BIM Library Plugin for Circular Economy: Leveraging Digital Product Passports for Sustainable Design

João Palma[1], António Aguiar Costa[2]

[1]Civil Engineering Research and Innovation for Sustainability (CERIS), Instituto Superior Técnico, University of Lisbon, Portugal, joao.palma@tecnico.ulisboa.pt

[2]Civil Engineering Research and Innovation for Sustainability (CERIS), Instituto Superior Técnico, University of Lisbon, Portugal, aguiar.costa@tecnico.ulisboa.pt

Abstract

This paper presents the development of a BIM library plugin for BIM authoring software, designed in accordance with international standards and best practices established by leading BIM platforms. The library incorporates the Digital Product Passport (DPP), recognized by the Ecodesign for Sustainable Products Regulation (ESPR) as a fundamental tool in facilitating the transition to a Circular Economy. By providing standardized data on product materials, components, and lifecycle attributes, the DPP enhances transparency and informed decision-making. The proposed plugin enables designers to Visualize, compare, and integrate DPP data within BIM models, thereby fostering sustainable design practices and advancing Circular Economy principles.

1 Introduction

1.1 Framework

The Building Information Modelling (BIM) methodology aims to establish a standardized and integrated process for project development, serving as the foundation for interoperability between the various digital systems utilized in the design, construction, operation, and maintenance of assets [1]. BIM allows for the analysis of the life cycle cost of projects in the early design phases, and with a minimal increase in initial costs of approximately 4.6%, it is possible to achieve a 35.4% reduction in annual failure costs and a 10.4% reduction in life cycle costs over the first 35 years of use [2]. A key aspect of the BIM methodology is the creation of BIM models, which are 3D digital representations of real-world assets composed of BIM objects. These BIM objects encapsulate a wide range of information critical to the processes carried out throughout the project's life cycle. They are made accessible via BIM libraries, which function as digital infrastructures for storing and distributing data related to construction products and their associated BIM objects. The *NBS Digital Construction Report 2023* highlights the increasing demand among specifiers for manufacturers to provide BIM and digital objects. These digital assets streamline the specification process by offering readily available technical data and geometry that can be seamlessly integrated into models. Notably, some specifiers have indicated that the absence of digital objects may deter them from selecting a particular product. In response to this growing need, manufacturers appear to be adapting, with survey results indicating that 56% now offer digital objects for most or all their products, an increase from 52% in 2021 [3].

Several standards have been established within the domain of BIM objects and BIM data management. The most relevant to the subject of this paper include:

- *ISO 22014:2024* – Establishes best practices for the development and application of library objects to support BIM-based design, specification, construction, and operational processes. Additionally, it offers further recommendations for specific use cases, such as assemblies, which are particularly relevant for BIM objects representing modular construction units.
- *ISO 23386:2020* – Specifies the methodology for defining properties and their associated metadata for use in construction, as well as the process for authoring and maintaining them.
- *ISO 23387:2020* – Establishes principles and structures for data templates, designed to support digital processes through machine-readable formats. These templates facilitate the exchange of information regarding various construction works entities, including products, systems, assemblies, spaces, and buildings, across all phases of the built environment's lifecycle.

- *ISO 7817-1:2024* – Defines the characteristics of different levels of detail required for the exchange and delivery of information throughout the lifecycle of built assets.

This paper presents research conducted under the "R2UTechnologies - Modular Systems" project, aimed at developing an innovative solution in Portugal for prefabrication and modular construction, addressing the growing demands of the global market.

1.2 State of the art of BIM libraries

The development of data structures for storing information related to BIM objects must consider multiple factors, including industry standards, regulatory requirements, and best practices. Beyond these considerations, such data structures should integrate universally applicable information that classifies BIM objects and enhances search efficiency. This approach ensures that users can effectively identify products that align with their project specifications. BIM libraries are generally accessible through various platforms, including web-based interfaces, desktop applications, and plugins integrated with BIM authoring software. While numerous BIM libraries are available within the construction industry, this state-of-the-art review focuses exclusively on platforms that offer advanced functionalities or sophisticated data structuring for BIM object management, with particular emphasis on manufacturer-specific objects linked to real-world construction products.

1.2.1 NBS

NBS is a UK-based company that offers a suite of interconnected platforms designed to support users throughout various stages of project development. This subchapter focuses solely on NBS Source, the BIM and construction products library of NBS.

