

NAVIGATING THE TWIN TRANSITION: DATA REQUIREMENTS AND ACCURACY IN CONSTRUCTION PRODUCTS FOR SUSTAINABLE BUILDING PRACTICES

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Abstract

The present research is an exploratory study on how lifecycle data for construction products can be structured and quantified to progress on sustainable and circular building practices within Europe's twin transition. Focusing on two envelope products—aluminium double-glazed windows and external thermal insulation composite systems (ETICS)—the research maps product-level data requirements across the construction process lifecycle phases. Grounded in a building refurbishment case in Porto, Portugal, the work employs a mixed-methods approach that combines qualitative stakeholder role-playing with data extraction from technical specifications, Bills of Quantities, and BIM models. The analysis assumed 12 essential product characteristics, highlighting how phase-specific data needs diverge by product type and cannot be captured by universal templates. Windows exhibit relatively linear data progression with straightforward reuse or recycling pathways, whereas ETICS presents complex, layer-based quantification and greater end-of-life uncertainty due to adhesive layers and mixed waste streams. A central finding is that inaccuracies in units and quantities—driven by design simplifications, over-ordering, and on-site modifications—constrain circular forecasts. The paper advocates for Design for Disassembly and lifecycle data carriers (Digital Product Passports) integrated with BIM to enable real-time, end-to-end traceability and robust circularity forecasting, while outlining a roadmap for catalogue expansion and standardised data-entry practices.

1. Introduction

Data must be assumed as the central enabler of innovation in the construction sector, driving both digital and green transitions at product, building and city level. This dual digital-green transformation, increasingly referred to as the twin transition in European policy and research on the built environment, is closely linked to initiatives such as the Renovation Wave, Construction Product Regulation (CPR) and Ecodesign for Sustainable Products Regulation (ESPR) revisions, Circular Economy Action Plans and Energy Efficiency Directive [1], [2], [3], [4]. All of which have a focus on the characteristics of construction products utilised in building

projects. From a digital perspective, these policy objectives increasingly recognise Building Information Modelling (BIM) during the design and construction phases as a critical infrastructure for communicating product lifecycle data to enable robust circular economy forecasting and waste management [5], [6]. In this context, the circular economy is not simply treated as an additional feature to digitalisation but remains the primary driver, shaping how data is structured, shared, and governed to align construction practices with European policy actions.

Despite the progress in the twin transition, critical gaps persist in defining and managing product-level data and quantification across the construction process lifecycle. The CPR and ESPR establish requirements across technical, environmental, and economic dimensions, also addressed through CE marking, Environmental Product Declarations (EPDs), emerging Product Circularity Data Sheets (PCDS) and Material Passports (MP) [7]. While many frameworks advocate for DPPs to consolidate all data from all dimensions, few studies provide specific product-level and phase-specific analyses of information needs and quantification accuracy of different construction products. Therefore, phase-specific data needs focussed on construction products remains unexplored. This leads to data deficiency, ambiguity, and inaccuracies, reducing stakeholder trust and informed decision making [5], [8]. The gaps grow further apart due to the limited understanding of how product data and quantities evolve across the construction phases, creating fragmented information and discontinuous handovers [9]. Therefore, DPPs and MPs are emerging as crucial instruments for structuring and preserving product data over time, but limitations related to data entry standardisation remain.

Traditional AutoCAD methods deliver static 2D outputs with manual Bill of Quantities (BoQ) creation, while BIM transforms these into dynamic 3D environments with the possibility of integrating geometries, attributes, quantities, cost estimates, and lifecycle metadata [10], [11], [12]. BIM-enabled BoQs develop design-to-construction contracts, bridging policy and practice, with the ability to provide deliverables across phases, such as design baseline quantities, asset tags for facility management, and quantity take off (QTO), impacting budgets and waste at deconstruction [9], [13], [14]. BIM maturity gaps persist in circular workflows due to ambiguous Level of Information Need (LOIN). Current construction practices in specifying, ordering, and managing products rarely consider the full implications of reuse and recycling, missing out on circular opportunities from design onward. Therefore, with the increasing desire to operationalise and enhance BIM proficiency, standardised data dictionaries, such as the buildingSMART Data Dictionary (bSDD), are essential for harmonised attributes and standards integration and requires further expansions in everyday workflows [9].

