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EARLY-PHASE BIM-LCA INTEGRATION: PRACTICE-BASED CHALLENGES AND RESEARCH-INFORMED SOLUTIONS

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Introduction

As the construction industry faces increasing pressure to reduce its environmental impact, Life Cycle Assessment (LCA) has become an indispensable tool for quantifying and mitigating the ecological footprint of buildings (Röck et al., 2020). Its integration with Building Information Modeling (BIM) presents the potential for a more efficient workflow, where LCA results can directly influence architectural designs from an early stage, supporting environmentally aware decision-making processes. While BIM-based LCA is widely adopted in later project stages, its integration into early phases remains challenging. This is mainly due to the intrinsic properties of the early design process, where most details required for conducting LCA are yet to be decided and/or not integrated into the conceptual BIM models. Therefore, in this study, we focus on the most common problems that hinder early-phase BIM-LCA integration and possible approaches to address them. Among the various issues raised, this contribution concentrates on three recurring themes that were emphasized across multiple discussion groups and closely align with unresolved gaps identified in the literature. Although the list of challenges could be extended, this contribution focuses on the most prominent issues raised by practitioners during our workshop with BIM-Allianz (BIM-Allianz e.V., n.d.).

The workshop brought together 13 professionals from architecture and planning offices, enabling us to capture practice-oriented insights that are often underrepresented in the literature. The methodology followed a structured World Café format, enabling small, rotating discussion groups to explore key topics collaboratively. These topics focused on challenges related to BIM-LCA integration and the comparison of current tools and workflows with ideal ones. A variety of issues were raised during the discussions, from transparency and material databases to benchmarking and retrofit potential. For this contribution, we focus on **three** recurring themes that closely align with our current research needs and are also echoed in the literature (Figure 1):

(1) limited interoperability between BIM and LCA data,
(2) a lack of visual and intuitive feedback, and
(3) insufficient support for uncertainty and low-LOD models.

The proposed solutions, in turn, are grounded in recent academic research addressing these practical barriers.

By outlining these challenges and potential solutions, we aim to highlight research directions that are still in demand to ensure seamless integration in practice. This would enable architects and LCA experts to utilize more streamlined BIM-LCA workflows, thereby increasing the adoption of informed decision-making regarding environmental impact from the early phases onward.

Challenges and Potential Solutions

Interoperability and Data Exchange Limitations (1)

One recurring challenge lies in the lack of interoperability between BIM models and LCA tools (1a). Most BIM authoring tools rely on proprietary formats with differing semantic structures, making it challenging to extract consistent data—such as quantities or building element classifications—for downstream LCA use. This often results in a labor-intensive process still dependent on manual input and expert knowledge. In parallel, there is also a lack of interoperability among LCA databases themselves (1b), as they employ heterogeneous data schemas (e.g., ILCD, ISO 14048), which complicates their integration into unified BIM-LCA workflows.

A promising solution lies in the development and adoption of open standards (e.g., IFC, MVD, IDS, bSDD), which can enable structured data exchange from BIM to LCA tools (1a), while also providing a foundation for harmonizing heterogeneous LCA database schemas (1b). Ontology-based frameworks and semantic standards, such as those aligned with ISO 12006 and the buildingSMART Data Dictionary (bSDD) (buildingSMART International, n.d.), offer a promising pathway to bridge differences across lifecycle inventory structures by establishing shared concepts and mappings. Only then can it be possible to standardise the needs of the data exchange and thus achieve a degree of automation, as already demonstrated in some studies in the literature (Kamari et al., 2022; Lützkendorf, 2019; Carvalho et al., 2021; Tam et al., 2022).

