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Creating Data Mapping and Naming Conventions for Enhanced OpenBIM-LCA Interoperability

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ABSTRACT: Integrating Building Information Modeling (BIM) with Life Cycle Assessment (LCA) has comprehensively evaluated environmental impacts by advancing sustainable construction practices. However, BIM models often lack sufficient detail and essential information for LCA, depending on the Level of Detail (LOD) and the Level of Information (LOI) incorporated during the design phase. These discrepancies prevent the direct mapping of BIM components to LCA data, which results in incomplete or inaccurate environmental assessments. This paper presents the creation of an effective mapping strategy that systematically aligns BIM data with LCA requirements to bridge the gaps in data transition and facilitates automated sustainability assessments. The focus will be on developing a mapping methodology that incorporates five components: Industry Foundation Classes (IFC); LCA stages; Uniformat classifications; Masterformat specification; and Ecoinvent Life Cycle Inventory (LCI). The said methodology notably relies on IFC, a neutral and open standard format that aligns with OpenBIM's principles, and it involves enriching IFC files by implementing a standardized system for the naming convention, which is crucial for mapping accurate information (building elements and materials) in LCA. By using a rule-based approach, this methodology translates BIM elements into a format that is compatible with the LCA tool to enhance consistency and reduce manual intervention. This approach will bridge the existing gaps in the data transition and will enhance the interoperability between BIM and LCA tools. Furthermore, it offers a scalable solution for users to streamline the sustainability analysis in the construction industry.

1. INTRODUCTION

The construction industry is facing significant limitations in minimizing its environmental impact, which not only affects the global carbon emissions but also the consumption of resources. Life Cycle Assessment (LCA), as an integral method, is following standardized procedures, such as ISO 14040/14044, to quantify the environmental impacts of buildings all over their lifespan (Theißen et al., 2021). Building Information Modeling (BIM) offers a digital platform that links and enriches all the related data of a building across its life cycle (Koutamanis, 2017). Although software developers are bringing proprietary BIM systems to the construction industry, those applications lack universal solutions for all their users due to the absence of interoperability between BIM tools and other tools (Theißen et al., 2021). However, the integration of BIM and LCA is a promising way to do environmental evaluations and make sustainable design decisions (Tecchio et al., 2019). That integration would reduce the additional efforts required for LCA and would accelerate its process (Morsi et al., 2022), and therefore, would yield quick and reliable results (Obrecht et al., 2020).

Although there are some advancements made in the integration of BIM and LCA and its potential, this process is facing significant challenges, especially the ones related to the strategies used in exchanging the data, such as non-standardized data mapping and naming schemes. Studies showed that openBIM and Industry Foundation Classes (IFC) have the potential to provide more efficient and comprehensive LCA performance. IFC is a universal format for open data exchange that is designed to overcome the existing issues between BIM and LCA tools. Although IFC provides a common framework, it has limitations due to the inconsistent population of attributes in BIM models and the lack of standardized naming conventions (Theissen et al., 2020). Parece et al., (2024) believed that the lack of standardized environmental data and a common language, such as data structure and naming conventions, are barriers to the mapping process between the building elements and their corresponding environmental impacts in LCA databases (Parece et al., 2024). Thus, more researches on standardized data mapping and naming conventions for BIM-LCA integration are needed (Chen et al., 2024; Obrecht et al., 2020). These methods are needed to address the data structures, attribute definitions, and naming schemes to provide consistency and interoperability across the different platforms and databases.

To reduce the potential errors and to increase the accuracy of the analysis, automated data exchange methods to streamline the integration process of BIM and LCA and to minimize the manual efforts and errors, are considered crucial (Obrecht et al., 2020; Wastiels & Decuypere, 2019). In addition, enhanced LCI databases with comprehensive coverage of building materials and processes are critical for achieving accurate LCA results (Elduque et al., 2015; Mirzaie et al., 2020) and yet reliable assessments of the environmental impacts.

