomczak et al., 2022). It is based on XML format and reuses popular technical solutions for easy software implementation. IDS is dedicated to specifying information following the IFC schema. Its scope is limited to alphanumeric information and does not support geometrical or spatial checks. IDS files consist of metadata describing, among others, authorship and purpose and a list of specifications. Each specification contains an applicability filter, allowing the selection of objects to be verified and requirements to be fulfilled. Both parts use facets, for example, for matching elements containing certain materials or mandating the existence of an attribute.

2. RESEARCH METHODOLOGY

The research strategy is based on elements of the constructive research approach (Lukka, 2003), a procedure for developing innovative constructions to solve real-world problems while contributing to the theory. Its key steps are problem awareness, solution development and evaluation. The summary of the research plan is shown in Figure 1.

We derive information needs from the DfD/A standard (International Organization for Standardization, 2020) and supplementary literature, providing the problem awareness. The authors' experience and data from practitioner interviews (Çetin et al., 2023) ensure practical relevance. Based on that, we filter down data needs to those highly sought-after but seldom satisfied. The following section delves into the required information about materials, environmental data, and disassembly. We provide universal specifications adjustable to specific contexts, assumptions and needs. Methodologies for obtaining actual values, like LCA and circularity calculations, are outside the paper's scope.

Understanding the solution area is established in the previous work of Tomczak et al. (Tomczak et al., 2022). The construct being developed is a solution to specify and verify BIM content, defined in a standardised IDS form.

The development of computer-interpretable IDS specifications starts with legal reasoning applied to each information need and transformation into actionable form. The IFC support for each aspect is investigated. For simplicity, only the latest IFC version 4.3 is considered. To find standard terms and properties describing the built environment, we browse the bSDD (buildingSMART International, 2023b) – the buildingSMART service for publishing data dictionaries. The specification is authored with IfcTester – a rule-checking Python tool from the IfcOpenShell library (Krijnen et al., 2023), based on the IDS schema version 0.9.6 (buildingSMART International, 2023a). In the paper, we present exemplary specifications in a simplified pseudo-code form. The actual IDS file is provided as supplementary materials (Tomczak, 2023), and its correctness is verified with the IDS Audit Tool (Benghi, 2023).

We evaluate information needs concerning how feasible they can be captured in BIM. Considered aspects include IFC schema support – are they explicitly defined or allowed by the schema, level of standardisation – are the terms determined by a standard or data dictionary, or custom, and directness of information – can the value be captured explicitly, does it only state the result of expert assessment or reference external resources.

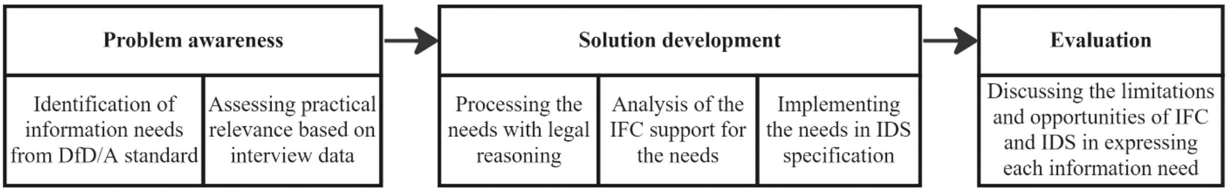

Figure 1. Methodological Steps of the Research

3. SOLUTION DEVELOPMENT AND EVALUATION

3.1 Material Information

One must know the quantities, materials, and product characteristics to reuse building products efficiently. BIM data usually contains the bill of quantity, elements' geometry, location, and characteristics. IDS can be used to cross-check the presence of such information, except when it requires computation or geometric operations.

3.1.1 Composition

Essential information need is to know the materials an element is made from. The simplest approach in IFC is to associate an element to one IfcMaterial. But elements are sometimes defined by types or modelled as an aggregation of several parts, each made of different materials. Linear elements are usually modelled by extruding profiles, while planar elements tend to be made of layers. Some materials are a mixture of constituents. Such an example is reinforced concrete with steel reinforcement not graphically represented by its shape.