The paper addresses critical gaps in the construction industry by investigating data requirements, measurement criteria, and quantification accuracy across the lifecycle phases using two primary building envelope products as cases: Window and External Thermal Insulation Composite System (ETICS). Both are common in new build and refurbishment projects in Portugal and across Europe, ensuring scalability and relevance. By analysing these products across the design, construction, facility management, and deconstruction phases, the study develops a whole lifecycle perspective essential to forecast reuse and recycling potential. This exploratory study focuses on product data and BIM-based circularity assessment. A central motivation is to “address the obvious” by making explicit and formalising what practitioners intuitively know and perform but rarely document. Within the context of BIM and BoQs, such undocumented practices create data handover breaks that hinder circular economy accomplishment [15]. The aim is therefore to explore product-level lifecycle data and assess

the accuracy challenges associated with quantification for relevant product types. Windows and ETICS were chosen, given the findings of previous research, both of which embed factors that carry significant financial and circular consequences [16]. The research positions DPPs and MPs as paramount tools for structuring and preserving product data over time, turning phase transitions into traceable data flows for sustainable building practices [17], [18].

The motivation can be summarised by the following research questions:

- What specific product-level data is required for Windows and ETICS at each construction process lifecycle phase based on technical, environmental and economic resource dimensions?
- How do units of measurement and quantity values evolve from design specifications to deconstruction yields, and what are the primary constraints introducing ambiguities or variation in these transitions?
- What are the implications of quantification inaccuracies for the reliability of BIM-based circularity forecasts and the effective implementation of DPPs?

2. Methodology

The research frames into an exploratory perspective, adopting mixed-methods approach, focused on qualitative mapping and grounded in a thoroughly documented single case study consisting of a residential building representative of Portuguese housing archetypes. The scope is narrowed down to priority building envelope products: square aluminium and double-glazed Window units, and ETICS with EPS insulation. From a deconstruction point of view, taking the post-intervention building serves as a baseline to forecast the lifecycle of its products across phases. Through documented stakeholders actions along the value chain, current practices of measurement and quantification are identified across the phases. Key data sources used are technical specifications, BoQ and BIM model, from which attributes, units, and quantities are extracted to define data requirements and accuracy implications. Each attribute is assessed based on who needs it, at which phase, and for what decisions, enabling a comparative analysis of chosen products. Despite the use of a single case study, the rigour, scientific soundness and representativeness are ensured through the existing documentation and the triangulation and reviews conducted during on-site data collection.

3. Development

3.1 Data requirements

The study works with 12 essential attributes spanning technical, environmental and economic dimensions, that are envisioned as the constituent pieces of a DPP “puzzle” (Figure 1). These attributes reflect stakeholder information needs across all project phases and align with data dictionaries ensuring digital interoperability and relevance towards DPP data templates CPR [19]. The set is not exhaustive. The selection criteria is related to requirements identified in the literature (namely CPR and ESPR), combining their span across life cycle phases and domains such as performance, circularity and environment [1], [2], [20].

An analysis of manufacturer product documentation for the aluminium double-glazed windows and ETICS informs manufacturer identification and technical properties. The manufacturer is the overarching data requirement that remains relevant throughout all phases and product types, enabling accountability, regulatory compliance verification, and a technical contact point. For windows, key technical performance and geometry attributes include thermal transmittance, air permeability, and dimensions specified at the design phase. In the case of ETICS, thermal transmittance, reaction to fire and thickness of insulation are prioritised due to their importance in energy performance and fire safety concerns of building envelopes. The performance data remains critical until deconstruction for potential reuse or upgrade at product end-of-life. The rest of the requirements in the puzzle are relevant for both products addressing environmental and economic resource dimensions. Given the data absence in current product documentation relevant for the deconstruction phase, key data points of waste code and potential outlets extracted from the Waste Audit Guidelines are identified to support future circular deconstruction and comply with regulatory Waste Framework Directive [6], [21], [22], [23]. Each data attribute in the puzzle is mapped across construction project phases to illustrate who needs what when, as shown in the following Figure 2 for windows and Figure 3 for ETICS. The changing shaded puzzle pieces highlight the phase specific data points extracted based on stakeholder practices and needs. In summary, the phase-based mapping for window and ETICS demonstrates how designers specify the performance and composition during design; contractors require dimensional and composition accuracy for installation; and facility managers track expected service life and warranty period. Lastly, at the deconstruction phase, teams depend on composition, weight and volume to determine reuse and recyclable fractions.