NBS Source serves as a construction products library where manufacturers collaborate with NBS specialists to produce standardized specification data. This data facilitates the creation of technical specifications for projects by providing a structured and detailed format that enhances content filtering and enables the automatic completion of specifications. As a result, the platform significantly reduces the time required to search for products that meet project requirements and streamlines the specification process. NBS Source was formed through the integration of the former NBS National BIM Library, creating a unified platform that consolidates real-world product information with BIM objects representative of those products. The NBS National BIM Library was one of the largest BIM object repositories in the UK, offering both generic and manufacturer-specific objects that adhered to the NBS BIM Object Standard (BOS) [4]. This standard defines the essential information—both geometric and non-geometric—that should be included in BIM objects, as well as guidelines on how these objects should behave and be presented within BIM authoring software. Furthermore, the BOS ensures the development of high-quality BIM objects suitable for use in Common Data Environments (CDEs). Importantly, the standard is software-agnostic, allowing users the flexibility to develop BIM objects using their preferred BIM authoring software

NBS Source is structured in accordance with Uniclass 2015 and offers a comprehensive set of filters that allow users to refine content based on various criteria. Users can filter products by Uniclass 2015 subcategory, manufacturer, third-party certification, and whether the products include an associated BIM object or comply with the NBS BIM Object Standard (BOS). Additionally, filtering options include the BIM software platform, general properties such as size, shape, material, finish, colour, and warranty duration, as well as environmental properties like recycled content, recyclability, the presence of red list materials, embodied carbon, country of material origin, and country of product manufacture.

The data structure of the products within NBS Source is subdivided into the following sections:

- *Application*: Types of building to which the product or system is applicable (residential, industrial, commercial, etc).
- *Description*: description of the product or system.
- *General information*: General information about the product or system, including information such as: colour, finish, material, shape, size, duration of warranty, Uniclass 2015 category and CAWS classification.
- *Specification data*: Standardized data structure, defined according to Uniclass 2015 categories, containing information relevant to the production of technical specifications. This data is also known as “Enhanced Data” and is compatible with the data structure of NBS’s specifications platform (NBS Chorus).

- *Environmental information*: Environmental information about the product or system, including information such as: percentage of recycled content, recyclability, country of origin of the product, country of origin of the material and red list materials.
- *Digital objects*: List of available BIM objects associated to the product or system, containing a hyperlink that redirects the user to the respective section of the NBS National BIM Library.
- *Literature*: Set of technical literature associated with the product or system, generally available in PDF format, that includes documents such as: brochures, user manual, maintenance manual, technical drawings and technical specifications.
- *Case studies*: Presentation of real-world applications of the product or system.
- *Third party certifications*: Third-party certification associated with the product or system.
- *Similar products*: Similar products from the same manufacturer.

NBS Source also enables users to browse manufacturer libraries, with each manufacturer having a dedicated section divided into six subsections: Overview, Products, CPD (Continuing Professional Development), Third-Party Certification, Case Studies, Literature, and About Us. The Overview and About Us sections provide general company information, including contact details. The Products section displays all the manufacturer's products, allowing users to filter them based on the previously mentioned criteria, along with an additional filter called "Product Range", which consists of personalized product classifications. The standardized data structure enhances the efficiency of product comparisons, as similar products share the same classification and, consequently, the same data structure. Additionally, NBS Source includes a product comparison tool that allows users to compare up to three different products. Both NBS Source and NBS Chorus are accessible through a plugin for the BIM authoring software Autodesk Revit. This plugin enables users to import BIM objects directly into their 3D models and provides additional functionalities, such as updating the 3D model or importing BOS-compliant properties.

1.2.2 Cobuilder

Cobuilder is an IT platform specializing in the standardization and management of data relevant to the construction sector. The Norwegian company of the same name, which developed the platform, is one of the leading advocates for digitalization in the construction industry and serves as a strategic contributor to organizations involved in BIM standardization, including ISO, buildingSMART, CEN, and CENELEC. Cobuilder's solutions are centered on the development and management of data structures for construction products, supply chain integration, and the organization of information related to users' projects, work teams, and companies. The two platforms relevant to the subject of this paper are *Cobuilder Define* and *Cobuilder Supply*.

Cobuilder Define enables the development of Product Data Templates (PDTs), groups of properties, individual properties, and their attributes within a collaborative environment. This supports companies in transitioning from traditional data structures to new standardized frameworks designed in accordance with EN ISO 23387:2020 for data templates and EN ISO 23386:2020 for data dictionaries [12][13]. The platform contains more than 2500 PDTs and 24000 available properties, as well as property groups, and attributes. Once the desired PDT has been selected, the user can consult the following information:

- *Descriptions*: Provides multiple translations for the construction object.
- *Groups of properties*: Includes groups of properties relevant to the construction object. This section features property groups associated with standards, presented as "EN xxxxx-x:xxxx Properties," where "xxxxx-x:xxxx" corresponds to the standard number and publication year. It also includes property groups related to Environmental Product Declarations (EPD) and data exchange formats such as IFC and COBie.
- *Properties*: Lists the properties relevant to the construction object, specifying the property group to which they belong and the units in which they are expressed.
- *Attributes*: Represents the metadata of properties. Each property is defined by a set of attributes, including physical quantity, units of measurement, Global Unique Identifier (GUID), data type, associated property groups, and method of measurement.
- *Classifications*: Categorizes the product according to widely used classification systems in the construction industry, including Uniclass 2015, its previous versions Uniclass 1.4 and

Uniclass 2, as well as Omniclass, CI/SfB, UNSPSC, NRM 3, CPV, IFC entity, and Revit category.
- *Documents*: Lists the standards with which the PDT complies. Once all required information is provided, the product is considered compliant with the standards specified in this section.