This study explores the current challenges and practices that are related to data mapping and naming conventions to enhance the interoperability between BIM and LCA tools. Although the global focus is on sustainable buildings that require more efficient methods for the integration of BIM and LCA, seamless data exchange remains a significant challenge. Thus this paper focuses on evaluating these challenges, which include the roles of IFC and openBIM, the classification systems (Masterformat/Uniformat), and LCI databases (Ecoinvent), and then after identifying the key gaps with the aim to create robust data mapping and naming conventions system by incorporating classification systems such as Masterformat and Uniformat and linking them to the objects associated with the BIM models to reduce the manual interventions toward more accurate LCA results for the whole building.

2. BACKGROUND

Integrating BIM with LCA is a widely recognized approach to evaluate the environmental impacts of buildings across their life span. Several studies have explored different methods of BIM-LCA integration (Bouhmoud et al., 2022; Budig et al., 2021; Jrade et al., 2023; Parece et al., 2024). Wastiels & Decuypere, (2019) categorized these methods into five main types based on data exchange and interoperability: (1) manually extracting the bill of quantity (BOQ) from the BIM model for use in LCA tools; (2) exporting IFC data to generate the BOQ and importing it into LCA tools; (3) using a BIM viewer for data transfer; (4) developing dedicated LCA plug-ins; and (5) embedding LCA information directly into BIM objects. Although these methods have advanced the field, they still have some drawbacks, particularly that they often depend on partial automation or manual data processing, which can be difficult to be error-free.

Zheng et al., (2023) studied the performance of the current approaches used for the integration of BIM and LCA to evaluate the trade-offs between their accuracy and efficiency. Their study showed that although the conventional methods provide the most accurate BOQ data and LCA results, but they are very time-consuming and costly. Developing plug-ins is faster but still has a deviation of about 6% in LCA results. Although parametric tools outperformed the IFC-based approaches for BOQ's extraction and calculation's time, IFC-based approaches are proved to have more reliable outcomes with only a 1% error, which means that automating the quantity takeoff (QTO) and the selection of LCI dataset, refining BOQ's data for the developed plug-ins and ensuring the correct IFC property exports must be considered.

Recent literature also underscores persistent challenges at early design stages, where BIM models often have low Levels of Detail (LOD) and Information (LOI). These conditions necessitate additional, often manual interventions, such as exporting and cleaning data via spreadsheets, to prepare it for LCA tools (Obrecht et al., 2020; Theissen et al., 2020). Inconsistent exchange of data maybe the result of interoperability issues between different platforms, which is another challenge to consider. Such type of challenge is the inconsistent format of the data and the lack of unified standards and standardized naming conventions (Chen et al., 2024; Obrecht et al., 2020). For instance, Parece et al. (2024) presented an approach using standardized classification systems and a refined naming convention to develop a framework to leverage data mapping techniques for bridging the gaps between BIM models and LCA datasets. Their methodology addresses inconsistencies that arise from varying LOD and LOI in the BIM model's data. Moreover, their study showed the effectiveness of using IFC to enhance the interoperability between different software platforms.

IFC standard plays a crucial role in OpenBIM by providing a neutral format for exchanging data between different platforms (Afsari et al., 2016; Ait-Lamallam et al., 2021; Jiang et al., 2019; Oostwegel et al., 2022). It allows geometric and semantic exchange of data, which considerably enhances the integration of BIM with LCA (Stouffs et al., 2018; Theissen et al., 2020). Physical characteristics of building's components are considered geometric data, while the semantic data contains contextual data such as material properties, manufacturing processes, and other attributes (Theissen et al., 2020). MasterFormat and UniFormat further improve standardization by offering widely accepted taxonomies to categorize construction elements. Their consistent use in BIM and LCA can promote more accurate and efficient data transfer (Fazeli et al., 2021). However, a direct mapping between these systems and LCA databases is not always a straightforward step, yet it needs more effort toward accurate correspondences. Therefore, due to the deficiency of a direct mapping between the classification codes and LCA data, developing mapping tables or algorithms to facilitate the transfer of data is a necessity.