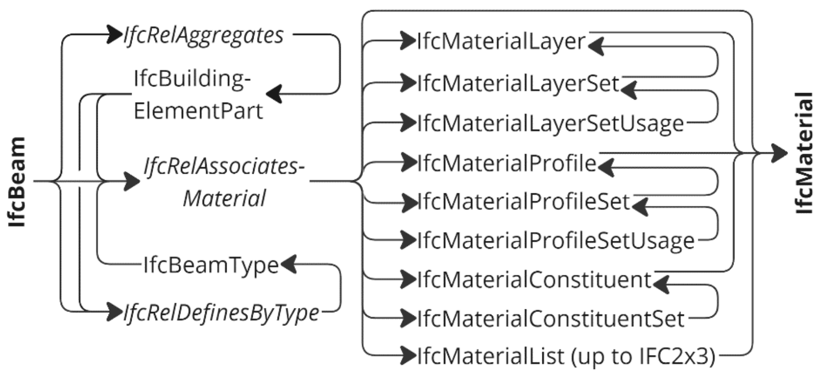

Figure 2. The Pluarity of Ways to Associate a Material to a Beam in IFC

After a closer look at IFC documentation (buildingSMART, n.d.), we reveal forty ways to associate material with an element, as presented in Figure 1. Fortunately, the IDS software automatically handles all possible material associations, allowing the author to be unaware of the definition.

Building and product regulations, such as EU REACH (Goddin et al., 2019), define what substances are prohibited in buildings. Listing 1 demonstrates how one can check the absence of certain materials among walls, roofs or their parts. Since the clause checks exact and case-sensitive spelling and material names are not standardised in BIM, such a requirement is useless.

```
(1)   No occurrences are allowed of (IfcWall and IfcRoof or
      (IfcBuildingElementPart being PartOf: (IfcWall or IfcRoof))), containing
      material: ("Asbestos", "Chrysotile", or "Amosite").
```

Looking for lead among materials omits the possibility of it being contained in materials such as paints. Toxic substances do not need to be in quantifiable amounts to cause harm. While possible to define in IFC even the most negligible fractions (as IfcMaterialConstituent), it is not a common practice. Instead of listing all materials, modellers should answer the closed question: 'Does the material contain lead?', enabling straightforward compliance checking. Reformulating the query to 'Is it free of lead?' (Listing 2) prevents overlooked false positive results.

```
(2)   All IfcMaterials need to have a property "LeadFree" in a set
      "MaterialSafety" with a value equal to "Yes".
```

3.1.2 Quality

The next desired information is the material characteristics. Apart from checking the existence of desired data, one can check with IDS if the provided values make sense. Such quality assurance procedures can identify wrong data types or unit mismatches.

The IFC provides common material properties, such as MassDensity, and material-specific properties like YieldStress for steel and StrengthGrade for wood. Listing 3 shows how to check if the wood density value is in a reasonable range and that the strength grade takes one of the allowed values. To account for naming uncertainty, we use IDS XML restriction patterns, a flavour of regular expressions. They allow finding all terms containing the letter 'C' followed by two digits (denoted by '\d').

```
(3)   All IfcMaterial's named ("Timber", "Wood", "Oak", or "Pine") or with the
      name following the pattern ".*C\d\d.*", need to have a property
      "MassDensity" in a set "Pset_MaterialCommon" with a value greater than 300
      and lower than 1250, and a property "StrengthGrade" in a set
      "Pset_MaterialWood" with one of the values ("C14", "C18", "C24", "C30",
      "C35").
```

When thinking in the long term about future disassembly, there is a problem of changing quality in time. Apart from degradation, timber weight changes with moisture, concrete shrinks and hardens with time, and steel expands with temperature and is susceptible to fatigue. Either the information needs to be frequently updated or values treated with caution, assuming they were only valid at the time of data creation.

3.1.3 Identity

Instead of writing down all the technical characteristics, one might reference the product's origin, leaving the responsibility for providing such information to the manufacturer. One solution to this is providing a fourteen-digit GTIN barcode number (GS1, 2023), enabling unique identification. IDS could check if the format of the code is followed.