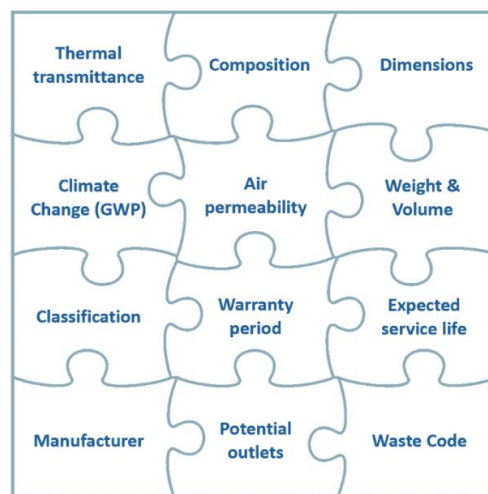


Figure 1: Example of the defined data requirements for windows.

3.2 Aluminium double-glazed window product behaviour

Window measurement criteria follow a linear progression from design specifications in bill of quantities to deconstruction yields, whereas quantification varies across phases:

- Design: specified as total m² (frame and glass) or individual units with defined dimensions and opening type; modelled in BIM as single component enabling quantity extraction in either format.

- Construction: Ordered as per specification and installed as units; minimal over-ordering due to high value product, but it may account for potential breakage and spare parts.
- Facility management: Managed as individual tagged units and quantities maintained according to the exact installation count unless damages or replacements made.
- Deconstruction: Varies by circular pathway - either intact units for reuse, kg/volume post-separation of frame and glass for recycling, or frame reuse with glazing upgrade combining both reuse and recycling quantification measurement criteria. Yields are typically lower due to damage sustained during the removal process, highly dependent on the disassembly technique employed.

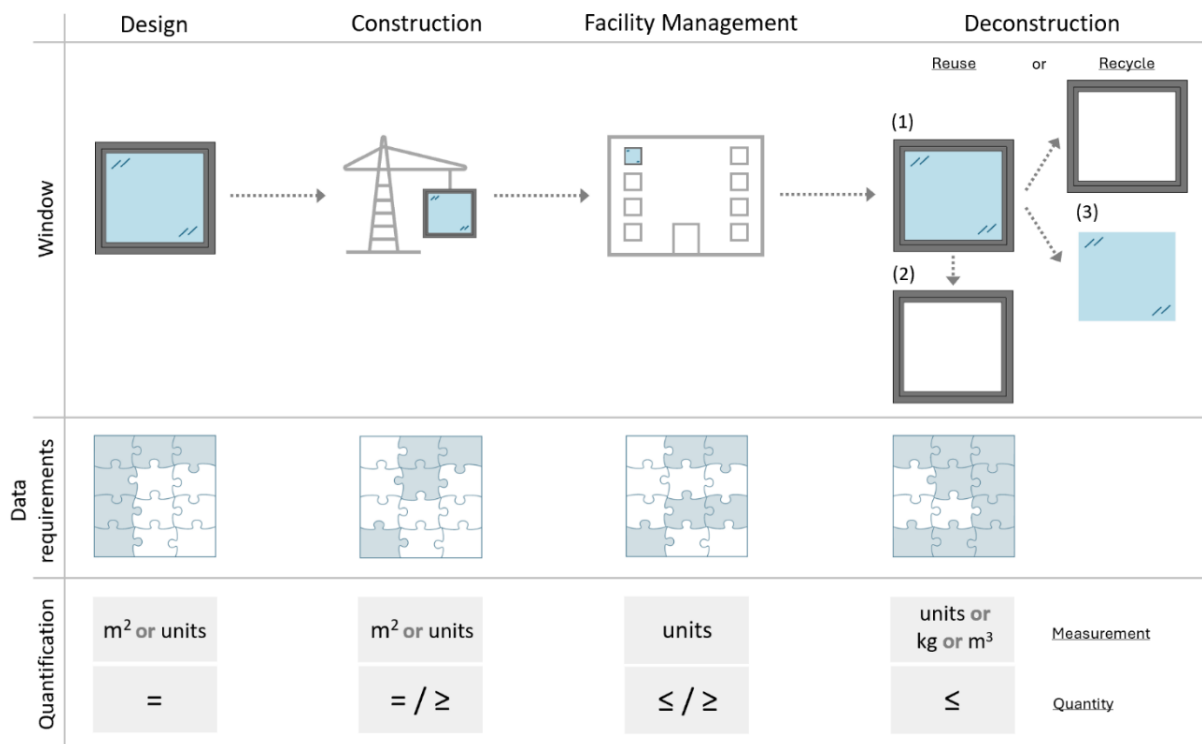


Figure 2: Window data requirements and quantification across phases.