Attaining an accurate LCA evaluation is possible by incorporating Ecoinvent, which is a well-known LCI database that contains environmental data for various materials and processes (Ecoinvent v3.11, 2024; Elduque et al., 2015; Mirzaie et al., 2020) into BIM models. During this process, the evaluation procedure can be significantly enhanced as it provides a standardized source of environmental data. However, the lack of direct compatibility with BIM models necessitates the transformation and mapping of data, which is a very time-consuming step that requires custom data mapping procedures (Mirzaie et al., 2020).

Although several studies have addressed subsets of these problems, such as partial mapping approaches, single classification systems, or proprietary plug-in developments, there is a lack of a comprehensive, standardized framework that simultaneously addresses the issues of LOD/LOI variability, interoperability, and detailed mapping to LCI databases. In response, this paper proposes a unified data mapping and naming system that systematically links IFC entities to both MasterFormat and UniFormat classifications, then associates these classifications with validated LCI data (e.g., Ecoinvent). Ultimately, it streamlines the workflows of BIM and LCA, enhances interoperability among diverse tools, and fosters more reliable and efficient whole-building LCA outcomes.

3. METHODOLOGY

The outline of this methodology is the systematic approach developed to enhance OpenBIM-LCA interoperability by analyzing the LCA of the imported IFC files regardless of the design detail and information discrepancies. To address discrepancies that may arise from differing LOD and LOI, a multi-step process is defined by integrating and mapping IFC entities to LCA stages, Uniformat, Masterformat, and Ecoinvent LCI data, whose all are supported by a comprehensive database that serves as a standardized naming system. This database was created via a manual mapping step to ensure that every IFC entity was thoroughly reviewed and accurately linked to the Uniformat codes, LCA stages, Masterformat specifications, and the corresponding LCI data. Figure 1 illustrates the overall workflow of the methodology.