However, there is a risk of faulty information. From observation of design practice, we identify three approaches to modelling buildings: (1) with generic objects, (2) with object libraries obtained from a manufacturer, and (3) with any library of similar objects. The first approach is predominant in early-stage design, when a manufacturer is unknown, and on public projects, where documentation should not favour any provider. Here, the details could be provided only if documentation is updated at the as-built stage. The second approach is possible only if the manufacturer offers such a digital catalogue. Common challenges here involve the incompatibility of such product library with project modelling standards and the amount of redundant information. The third approach, seemingly similar to the previous, carries the risk of wrong barcode numbers, as the product does not necessarily match the model. A high risk of false positive information lowers the trustworthiness of the product information in models.

3.2 Environmental Impact

3.2.1 LCA Indicators

83% of the interviewees think life-cycle assessment (LCA) information should be part of digital documentation; at the same time, all respondents confirm its lack or low availability (Çetin et al., 2023). The key inputs to LCA are quantities and environmental indicators.

Environmental Product Declaration (EPD) provide indicators about particular construction products. To store such information in BIM, products must be mapped to model elements. The task is simple for countable components made of a single material, like timber beams, but complex for composite elements, like a reinforced concrete wall with insulation. A single, homogenous object in BIM, but in reality, three separate products: steel reinforcement, concrete mix and insulation. If not modelled separately, the EPD data must be summed before storing.

We identified three approaches for handling environmental indicators in BIM: (1) directly copying the content of an EPD to the model, preserving the original functional unit, (2) parametrising the EPD data within the model, and (3) only referencing the source EPD document.

The first two approaches provide data for the calculation directly in BIM. The first is the original static value, while the second adjusts to changes in geometry. The downside of both is the impact on storage size and performance. A typical product has around thirteen EPD indicators with a separate value for each of the ten LCA stages, meaning 130 data fields per element. On a medium-sized building, with around a thousand elements, that is already over one hundred thousand data points.

EPDs are usually reported for a reference functional unit, such as one cubic meter of timber products, one kilogram of steel beam, or one piece of reference window of a certain width and height (The Norwegian EPD Foundation, 2021). This does not correspond to the actual geometry in the model. Parametrising the EPD data within the model can address this. This way, indicator values are scaled, adjusted and responsive to the geometry changes. It allows automatic calculation and reporting and supports model-based decision-making. The downside of parametrising is high computational demand, as all the values get recalculated on each model update.

Such specification might be expressed as: “All building products should have LCA indicators values corresponding to assumed system boundary from relevant EPD declaration”. However, the requirement does not specify enough information to transcribe that into machine-interpretable form. The semantic meaning of some of the concepts requires an expert’s interpretation. With the help of the IFC schema (buildingSMART, n.d.), we can map the “building product” to all objects modelled as IfcBuiltElement. Based on the assumptions, the modeller should know which indicators fall within the scope and associate them with names from a data dictionary. In this case, the relevant documentation is the content defined by the EPD standard (International Organization for Standardization, 2022), corresponding to a particular product. Specifying and validating the existence of such numerical values is simple, provided that the standard parameter naming is applied. In the bSDD, we find a dictionary called “EPD Indicators and modules” (buildingSMART International, 2023b) containing names from the ISO 22057 standard (International Organization for Standardization, 2022), such as “global warming potential – biogenic”. However, in that dictionary, parameters are not diversified for each stage, which might lead to misinterpretation. It is not easy to unify how the information is specified, as some EPDs have stages separated into extraction (A1), transport to factory (A2), and manufacturing (A3), and others provide one value for the whole product stage (A1-A3). There are also discrepancies between assumed system boundaries. While some EPDs provide the end-of-life stage, others do not.

Listing 4 presents how the IDS clause requesting information about an indicator might be constructed. Because the IDS standard does not apply inheritance, the applicability section requires listing all possible sub-entities of IfcBuiltElement.