Cobuilder Supply serves as Cobuilder's construction products library, designed primarily for manufacturers. This platform provides analytical tools that enable manufacturers to monitor the performance of their construction products and systems. These analytical insights, which include metrics such as the number of views, downloads, and geographic regions with the highest interest, are crucial for manufacturers to evaluate market engagement.

Each product on *Cobuilder Supply* has a dedicated product page displaying a comprehensive set of information. In addition to general product details, such as the construction object, applicable standards linked to the selected PDT, product definition, country of production, and manufacturer, users can access the following sections:

- *Properties*: Lists the set of properties associated with the selected construction object. These properties derive from multiple sources, including applicable European standards, IFC property sets (aligned with the corresponding IFC entity), COBie, and environmental certifications such as EPD or BREEAM.
- *References*: Specifies the set of standards from which the properties of the selected PDT were derived. If the PDT is correctly and fully completed, the construction product will comply with the standards listed in this section.
- *Classifications*: Categorizes the product according to widely used classification systems in the construction industry, including Uniclass 2015 (as well as previous versions Uniclass 1.4 and Uniclass 2), Omniclass, UNSPSC, NRM 3, CPV, and classifications based on IFC entity and Revit category.
- *Documents*: Contains documents related to the construction product or system, including technical drawings, information sheets, Declaration of Performance, assembly instructions, user manuals, and certification-related documents.
- *BIM files*: Provides BIM objects that serve as digital representations of the product.
- *Components*: Lists the individual elements that constitute the construction product or system. For example, a window system may include components such as glass panels and an aluminium frame.
- *Versions*: Displays a history of all past versions of the product.

Product information can be exported in Excel and PDF formats. These formats organize the data into three main sections: general product information, classifications, and properties, encompassing the details outlined above.

1.3 Digital Product Passports

The construction industry significantly impacts various economic sectors and influences overall quality of life. It consumes a substantial number of resources, accounting for approximately 50% of raw material extraction, and is responsible for over 35% of total waste production in the European Union, as reported by Eurostat in 2016. Greenhouse Gas (GHG) emissions from activities such as material extraction, the manufacturing of construction products, construction processes, and rehabilitation are estimated to contribute 5–12% of total national GHG emissions [5]. According to models developed by the International Resource Panel, emissions from the material cycle of residential buildings in the G7 countries and China could be reduced by at least 80% by 2050 through the implementation of material efficiency strategies [6]. Material and product passports have been recognized by the Ecodesign for Sustainable Products Regulation (ESPR) as essential instruments in facilitating the transition to a Circular Economy, which aims to minimize waste and optimize resource efficiency. Furthermore, they exemplify a key circular strategy for enhancing the management of Construction and Demolition Waste (CDW) [7]. One of the primary challenges in circular supply chain management is the absence of accurate product data, which significantly restricts the potential for circularity [8]. Digital Product Passports (DPPs) play a crucial role in addressing this issue by providing comprehensive and reliable data, thereby enabling informed decision-making within the framework of a Circular Economy [9].

Digital Product Passports (DPPs) serve as essential identity documents for materials and products, primarily aimed at providing comprehensive information on the technical characteristics of construction

products. Their objectives include facilitating the detailed description and traceability of product usage, documenting modifications throughout their lifecycle, tracking their integration within construction projects, and analysing their interactions with both structures and other products. Additionally, DPPs support the assessment of product recovery, reuse, and recycling potential, thereby advancing sustainability practices and ensuring greater compliance with regulatory frameworks.

The European Union's Ecodesign for Sustainable Products Regulation (ESPR), which entered into force in July 2024, introduced a range of new measures and fundamental requirements—most notably, the implementation of DPPs—to promote sustainability and reinforce legal adherence.

Preliminary ESPR guidelines establish mandatory data requirements for inclusion in these digital passports. The required information encompasses:

- Unique product identifiers and Global Trade Identification Numbers (GTINs).
- Instructions for installation, use, maintenance, repair, disassembly, recycling, and disposal.
- Manufacturer and importer details, including unique facility identifiers and unique operator identifiers.
- Essential warnings and safety information.
- Compliance documentation and voluntary certifications.
- Information on substances of concern.
- Relevant commodity codes.

The ESPR underscores the European Union's commitment to fostering a comprehensive and sustainable regulatory landscape, facilitating the transition toward a circular economy. DPPs constitute a pivotal instrument in addressing challenges related to the storage and exchange of material and product data. Currently, a substantial portion of this critical information remains either unknown or is not effectively shared among key stakeholders within the construction industry's value chain [10]. Furthermore, the inherently fragmented nature of the construction sector poses additional barriers to the seamless flow of information and the efficient exchange of knowledge among industry participants [11].