Limited Visual Feedback and Intuitive Interaction (2)

A common frustration among architects is the absence of visual and real-time feedback in current LCA tools. While

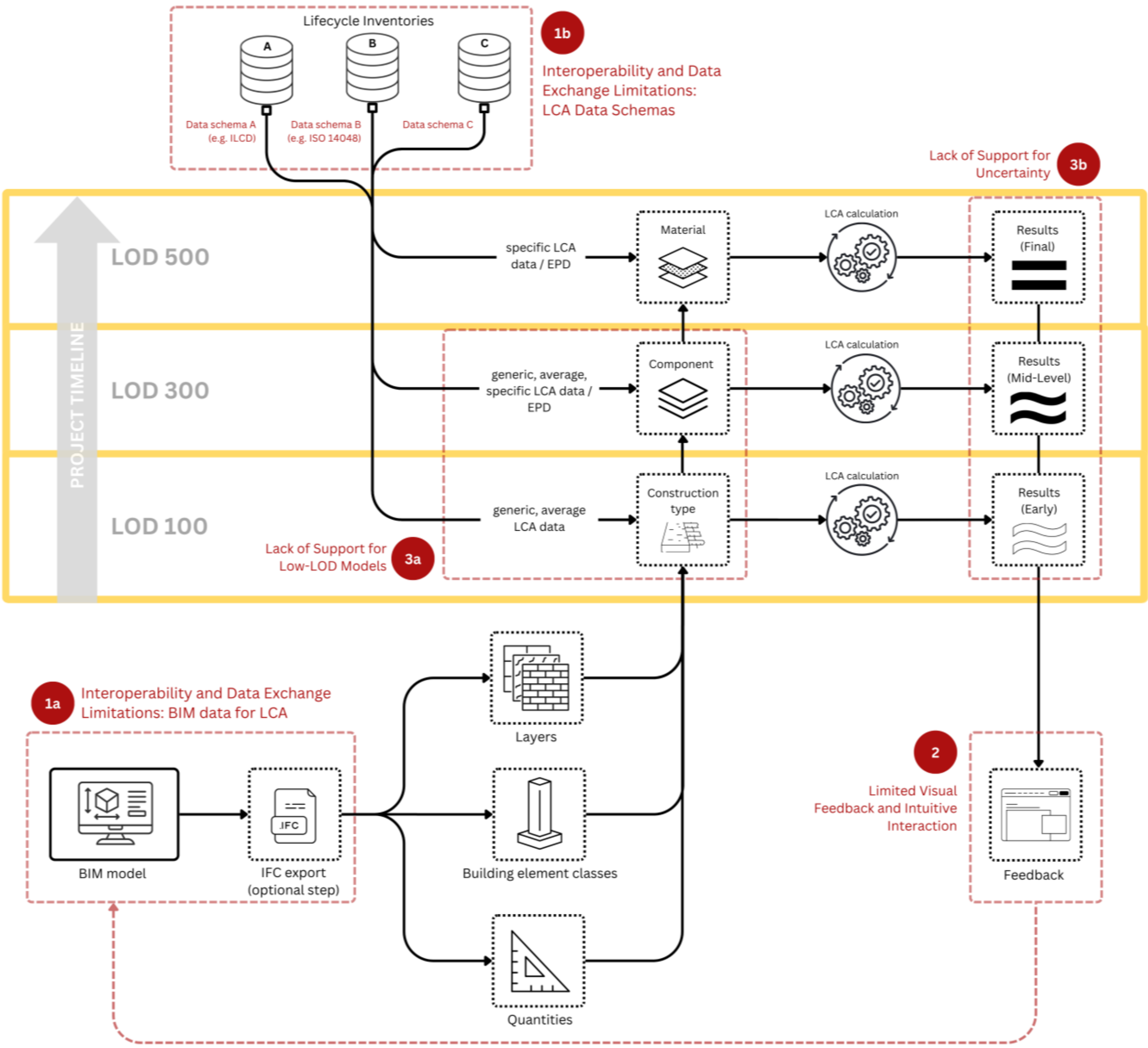

Figure 1: BIM-based LCA workflow across project phases, highlighting main bottlenecks.

these tools often produce tabular data, such outputs are not intuitive for designers and architects who rely on spatial and visual cues. This limits the potential of LCA as a design decision tool, particularly in early-phase workflows where fast iteration is crucial.