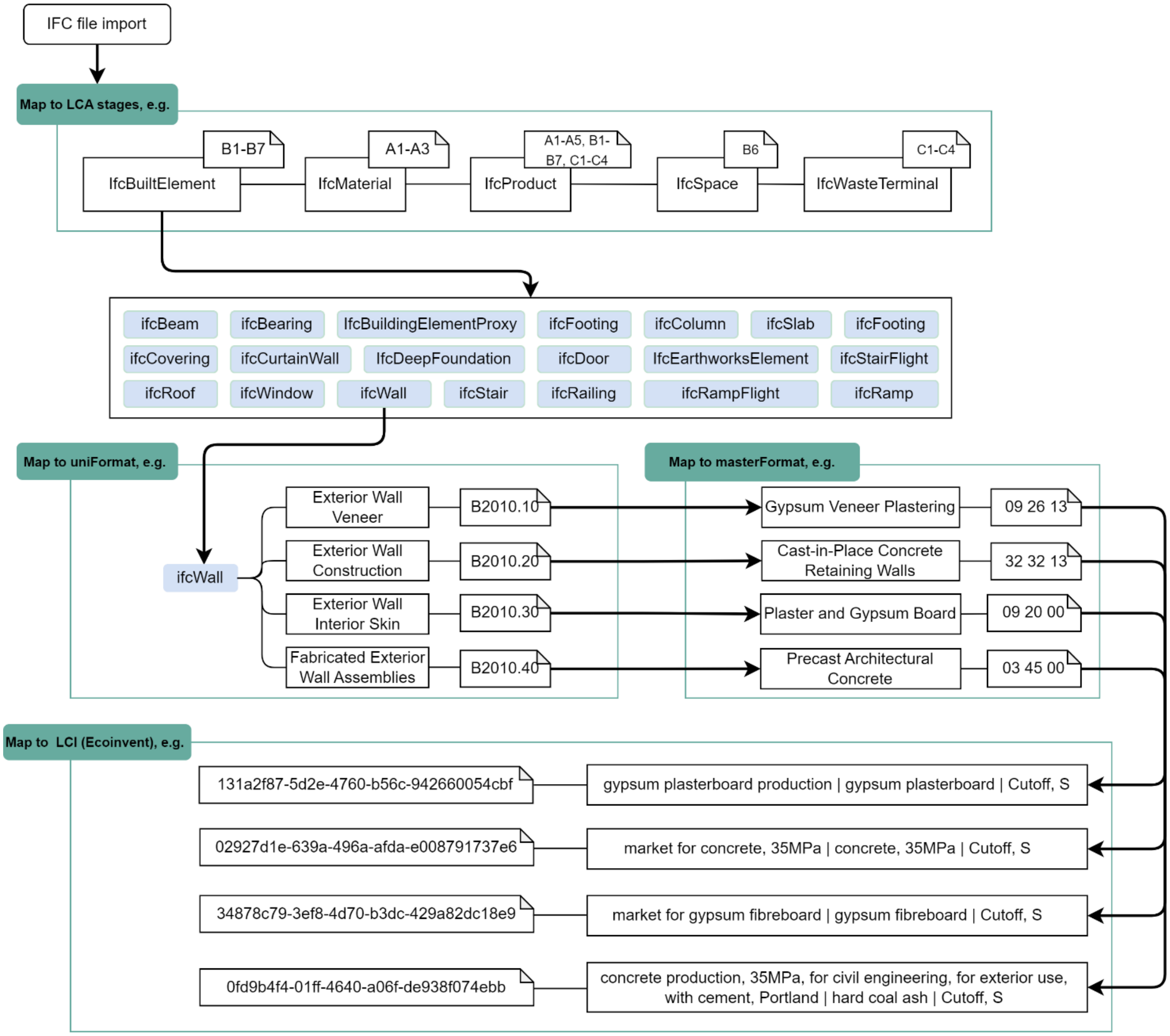

Figure 1: A sample flow of the data mapping for a uniform naming system

3.1 DATA COLLECTION AND STANDARD IDENTIFICATION

The initial step involves identifying and extracting data related to the building's elements from the IFC file while considering the potential changes in the BIM model's LOD and Level of LOI across the project. Collecting and analyzing appropriate classification standards, which are employed by the construction sector is necessary to establish the mapping system. Masterformat and Uniformat are widely recognized systems that categorize the construction elements according to their materials, roles, and assemblies, which have made the organization of building's components comply with LCA requirements. Simultaneously, choosing suitable LCI datasets, such as Ecoinvent, is crucial, as it offers extensive environmental data concerning various construction materials and processes. These datasets serve as the foundation for evaluating the sustainability performance of building components by offering impact factors related to material extraction, processing, transportation, and disposal. Proper alignment of classification systems with LCI datasets is crucial to achieving accurate LCA assessments. These layers of the mapping processes are interlinked and further associated with LCI data, ensuring that both functional and detailed construction data are captured.

3.2 ESTABLISHING MAPPING RELATIONSHIPS

As can be seen in Figure 1., the first step after reviewing IFC inheritance listings from BuildingSMART (BuildingSMART, 2024), each IFC entity is assigned to an appropriate LCA stage (e.g., material production, construction, use phase, and end-of-life), to facilitate the automated sustainability analysis within BIM environments. This structured data collection and standard identification approach lays the ground to establish consistent and reliable mapping relationships between BIM and LCA components. Figure 2. Illustrates a part of the mapped data.

A	B	C
IFC Entity	**Stage Level**	**LCA Stages**
IfcActionRequest	Construction, Use	A4-A5, B1-B7
IfcActor	Not directly related	-
IfcActorRole	All	A1-C4, D
IfcActuator	Use	B1-B7
IfcActuatorType	Use	B1-B7
IfcAddress	All	A1-C4, D
IfcAdvancedBrep	Product	A1-A3
IfcAdvancedBrepWithVoids	Product	A1-A3
IfcAdvancedFace	Product	A1-A3
IfcAirTerminal	Use	B1-B7
IfcAirTerminalBox	Use	B1-B7
IfcAirTerminalBoxType	Use	B1-B7
IfcAirTerminalType	Use	B1-B7
IfcAirToAirHeatRecovery	Use	B1-B7
IfcAirToAirHeatRecoveryType	Use	B1-B7
IfcAlarm	Use	B1-B7
IfcAlarmType	Use	B1-B7
IfcAlignment	Construction	A5
IfcAlignmentCant	Not directly related	-
IfcAlignmentCantSegment	All	A1-C4, D

Figure 2: A sample of the mapped data between IFC entities and LCA stages

Next, each building's element is assigned a Uniformat code based on its function. For instance, exterior walls might be mapped to a Uniformat code of B2010; a sample of the mapped details is shown in Figure 3. The mapping process links each Uniformat code to the corresponding Masterformat sections that provide detailed specifications for the construction.