1.4 Objectives

The main goal of this research is to create a BIM library as a plugin for BIM authoring software, designed to store and distribute BIM objects and data for modular construction units and their components. The product data is structured according to standards related to Product Data Templates (PDTs) and the Level of Information Need (LOIN). Additionally, the research integrates a DPP platform within the BIM library, making publicly available DPP data accessible to designers directly through the BIM software. The plugin also includes a Life Cycle Assessment (LCA) tool, fully compatible with the library's data structure and the DPP platform, to support sustainable decision-making and circular economy practices. Furthermore, these systems are interconnected through an Application Programming Interface (API), allowing DPP data to flow between the BIM library and the DPP platform. This integration enables designers to access detailed information about reusable products and incorporate it into their 3D models. The overall objective is to create a collaborative environment that connects suppliers of reusable products with designers working on new projects, thereby promoting the use of sustainable, circular products. The overview of the system proposed in this research is illustrated in Figure 1.

1.5 Methodology

The BIM authoring software plugin was developed as a Windows Presentation Foundation (WPF) application plugin for Autodesk Revit, employing C# for the application logic and XAML for the design of the user interface. The initial prototype of the BIM library was conceptualized using Figma, serving as a preliminary model to guide the development of the application. The application programming interface (API), constructed with Next.js API Routes, enables communication between the BIM library and the DPP platform, thereby facilitating access to publicly available passport data. In order to ensure machine readability and support automated operations, all data exchanged between these platforms is standardized in compliance with European standards. This standardization guarantees data consistency and promotes seamless integration across various systems and functionalities. Data is transferred between the BIM library and the DPP platform in the JSON format, and the standardization of the data within the Revit environment is achieved through the use of shared parameters. These parameters are linked to GUIDs, ensuring that the data remains identifiable and machine-readable.

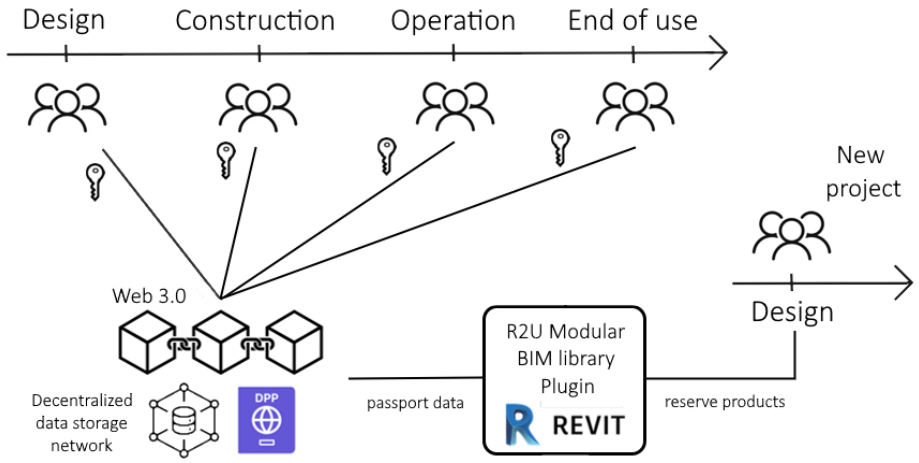

Fig. 1 Overview of the system architecture of the R2UTechnologies BIM and DPP platforms

2 Implementation of the BIM authoring software plugin

In order to unequivocally identify the product data used in the development of projects, it is required for this data to be structured according to certain guidelines established by standards aimed at creating a universal digital language, namely the EN ISO 23386:2020 and the EN ISO 23387:2020. This common data structure, denominated as Product Data Template, describes the characteristics of construction products or systems through the use of properties, which are organized into groups of properties. These PDTs can be used as a Single Source of Truth for these products and systems. The unequivocal identification of these properties allows the automatic compliance verification of the BIM objects with the different requirements established, and this automated method can reduce the verification time by 125 minutes per object when compared to traditional methods [14]. The plugin is composed of two main components: the BIM library and a LCA tool.

2.1 BIM library and update functionality

The BIM library allows users to consult product and manufacturer information, import BIM objects along with their respective data and update the 3D model. The update functionality is made possible through the use of identity properties, which are properties that associate the BIM objects in 3D models to the modular units of the BIM library. These properties are automatically attributed and cannot be edited by the users. There are three main identity properties, each one related to: (1) the BIM object, which is analogous to the Family concept in Revit; (2) the variant, which is analogous to the Type concept in a Revit family, and (3) the version of the object, which changes every time the data structure of the object changes (e.g., changing the selected PDT) or the value of the properties change. The unequivocal identification of BIM objects is important in several areas, such as the interoperability between BIM authoring software and energy analysis software, where it is possible to achieve an improvement of around 4.88% in the accuracy of energy simulation results when using invariant signatures to map space objects [15].