3.3 ETICS product behaviour

ETICS quantification shifts from simplified surface area to complex layer-based yields:

- Design: Specified in total m² system with consideration of single-element surfaces; BIM model represents as a monolithic component.
- Construction: Ordered in m² or insulation board units, with >10% over-ordering typical to cover for site cuts, installation waste, and workmanship. System internal splits are calculated in terms of m² of insulation boards, kg of mortars, m² of mesh, litres or kg of paint, and number of mechanical fixings.
- Facility management: Maintained in m², local repairs and painting patchwork may introduce litres/kg. Quantities are exact number installed, unless local repairs performed during lifetime.

Legend	
=	Exact quantity
≥	Equal or more (over-ordering)
≤	Equal or less (losses/cuts, damage & contamination)
≤ / ≥	Variable (repairs/additions possible)

- Deconstruction: shifts to kg for recycling and waste auditing; EPS boards may be 70% recoverable for thermal insulation reuse or shredding, whereas adhered leftover layers of mortar, mesh, and coatings end up in landfill. Typical yields are often lower than initial specification due to damage sustained during the removal of the composite adhesive layers and lifespan modifications.

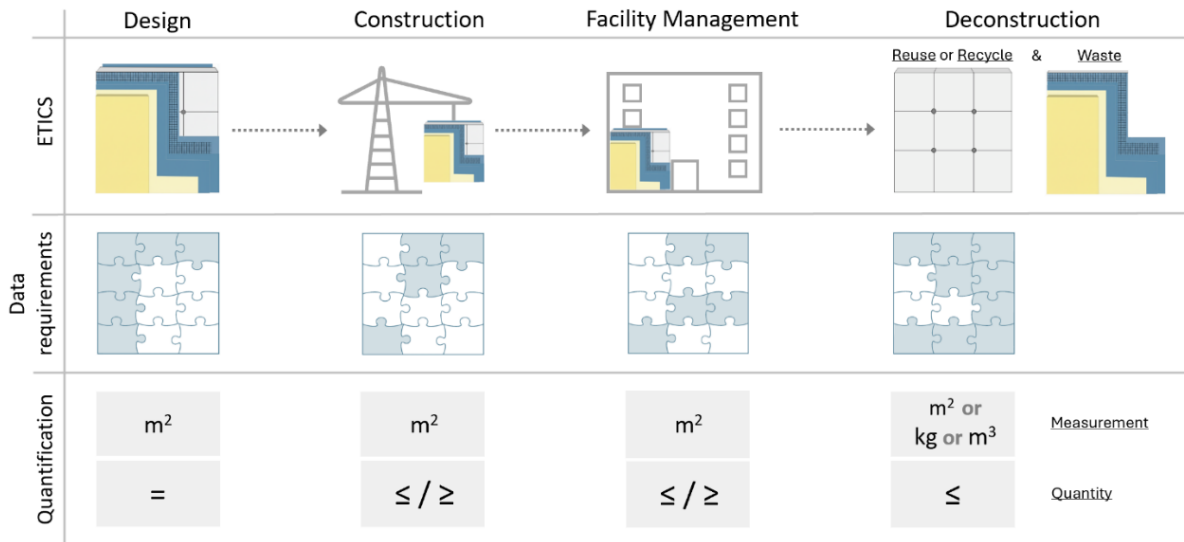


Figure 3: ETICS data requirements and quantification across phases.

4. Cross Product Discussion

4.1 Accuracy evaluation

Analysis shows shifts in units and quantities across project phases, driven by practical adjustments in design, construction, facility management and deconstruction. These are mostly unavoidable due to the product characteristics and stakeholders' interactions. While the changes are frequent occurrences, they are rarely documented, causing a chain of inaccuracy and information losses that undermines reliable circular forecasting. Consequently, these systematic but unformalised shifts explain why circular economy targets remain challenging to achieve, as optimistic design baselines, undocumented site waste, and unpredictable deconstruction stocks produce unreliable outcomes. To address these inaccuracies and uncertainties, structured data and digital traceability of DPPs are necessary.

Product comparison confirms that each product type follows its own quantification logic:

- Windows: consistent m² or unit tracking across phases and ease of component separation for reuse or recycling by weight at deconstruction.
- ETICS: complex shifts from surface area, unit counts in insulation board, patchwork repairs, and mixed end-of-life waste streams that complicate material accounting and recyclability estimates. For a 1 m² of ETICS, 60-70% of the insulation board mass is estimated on the safe side for reuse or recycling under favourable conditions, while mortar or finish layers go to landfill. This demonstrates how weight-based targets can obscure material recovery realities.