Masterformat code	Uniformat code	Uniformat	IFC entities
00 10 00	10	Project Description	IfcProject
01 10 00	1010	Project Summary	IfcProject
01 11 00	1010.10	Summary of Work	IfcTask
01 12 00	1010.30	Multiple Contract Summaries	IfcContract
01 14 00	1010.50	Work Restrictions	IfcConstraint
00 24 00	1020	Project Program	IfcProject
00 24 00	1020.10	Site Program	IfcSite
00 24 00	1020.50	Facility Program	IfcFacility
00 70 00	1030	Project Criteria	IfcConstraint
01 41 00	1030.10	Zoning Requirements	IfcSpatialZone
N/A	1030.15	Planned Unit Development Requirements	IfcSpatialZone
01 41 13	1030.20	Code Analysis	IfcBuildingElementProxy
N/A	1030.40	Design Loads	IfcStructuralLoad
01 81 13	1030.50	Sustainable Design Requirements	IfcBuildingElementProxy
01 81 16	1030.53	Facility Environmental Requirements	IfcBuildingElementProxy
01 81 19	1030.56	Indoor Air Quality Requirements	IfcBuildingElementProxy
01 35 91	1030.70	Historic Restoration Requirements	IfcBuildingElementProxy
02 00 00	1040	Existing Conditions	IfcBuildingElementProxy
02 20 00	1040.30	Assessment	IfcBuildingElementProxy
02 30 00	1040.50	Subsurface Investigation	IfcBuildingElementProxy
01 11 16	1050	Owner's Work	IfcBuildingElementProxy
N/A	1090	Funding	IfcCostItem
00 31 16	1090.10	Budget	IfcCostItem
N/A	1090.30	Sources	IfcBuildingElementProxy
N/A	1090.50	Cash Flow	IfcCostItem
N/A	20	Owner Development	IfcProject
N/A	2010	Site Acquisition	IfcProperty

Figure 3: A sample of the mapped data between IFC entities, Uniformat linked with Masterformat

3.2.1. MASTERFORMAT TO ECOINVENT LCI DATA

To collect, organize, and maintain data in the database, mapping Masterformat with LCI represents a crucial step. For LCA analysis, two factors are considered: 1) the IFC file, which corresponds with Masterformat, and 2) the Ecoinvent database, which serves as the primary reference for examining all the materials associated with the various stages of a building's life cycle. Consequently, to execute the LCA calculations, the Masterformat items must be aligned with the Ecoinvent database. LCI is an extensive dataset that measures the inputs (such as raw materials and energy) and outputs (such as emissions and waste), which are associated with any product or process throughout its life cycle. Obviously, LCI data is essential for LCA analysis to evaluate the environmental impacts of construction processes and materials. Ecoinvent is a worldwide database that encompasses data about materials, processes, and energy pertinent to numerous industries for evaluating environmental impacts. Masterformat is a standardized framework for cataloging construction specifications and materials and is commonly utilized in North America to systematize information for construction projects. In relation to the mapping process, it begins by identifying all the relevant Masterformat sections that relate to the processes and materials used in construction projects. The next step is to gather all the LCI data for the materials and processes from the LCI database, and Ecoinvent, which are related to construction projects.

Next, the mapping step is done by aligning the Masterformat items with the appropriate Ecoinvent data, matching the construction specifications in the Masterformat system with the associated environmental data from the Ecoinvent database. For instance, map the Masterformat section that is related to the cast-in-place concrete with Ecoinvent data for ready-mix concrete, which includes data about the energy use, raw material extraction, production emissions, and transportation impacts. Finally, this process integrates all the mapped data into the system, which enables to automatically analyse the environmental impacts of construction projects with reference to IFC file and Masterformat specifications. Figure 4. shows an example of this mapping process in the proposed framework.