The library categorizes its users into three distinct types: (1) Administrators, (2) Manufacturers, and (3) Default Users. Administrators and Manufacturers possess the ability to modify the visibility status of their objects, allowing them to be designated as either public or private. However, objects may only be rendered public if their data structure, derived from the specified PDT, has been fully filled. This approach ensures compliance of the corresponding construction products with regulatory frameworks, given that the PDTs are conceived in accordance with standards such as EN ISO 23387:2020 and EN ISO 23386:2020. Figure 2 illustrates the main page of the BIM library, where users can explore all publicly available products and filter content based on a diverse range of criteria. These criteria include the type of BIM object, file format, manufacturer, or classification according to widely used

classification systems in the construction industry. The BIM library component of the plugin incorporates the following features:

- Download BIM objects along with the standardized data associated with them.
- Updating the BIM model, namely the objects that contain identity properties belonging to the library.
- Updating the BIM model by changing the selected groups of properties in use.

Although BIM object files can be published in the BIM library with non-geometric data embedded in them, the separation of the BIM objects from their non-geometric data is considered the ideal practice. This offers greater flexibility during the download, more specifically during the selection of properties, allowing the users to integrate into the BIM objects only groups of properties relevant to certain BIM uses or project milestones. Figure 3 depicts the download page, where users can specify which variants and groups of properties to import into the 3D model.

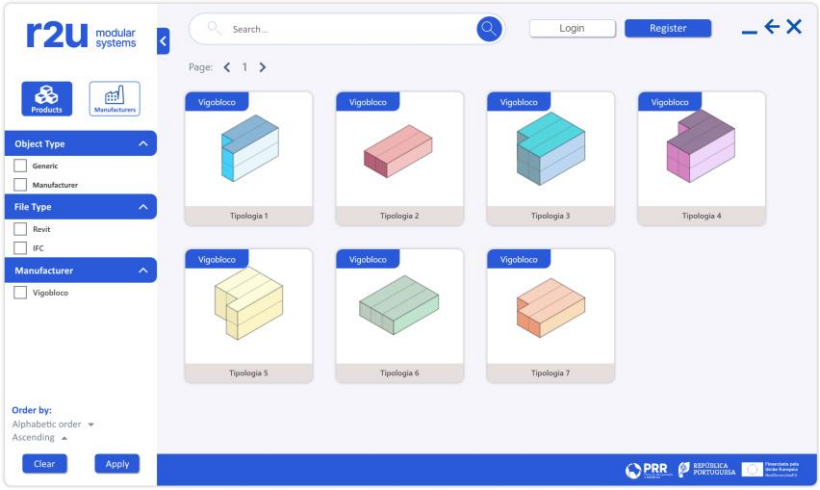

Fig. 2 Main page of the BIM library

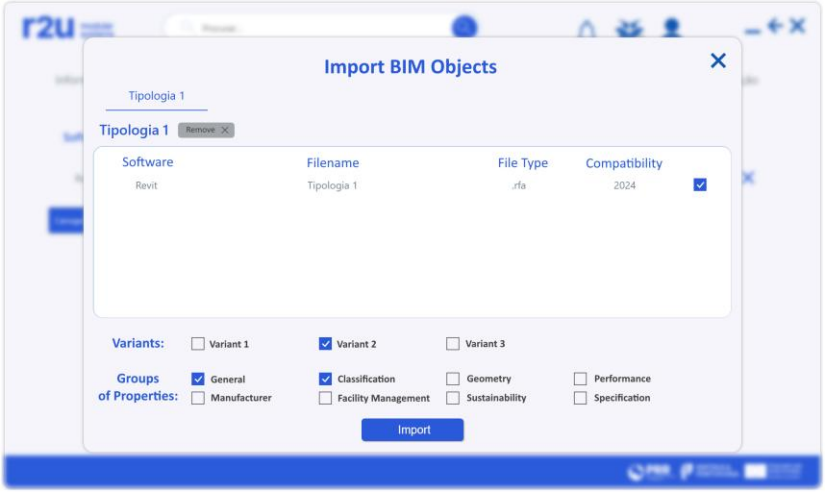

Fig. 3 Download page of the BIM library

The plugin's download functionality automatically manages the data based on the user's selection, excluding unselected properties even if they are embedded within the BIM object. This feature aligns with

the concept of LOIN as defined in ISO 7817-1:2024 [16] and is essential for preventing model overload caused by excessive data. By ensuring that only the necessary information is included, this approach helps maintain optimal performance, particularly in large-scale 3D models, where excessive data can lead to inefficiencies and reduced system responsiveness.

The principal objective of the library is to store and distribute BIM objects that represent modular units, making the rules governing the modelling and structuring of assemblies of paramount importance. The ISO 22014:2024 standard stipulates that the components of an assembly must be represented as library objects, rather than merely as graphical symbols. Consequently, both the complete assembly and its individual constituent parts must be defined as distinct library objects, each possessing appropriate naming conventions, descriptions, authorship, and classifications. However, while characteristic properties are required for the overall assembly, their inclusion for the constituent parts is optional [17].