Accuracy discrepancies stem from multiple recurring factors, including design simplifications, over-ordering, on-site modifications, unforeseen damages, contamination and mixed waste outlets at deconstruction. These variations are rarely formalised on handover deliverables, let alone within BIM environments, limiting reliable circular forecasts and introducing financial uncertainty into reuse and recycling decisions. These factors make quantity values approximate references rather than fixed metrics, which requires modelling of expected variance to produce realistic circularity projections [24].

4.2 Design for disassembly and circular forecasting

The study reveals design for disassembly (DfD) as a key enabler for reuse and high-quality recycling of construction products. Windows offer linear disassembly with separable frames and glass, yielding clear economic recovery potential. In contrast, ETICS faces adhesive limitations with the mesh and membrane layers, although the mechanical fixings between EPS boards allow an estimated 70% recovery under optimal conditions after accounting for adhesive losses on either side when separating layers [7]. Early definition of composition, weight, and volume data is essential to evaluate whether insulation separation justifies environmental and economic costs versus direct recycling. This is especially relevant given that the lightweight ETICS insulation boards dominate in volume, while heavier finishes skew weight-based circularity targets and may obscure true material recovery realities, changing perceived “quick wins”. Ultimately, quantification accuracy directly affects economic viability of circularity. Windows, being easier to disassemble, present more cost-effective reuse, while ETICS demand labour-intensive processes with high handling, over-ordering, and other hidden costs. The phase-based mapping underlines the need for consistent, traceable and phase-specific data to ensure budget reliability and credible circularity metrics.

4.3 Role of DPPs & MPs as product lifecycle data carriers

Together, DPPs and MPs, integrated with BIM and data dictionaries, serve as dynamic data carriers enabling lifecycle tracking of construction product data to ensure sustainable end-of-life strategies and interoperability. The identified data requirements in Figure 1 directly inform DPP design, allowing real-time extraction of key product-level information during the construction project phases to support circular decision-making [1]. By merging these manufacturer-driven data attributes with DPPs and BIM models from the project outset, the necessary Level of Information Need (LOIN) can be delivered to support circular economy forecasting and the development of Digital Building Logbooks. Therefore, there is a growing need for DPPs and MPs to capture reliable life cycle product-level data to enable scalable, sustainable and circular practices in construction [20].

5. Limitations

The findings of this study are subject to the following limitations:

- Although the exploratory study adopts a mixed-methods approach, the emphasis is mainly on the qualitative aspects, which limits the statistical robustness of results and calls for further qualitative research in future work.

- The analysis is grounded in a single Portuguese residential building case study, while the products and construction phases are typical within the EU context, the findings may not fully capture practices, regulations, or market conditions in other countries.
- The scope is limited to two construction products, windows and ETICS, rather than a comprehensive assessment of an entire building and its diverse assembly of components. This means that other construction product types with different data requirements and quantification behaviours were not examined. As each construction product category may exhibit distinct lifecycle data needs and circularity pathways, further conclusions are required from future studies.
- Additional iterations, such as focus groups and surveys, will be relevant to better assess the findings from this study, namely the extent of deviations and uncertainties in the quantification of products throughout their life cycle.
- From a technological perspective, ongoing developments will foster a better definition of the digital instruments, their involvement and role within the new and old processes.

6. Conclusions and Future Developments

In conclusion, this exploratory study delivers a phase-by-phase analysis of data requirements and quantification accuracy for two envelope products, windows and ETICS, grounded in a representative refurbishment case study. Key findings highlight that products behave differently across construction phases, acknowledging the inherent complexity, causing current data gaps that hinder circular economy implementation in practice. These results point to the need for product-specific data standards, in opposition to an universal approach. A comprehensive life cycle approach addresses product interdependencies and their distinct quantification behaviours by embedding life-cycle attributes into standardised DPP structures [5] This leverages BIM metadata capture, environmental benefits, economic reliability, and digital technologies that support circular practices and provide essential lifecycle visibility and traceability, enabling construction's twin transition. Given the exploratory character of the work, several limitations are associated as previously addressed. However, the insights from the data collection and extensive documentation allow solid key takeaways.

- Product catalogue expansion: Map phase-specific behaviours across and accuracy challenges faced for diverse construction products.
- Quantitative validation: Establish statistical ranges for waste factors, recovery rates, and deviation margins to better forecast reliable circularity and economic viability.
- Digital ecosystem: Address DPP data entry standardisation to balance digitalisation costs against long-term policy compliance benefits.

Therefore, the circular economy must direct digitalisation in line with EU policy actions to deliver accurate and scalable construction product circularity.

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