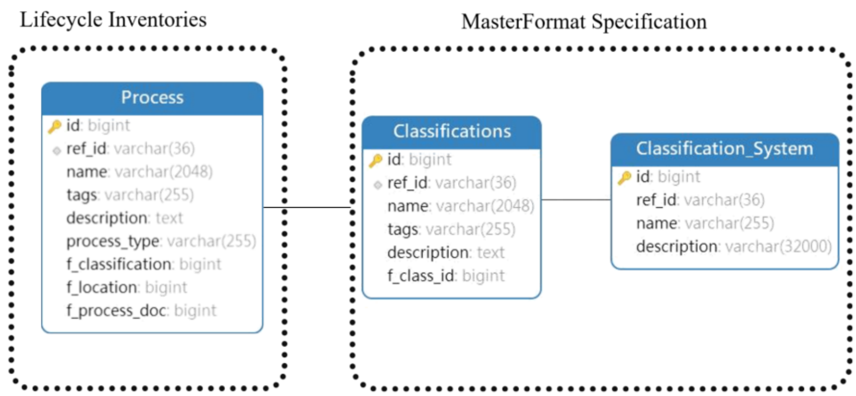

Figure 4: Mapping Masterformat with LCI

This mapping stage brings an enhanced accuracy and streamlined LCA process because of using the detailed LCI data with standardized construction classifications for LCA calculations. Therefore, this tool would be beneficial for stakeholders to improve the decision-making process based on various activities and materials involved in construction projects and for benchmarking purposes. Figure 5 shows a sample of the mapped data in Excel format.

E6 fx
1e1d4168-8e38-417f-8ba7-016279707523,49d975d1-df07-458b-a124-022f72d5a311,5bd88f20-ab1d-4088-9271-f84a69402d8f,f4edf1e5-9afe-47c2-bbd7-64f6e907cce1,1e1d4168-8e38-417f-8ba7-016279707523,29571778-0c70-4733-a70d-296fb6c8a137,337f7c7a-d5fb-4153-b9e9-29b2d9ca37c9,40c56ef3-5a45-4ff9-ae7f-60145e0a2e25,4965660e-4d8d-45a5-aa89-ab347951cd66,49d975d1-df07-458b-a124-022f72d5a311,5bd88f20-ab1d-4088-9271-f84a69402d8f,648ee433-a230-4ffd-be32-227b20311a6b,72cd269c-e27c-4696-82ec-

	C	D	E	F	G
1	MasterFormat		Ecoinvent Database		
2	Code	Description	Activity ID	Activity Name	
3	03 15 16	Concrete Construction Joints			
4	03 15 19	Cast-In Concrete Anchors			
5	03 20 00	Concrete Reinforcing	1e1d4168-8e38-417f-8ba7-016279707523,49	reinforcing steel production | reinforcing steel | Cutoff, S	
6	03 21 00	Reinforcement Bars	1e1d4168-8e38-417f-8ba7-016279707523,49	market for reinforcing steel | reinforcing steel | Cutoff, S	
7	03 21 11	Plain Steel Reinforcement Bars	1e1d4168-8e38-417f-8ba7-016279707523,49	reinforcing steel production | reinforcing steel | Cutoff, S	
8	03 21 13	Galvanized Reinforcement Steel Bars			
9	03 21 16	Epoxy-Coated Reinforcement Steel Bars			
10	03 21 19	Stainless Steel Reinforcement Bars			
11	03 21 21	Composite Reinforcement Bars			
12	03 21 21.11	Glass Fiber-Reinforced Polymer Reinforcement Bars	7ff9a9f3-8dcf-44a9-9fb1-fac9deca3894	fibre-reinforced concrete production, steel | fibre-reinforced concrete, steel |	
13	03 21 21.13	Organic Fiber-Reinforced Polymer Reinforcement Bars	7ff9a9f3-8dcf-44a9-9fb1-fac9deca3894	fibre-reinforced concrete production, steel | fibre-reinforced concrete, steel |	
14	03 21 21.16	Carbon Fiber-Reinforced Polymer Reinforcement Bars	7ff9a9f3-8dcf-44a9-9fb1-fac9deca3894	fibre-reinforced concrete production, steel | fibre-reinforced concrete, steel |	
15	03 22 00	Fabric and Grid Reinforcing			
16	03 22 13	Galvanized Welded Wire Fabric Reinforcing			
17	03 22 16	Epoxy-Coated Welded Wire Fabric Reinforcing			
18	03 22 19	Composite Grid Reinforcing			
19	03 23 00	Stressed Tendon Reinforcing			
20	03 24 00	Fibrous Reinforcing			
21	03 25 00	Composite Reinforcing			