2.1.1 Product section

Each construction product or system has a dedicated section, editable only by its owner, which structures the information according to the following subsections:

- *General Information*: Set of general information about the construction product or system, including: (1) the manufacturer; (2) the country of origin; (3) the creation date; (4) the date of the latest version; (5) the version number, (6) the regulatory document(s) it complies to, and (7) the product code (Presented in Figure 4). This code is defined by the manufacturer in order to support the supply chain in the process of identifying and organizing items.
- *BIM objects*: BIM authoring software files that store the BIM object associated with the construction product or modular system. This subsection may also include open file formats such as IFC files.
- *Properties*: All the properties contained within the groups of properties belonging to the selected PDT. These groups of properties must be defined in a way that makes their selection intuitive for a specific BIM use, associating the properties according to the type of data they represent. These data types can be, for example: (1) geometric; (2) Facility management; (3) general; (4) classification; (5) performance; (6) sustainability; (7) specification; (8) manufacturer.
- *Documentation*: A set of documents related to the construction product or system, such as: (1) technical drawings or information sheets (2) Declaration of Performance; (3) instructions for assembly or application; (4) user manuals and (5) documents related to any type of certification.
- *Classification*: Classification of the product or system according to a set of classification systems popular in the construction industry, specifically: (1) Uniclass 2015; (2) Omniclass; (3) MasterFormat; (4) UniFormat; (5) UNSPSC. This subsection may also include IFC classification and the Revit category.
- *Passports*: List of publicly accessible passports obtained from the Digital Product Passport platform, along with comparison and visualization tools for the LCA data.

All data, except for the passports which are managed through the DPP web platform, is editable by the respective manufacturer through the plugin. Upon selecting a DPP from the list, the user can visualize all associated data, which is organized into four key sections:

- *General Data*: Includes the passport name, Passport ID, URL, and the ID of the selected PDT.
- *Properties*: Comprises a set of attributes derived from the selected PDT.
- *History*: Documents the projects in which the product has been utilized, along with any modifications it has undergone.
- *Files*: Contains relevant documentation, particularly data required by the preliminary Ecodesign for Sustainable Products Regulation (ESPR) guidelines.

The user has the option to select a passport for comparison, which adds it to the comparison icon located at the top of the window. This icon provides access to the comparison page, where the user can review all selected passports side by side. To ensure data consistency, the data structure of all passports chosen for comparison must derived from the same PDT. The user can also visualize LCA data through column charts, which illustrate the contribution of each LCA phase (A1-A3, A4-A5, B, C, and D) to the cumulative value across various environmental impact categories. These categories include Global Warming Potential (GWP), Abiotic Depletion Potential for Elements (ADPe), Abiotic Depletion Potential for

Fossil Resources (ADPf), Acidification Potential (AP), Eutrophication Potential (EP), Ozone Depletion Potential (ODP), and Photochemical Ozone Creation Potential (POCP). Figure 5 illustrates the data presentation page of a selected DPP.

In order for the properties to be in compliance with the EN ISO 23386:2020 standard, these must be associated with a set of standardized attributes. These attributes are the metadata of the properties and includes information such as: (1) the GUID identifier; (2) the definition; (3) the physical quantity; (4) the groups of properties to which the property belongs; (5) the units in which it is expressed; (6) the data type or (7) the method of measurement, usually specified by a standard. The standardized data structure is essential for various purposes such as organizing and filtering the content, product comparison, and making data interoperable, that is, identifiable by other humans and digital systems. In the context of the current project, the standardization of data is essential to facilitate the automatic calculation of LCA metrics for key environmental impact categories.