(4) All *IfcBuiltElements* need to have a property set "*GlobalWarmingPotential*" with a property "*global warming potential - fossil fuels*" identified as "*https://identifier.buildingsmart.org/uri/LCA/LCA/2.0/prop/GWP_fossil*" with the value being a decimal greater or equal to 0.00.

The above formulation assumes that the attribute is either specified or calculated for each element separately. In reality, the environmental indicator for in-situ elements is usually a derivative of the volume of material and the reference value from EPD. Therefore, it might be better to assign the value from EPD to materials (IfcMaterial) instead, as this is the source of information. However, the IDS standard does not allow for checking properties of materials assigned to particular elements.

To be able to use such EPD information in BIM for decision-making, there are more aspects to consider. For example, EPD's transportation stage (A4) corresponds to the generic distance from a factory to a construction site under the assumed truck's utilisation and emissions rate, which all differ between EPDs. The actual values should be derived based on actual distances and vehicles used.

The direct and parametric approaches are easily confused. A more robust approach than internalising the data is only referencing external EPD. Such reference leads to the source of information, usually in PDF or XML form, on dedicated platforms, such as the Norwegian "EPD-Norge Digi" (International Organization for Standardization, 2022; The Norwegian EPD Foundation, 2021). Following this approach, a requirement might be expressed: "All building products shall be supplied with relevant environmental product documentation (EPD)". In Norway, all EPDs are identified by a "NEPD" prefix and eight digits following the format that can be expressed with an IDS pattern. Since the EPD reference term was not found in the bSDD (buildingSMART International, 2023b), we coined "EPD ID" (Listing 5).

(5) All *IfcBuiltElements* need to have a property "*EPD ID*" in a set "*LCA*" with the value following the pattern: "*NEPD-\d{4}-\d{4}*".

The limitation of only referencing EPD is that it can hinder the automation of LCA calculations based on BIM models, relying on software capability to read EPD platforms' content.

Apart from storing LCA data for each product in the model, it is also possible to store the results of holistic LCA analysis of a complete building. Those might be assigned to a building, analogous to Listing 4, or for each building story, normalised by the floor area. As there are differences in how the floor area can be calculated, the methodological assumptions should be clearly stated in the BIM documentation and are not prone to automatic validation using IDS.

Previous research shows the significance of omitted components for LCA results (Nawrocka et al., 2023). Usually not modelled in BIM are auxiliary elements (e.g. scaffolding), waste, leftovers, packaging, thin layers (e.g. paint), and small or connecting elements (like nails). By definition, BIM is only a simplified representation, and overflowing models with information is also not desired.

Lastly, many assumptions about LCA make the analysis results difficult to compare. From the study on methodological parameters of EN 15978 standard, it was found that among those with high influence on results are the purpose of assessment, specification of the object type, assumed scenario for lifecycle, level of detail, selection of environmental data source, reference study period, functional unit, system boundaries (Rasmussen et al., 2018). When not stored together with the LCA scores, it impairs its direct use for comparisons.

3.2.2 Material Circularity

To measure the circularity based on BIM, the model should specify the information on both material inputs and anticipated outputs. The inputs should define the fraction of material being biological, virgin resource, reused or recycled (Goddin et al., 2019). Such data can be captured like already explained LCA indicators. Since not all used materials are in the final product, the data should include the amount of unrecoverable waste.

The output data deals with higher uncertainty, as it is unknown if the anticipated scenario will occur, what technology will be available when disassembling, or whether no extreme events will happen. Regardless of the uncertainty, such data can be captured in custom IFC properties, for example, called

BiologicalContent or *EndOfLifeRecyclability*. Those could be specified and checked with IDS, similar to Listing 4. However, using custom, unstandardised terms limits the interoperability and consistent interpretation.4,4.

3.3 Disassembly Information

According to the interviews with industry representatives, all agree that disassembly instructions should be digitally documented, but all admit that is never the case (Çetin et al., 2023). There are many aspects of disassembly, and in this section, we address the main ones.

Structural designers wanting to document the disassembly sequence could put an integer for each building component. Listing 6 demonstrates how to require such information.

(6) All *IfcBuiltElements* need to have a property "*Disassembly sequence*" in the set "*Disassembly*", with the value being a positive integer.