Figure 5: Sample mapped data in Excel format

An IfcWall element is manually examined, and its material layer details are extracted, even though if some properties (like insulation type or density) are missing so that a later mapping can accommodate these variations. The naming convention is designed to encapsulate key attributes such as element type, material, function, and specification reference. An example of the naming format may: <ElementType>_<LCAStage>_<UniformatCode>_<MasterformatCode>_<LCICode>. A wall element might be manually mapped and stored as "Wall__PreConstruction_Brick_B2010.1._09 26 13_131a2f87-5d2e-4760-b56c-942660054cbf" indicating its Uniformat and Masterformat associations, LCA stage, and material. This naming system ensures that each element is uniquely and consistently identified, which simplifies the subsequent mapping and data retrieval processes.

4. DATABASE DEVELOPMENT AND INTEGRATION

A centralized mapping database is critical to handle the complex connections among construction classification systems, LCI datasets, and IFC entities to function as the primary repository that holds and organizes the mapping relationships, facilitating effective retrieval and integration of environmental impact data. The database adopted a standardized format (relational SQL-based database), particularly a relational database (e.g., PostgreSQL or MySQL), for this purpose, as it allows for structured queries and ensures data integrity through relational constraints.

Figure 6 shows the specification entity is designed to store any hierarchical specification system. Each entry in that entity portrays a specification item with its attributes like name, version, and hierarchical relationships (parent-child). The mapping entity functions as a linking mechanism, mapping these specification entries to the external database (i.e., Ecoinvent). Moreover, the mapping entity facilitates the internal connections between specifications, qualifying interoperability and relationships among classification systems within the same dataset. In this way, flexible and scalable mappings for various use cases in construction, BIM, sustainability, and environmental impact assessments are supported through that developed structure. Version control is another major aspect of the database management. Since classification systems, LCI datasets, and BIM standards evolve over time, the database must support version tracking to guarantee that updates do not disrupt the existing mappings. Implementing version history tables allows users to access the most up-to-date information while maintaining a record of the previous versions for their own reference.

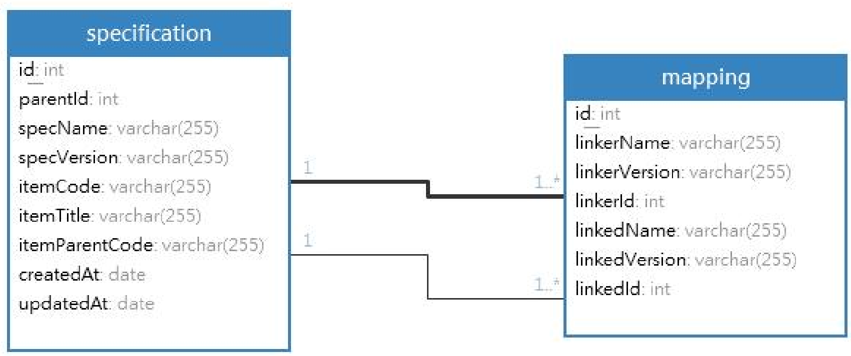

Figure 6: data schema to store specifications and map them to internal or external entities like the Ecoinvent database

Figure 7 displays the mapping of IFC data to an LCA model by extracting the QTO and integrating the mapping services, with both the Main Process and the Mapping Service working together for accuracy and efficient data mapping. An IFC file uploaded by the user initiates the process and includes detailed information about a building project. The system continues with extracting the QTO data by using IfcOpenShell 0.8.1, which identify and quantify the materials and components in the IFC file. After extraction, the mapping request data is prepared, and the extracted information for mapping is structured with relevant environmental datasets such as Ecoinvent. Once the mapping request data is prepared, the system initiates an automated search for links between the data provided by the user and the various classification systems. The system first examines IFC entities extracted from the uploaded IFC file and looks for corresponding matches in the established classification standards such as Masterformat and Uniformat. This bidirectional process means that the system will attempt to find relevant IFC entities linked to those classifications if the input data contains Masterformat or Uniformat codes.