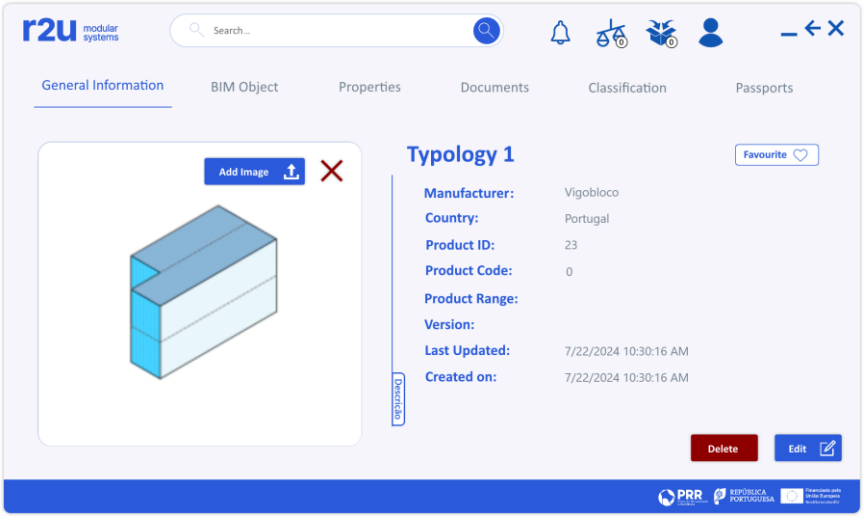

Fig. 4 “General Information” subsection of the product section

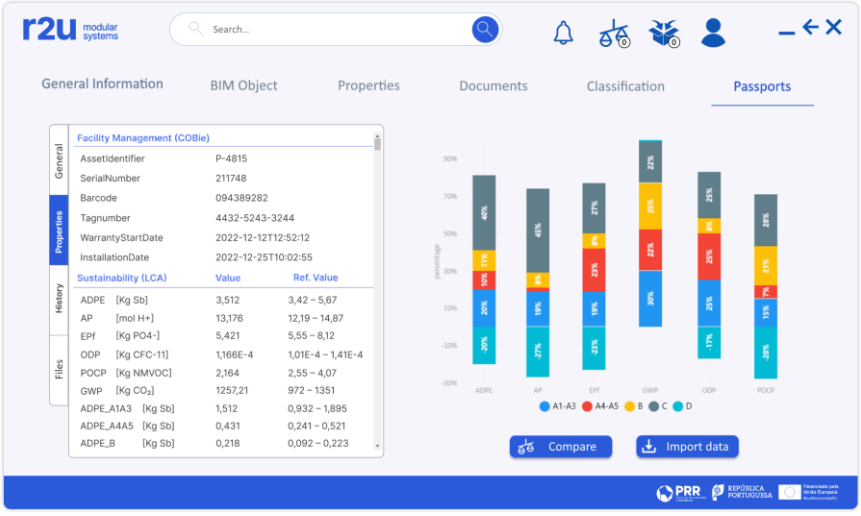

Fig. 5 Presentation of DPP data within the “Passport” subsection of the product section

2.1.2 Manufacturer section

The BIM library includes dedicated sections for manufacturers, enabling them to publish and manage information pertaining to their company, construction products, and systems. These sections structure the content according to the following five subsections:

- *General Information*: Manufacturer and contact information.
- *Certification*: Third-party certification issued to the manufacturer.
- *Case studies*: Presentation, with visual support, of real-world projects that use the manufacturer's construction products and systems.
- *Technical literature*: Technical literature related to the manufacturer's products and systems such as: (1) technical drawings; (2) data sheets; (3) catalogues or (4) instructions for assembly or application.

Manufacturers have access to an additional subsection that enables them to create custom labels for their products. These labels serve as a filtering mechanism on the library's main page and are accessible to users who have selected a single manufacturer as a filter option. Figure 6 presents the general information subsection of the manufacturers section. All data is editable by the respective manufacturer through the plugin.

Fig. 6 General Information subsection of the manufacturer section

2.2 LCA tool

The LCA tool allows users to perform automated LCA on the BIM model, provided that the BIM objects composing that model use the appropriate standardized properties. All BIM objects obtained from the BIM library are inherently equipped with a predefined structure of standardized properties discussed in previous chapters. This tool allows users to conduct a general LCA at the model level but also allows visualizing the contribution at many different hierarchical levels: the category level (e.g. walls, windows, doors, etc.), the element level (e.g. the contribution of each wall to the cumulative impact of all walls), and the material level (e.g. the contribution of each material within a specific element). Figure 7 presents a bar chart representation of the Global Warming Potential (GWP) results, detailing the contributions of each LCA phase (A1-A3, A4-A5, B, C, and D) within the "Walls" category. The sustainable data within the DPPs, being fully compatible with the data structure of the BIM object PDTs, is also seamlessly compatible with the LCA tool.

Users can also generate schedules and colour-gradient 3D views automatically, offering a more qualitative representation of the data and enabling quick identification of elements with higher environmental impacts. Figure 8 illustrates a 3D view created using the plugin's functionality.

Fig. 7 Bar chart representation of the GWP results for the "Walls" category

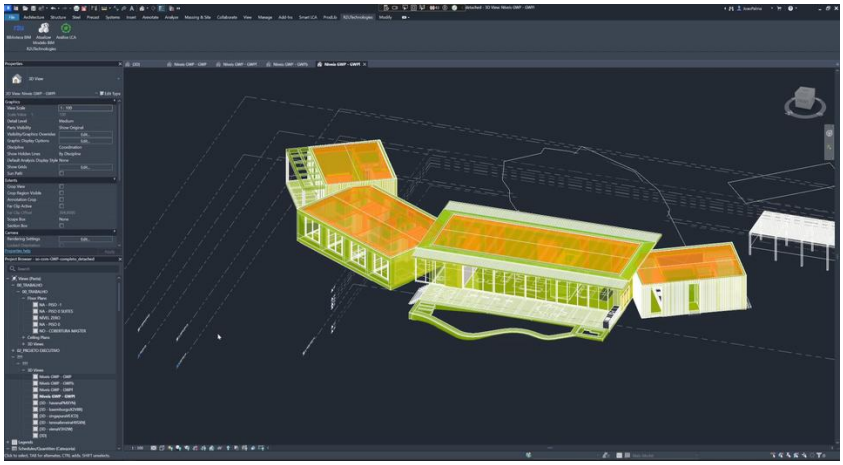

Fig. 8 Colour-gradient 3D view generated by the BIM authoring software plugin.