Another highly anticipated aspect mentioned by the DfD standard and practitioners [2], [3] is information about connections. This could be represented with simple 2D detail drawings, detailed shop drawings, 3D connection geometry or alphanumeric data. The IDS can only specify the latter.

Durmisevic et al. (Durmisevic et al., 2003) have developed a knowledge model for assessing disassembly potential. It is based on a series of seventeen numerical factors. Four apply to connections: *connection type*, *accessibility to fixings*, *tolerance* and *morphology*. All are expressed with a label with attached weight. For the type of connection, the list ranges from worst 0.1 for "direct chemical connection", such as weld or glue, to best 1.0 for "accessory external connection", such as connection system where a change of one element does not affect others. Similarly, the remaining parameters can be introduced: *form containment, connection accessibility*, and *crossings.*

Considering a case of a simple point connection between two linear elements, we face the challenge of various modelling approaches. Figure 3 shows three ways to represent connections in IFC. It could contain only the geometry of connected members or a well-detailed connection with bolts and plates. Assigning the connection type to an actual component, not auxiliary pieces, makes more sense. However, a member can have different connections at each end or multiple connections mid-length. One solution is to reflect only the worst connection of a component. Another solution applies only to analytical models, where IFC contains intermediate entities representing connection node, curve and surface. In analytical models, the connection type property can be attached to *IfcStructuralPointConnection* and denoted with a value from the knowledge model. This is implemented in Listing 7 but applies only to structural elements.

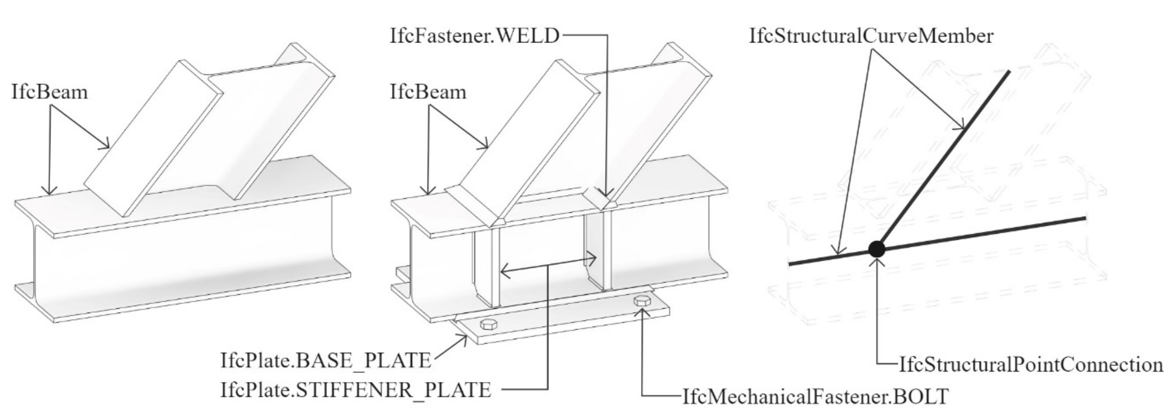

Figure 3. Three Approaches to Modelling Connection Between Beams: a) Implicit, b) Detailed with Connecting Elements, c) Analytical

(7) All *IfcStructuralPointConnections* and *IfcStructuralCurveConnections* need to have a property "*Connection type*" in a set "*Disassembly*", with a value being a decimal between 0.00 and 1.00.

More complex are connections between non-structural products, like between layers of a wall or between a wall and a window. The fact of being connected can be retrieved by tracking the elements' relationship, as demonstrated in the example below, but no additional information can be supplied.

(8) *IfcWall ←IfcRelVoidsElement→ IfcOpeningElement ←IfcRelFillsElement→ IfcWindow*

An *IfcPort* definition semantically fits the purpose (buildingSMART, n.d.) but is an abstract IFC entity that may not be instantiated. To our knowledge, there is no out-of-the-box solution to representing such connection information in BIM, both in IFC and native software formats.