After identifying the potential mappings, the system formulates a structured SQL query to request these links against the database. The database returns a set of results containing potential matches for the extracted IFC elements and classification codes. Since the returned data may contain duplicate, inconsistent, or redundant entries, the system then sanitizes and filters the results, removing redundant mappings, resolving conflicts in data relationships, and guaranteeing that only the most relevant and accurate links are retained. Lastly, the cleaned and structured mapping results are returned to the user for review, and for selecting the most suitable mapped item before proceeding with the preparation for the LCA model. Within this simplified process, the mapping between IFC-based construction data and environmental impact databases remains efficient and accurate for sustainability assessments. This study focuses on the methodological framework development, and as the importance of real-world validation and compatibility testing with other platforms is undeniable, the proposed framework is currently being prepared for a broader application and testing by using openLCA and the Ecoinvent database.

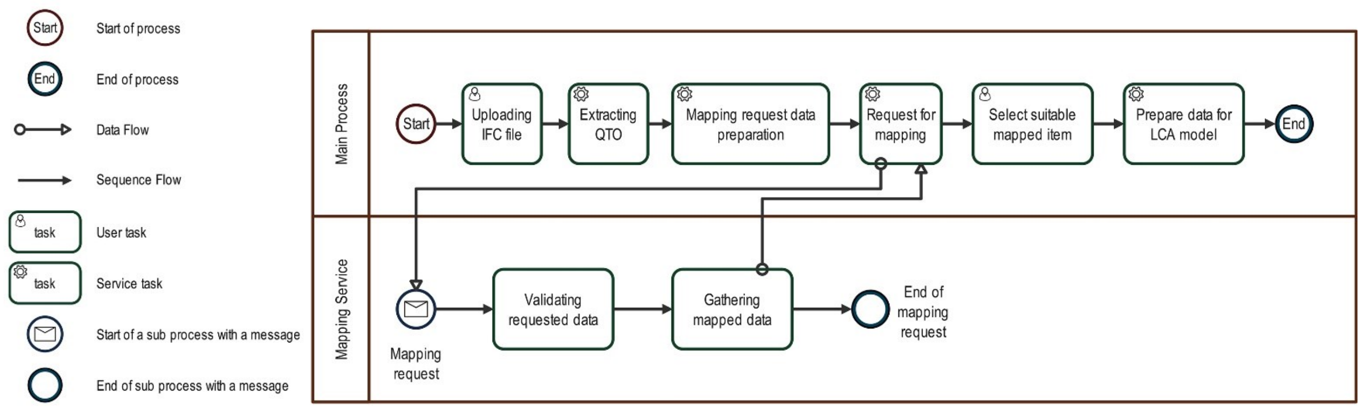

Figure 7: Workflow of mapping

5. CONCLUSION

This paper introduced a comprehensive framework that systematically connects IFC data to established classification systems, including Uniformat, Masterformat, and an LCI database, to benefit LCA at the different levels of detail. Using consistent naming conventions and organized mappings, the approach ensures accurate identification of the building elements, supports dependable material level analysis and allows for evaluations at the product and assembly levels. The result is a transparent and scalable approach that improves the accuracy of environmental impact assessments while minimizing manual effort and data inconsistencies.

This framework empowers decision-makers to conduct a holistic environmental evaluation by unifying critical data sources and classification standards. Evaluating material performance and recognizing key components that significantly affect results are made possible and become established as a foundation for future improvements and integrations. In summary, this standardized framework promotes a more effective BIM-LCA process and sets the stage for more sustainable design choices within the construction sector. Future work will focus on testing the framework with actual BIM models, and comparative analysis will be conducted to evaluate mapping accuracy, automation efficiency, and compatibility with LCA tools.

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