3 Conclusions

The separation of non-geometric data from the BIM object, facilitating customizable data selection, constitutes a pivotal feature for optimizing data management and enhancing computational efficiency, particularly in large-scale BIM models. This functionality allows users to tailor data selection to specific BIM applications while retaining the flexibility to update selected properties as required, thereby enhancing workflow adaptability. Moreover, data standardization plays a vital role in ensuring the clear and consistent identification of properties, which is crucial for achieving interoperability across various software tools. By harmonizing data formats and definitions, these tools can exchange and interpret information with greater precision, reducing errors and fostering seamless workflow integration.

The proposed system aims to bridge existing gaps in lifecycle information, thereby fostering more informed decision-making that supports sustainability. It has the potential to minimize waste while capitalizing on the advantages of modular construction, particularly in terms of disassembly, material recovery, and reuse. In doing so, the system contributes to the advancement of a circular economy within the construction sector.

Acknowledgements

This research was funded through the Recovery and Resilience Plan (PRR) as part of the project "R2UTechnologies - modular systems" (operation code: 01/C05-i11/2024.PC644876810-00000019).

References

[1] Eastman, Chuck; Teicholz, Paul; Sacks, Rafael; Liston, Kathleen. 2011. *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors*. 2nd Edition. John Wiley & Sons, Inc.

[2] Rad, Mohammad Amin Hamedi; Jalaei, Farzad; Golpour, Ashkan; Varzande, S. Saeid Hosseini; Guest, Geoffrey. 2021. "BIM-based approach to conduct Life Cycle Cost Analysis of resilient buildings at the conceptual stage". *Automation in Construction* 123.

[3] NBS Enterprises Limited & Glenigan. 2023. *Digital Construction Report*. https://www.thenbs.com/digital-construction-report-2023/

[4] NBS Enterprises Limited. 2019. NBS BIM Object Standard, Version 2.1.

[5] European Commission. "Circular Economy Action Plan for a Cleaner and More Competitive Europe". Accessed December 11, 2024. https://single-market-economy.ec.europa.eu/industry/sustainability/buildings-and-construction_en.

[6] Hertwich, E. & Lifset, R. & Pauliuk, S. & Heeren, Niko. 2020. *Resource Efficiency and Climate Change: Material Efficiency Strategies for a Low-Carbon Future*. International Resource Panel. https://www.resourcepanel.org/reports/resource-efficiency-and-climate-change/.

[7] European Environment Agency and European Topic Centre on Waste and Materials in a Green Economy. 2020. *Construction and Demolition Waste: challenges and opportunities in a Circular Economy*. https://www.eea.europa.eu/en/analysis/publications/construction-and-demolition-waste-challenges/.

[8] Wijewickrama, M. & Chileshe, N. & Rameezdeen, R. & Ochoa, J. Jorge. 2021. "Information sharing in reverse logistics supply chain of demolition waste: A systematic literature review". *Journal of Cleaner Production* 280, Part 1.

[9] Sesana, M.M.; Rivallain, M.; Salvalai, Graziano. 2020. "Overview of the available knowledge for the data model definition of a building renovation passport for non-residential buildings: The aldren project experience". *Sustainability* 12(2):642. Accessed December 11, 2024. doi:10.3390/su12020642.

[10] Heinrich, Matthias and Lang, Werner. 2019. *Materials Passports - Best Practice*. Technische Universität München in association with BAMB. https://www.bamb2020.eu/wp-content/uploads/2019/02/BAMB_MaterialsPassports_BestPractice.pdf.

[11] Fellows, Richard & Liu, Anita M. 2012. "Managing organizational interfaces in engineering construction projects: addressing fragmentation and boundary issues across multiple interfaces". *Construction management and economics* 30, issue 8.

[12] International Organization of Standardization. EN ISO 23386:2020. "Building information modelling (BIM) — Data templates for construction objects used in the life cycle of built assets — Concepts and principles".

[13] International Organization of Standardization. EN ISO 23387:2020. "Building information modelling (BIM) — Data templates for construction objects used in the life cycle of built assets — Concepts and principles".

[14] Doukari, Omar; Greenwood, David; Rogage, Kay; Kassem, Mohamad. 2022. "Object-centred automated compliance checking: a novel, bottom-up approach". *Journal of Information Technology in Construction* 27.

[15] Li, Hang; Zhang, Jiansong; Chang, Soowon; Sparkling, Anthony. 2022. "BIM-based object mapping using invariant signatures of AEC objects". *Automation in Construction* 145.

[16] International Organization of Standardization. ISO 7817-1:2024. "Building information modelling — Level of information need".

[17] International Organization of Standardization. ISO 22014:2024. "Library objects for architecture, engineering, construction and use".