The DFD/A standard (International Organization for Standardization, 2020) recommends versatile designs and provides an example of a dividing partition that could also function as a conduit for utilities. The IFC schema does not allow for polymorphism, for example, one object being both wall and duct. Hence, it is also not possible to check versatility with IDS.

Accessibility is another important aspect of disassembly. Since it primarily depends on geometry, it is impossible to specify with IDS. While geometrical computations could allow for checking, for example, if a connection is within hand reach from the floor, accessibility can be reduced by temporary obstructions. The IDS can only partially support such use case, as one can define a boolean property *IsAccessible* or a numerical *EaseOfAccesibility*, similar to Listing 2.

4. CONCLUSIONS

We studied desired circularity-related information and, through the development of IDS specification, demonstrated to what extent they find support in the IFC schema. A summary of the results is presented in Figure 4. Specifying circularity needs with IDS, demanding from BIM authors and verifying with ACC leads to increased data quality and availability, helping with future building disassembly, reuse or adaptation.

Some circularity use cases require information beyond BIM and IDS's scope. Relatively difficult to express in BIM is information related to disassembly instructions, end-of-life predictions and connections between components. Other aspects were possible to capture but often relied on defining custom properties, which limited data consistency and interoperability. Aligned with previous findings (Amor & Dimyadi, 2021), a significant challenge to ACC is the human inability to interpret requirements consistently. This is highly visible in circularity, as most terms are not standardised. A remedy to that we find in existing standards like IFC and in joint efforts to unify the language and definitions, for example, in the form of standardised data dictionaries.

Information need	Claimed demand	Claimed low supply	IFC schema support	Level of standarisation	Directness of information
Quantities			Explicit	Part of IFC	Explicit
Connection information			Difficult	Custom terms	Assessment
Disassembly instructions			Difficult	Custom terms	External
Disassembly sequencing			Feasible	Custom terms	Explicit
Material composition			Explicit	Custom terms	Explicit
Materials characteristics			Explicit	Part of IFC	Explicit
Environmental impacts (LCA)			Feasible	Found in bSDD	External
Material circularity			Feasible	Custom terms	External
Material safety			Feasible	Custom terms	Assessment
Manufacturer details			Feasible	Custom terms	Explicit
Service life			Feasible	Custom terms	Explicit
Size of elements			Explicit	Part of IFC	Explicit

Figure 4. Summary of Information Needs Analysis

It is only possible to check what is explicitly modelled. A lack of elements could lead to underestimated LCA results, but IDS can prevent element omittance. Difficult to detect are false positive values, potentially resulting from copying content from BIM libraries or other projects.

Unlike labour-intensive manual checks, ACC can process large quantities of data. However, limiting the information overflow is advised. We questioned the effectiveness of digitising aspects like accessibility, which require geometrical computation or expert assessments and are prone to change. The paper provides a rationale for setting BIM expectations.

Additionally, we identified the learning aspect of applying IDS. By showing the possible options, the strict IDS form educates the sustainability experts on how much they can reasonably require in BIM. Knowing how to ask without specific technical knowledge of schemas like IFC reduces the entry barrier to ACC. The paper stresses the gap between plain text needs and executable implementation. Not being able to require certain aspects should lead to reconsidering their formulation.

Further work could extend the scope to adaptability, versatility and extendibility of buildings. Other aspects to consider include geometrical checks and defining the missing terms. Research on case studies and testing requirements on actual project data could provide more input on defining common requirements.

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AUTHOR CONTRIBUTIONS

Artur Tomczak: Conceptualization, Investigation, Methodology, Writing – Original Draft Preparation, Writing – Review & Editing, Resources, Visualization;
Claudio Benghi: Validation, Resources, Writing - Review & Editing;
Léon van Berlo: Validation, Writing - Review & Editing;
Eilif Hjelseth: Conceptualization, Writing – Review & Editing, Validation, Supervision.

DECLARATIONS

Competing interests The authors declare their involvement in buildingSMART – open, neutral and international not-for-profit organisation developing openBIM solutions, including IDS, IFC, and bSDD covered in this paper. It does not interfere with the findings and quality of the research.

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