The problem is especially pronounced in smaller design offices, where there is typically no in-house LCA expert to interpret these results. A promising solution lies in embedding real-time 3D feedback and interactive dashboards directly into BIM environments, utilizing tools such as IFC.js or Three.js.

Recent efforts show that communicating environmental impacts visually, through 3D feedback dashboards or live carbon intensity overlays via hotspot analysis, can make LCA results much more tangible and comprehensible (Haschke & Gengnagel, 2023; Forth et al., 2023; Hollberg et al., 2021; Palumbo et al., 2020; Forth, 2024) (Figure 2).

Lack of Support for Uncertainty and Low-LOD Models (3)

This challenge can be understood along two dimensions: (3a) uncertainty in early data and (3b) lack of support for low-LOD models. Early design phases are characterized by a high degree of uncertainty; yet, most BIM-LCA tools produce results that convey a false sense of precision. This is problematic, especially when detailed information about materials and assemblies is not yet available. Many tools also assume complete or high LOD BIM models, which are rarely present at the conceptual stage. As a result, users are either forced to rely on manual data approximations or are unable to proceed with meaningful environmental assessments. To address this, LCA tools should incorporate probabilistic modeling approaches and allow for parameter ranges or typology-based defaults.

To account for variation across building types, databases such as the German Konstruktionsatlas published by the Construction Costs Information Center of the German

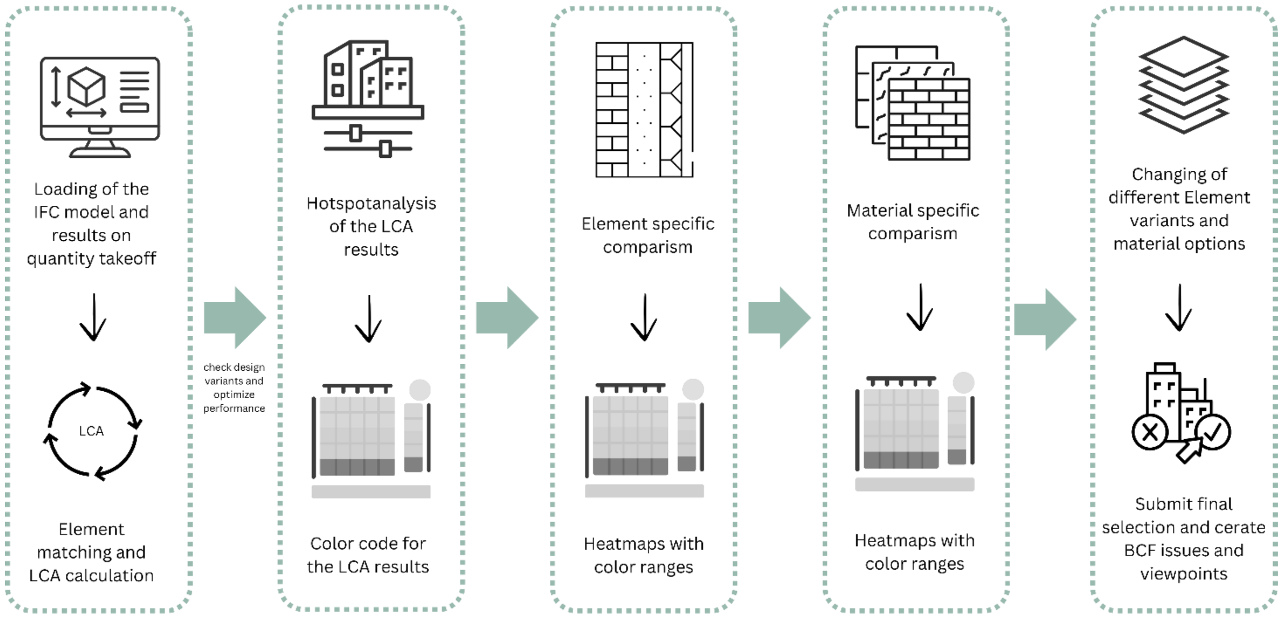

Figure 3: An example on design decision support using real-time visualization methods (Forth, 2024)

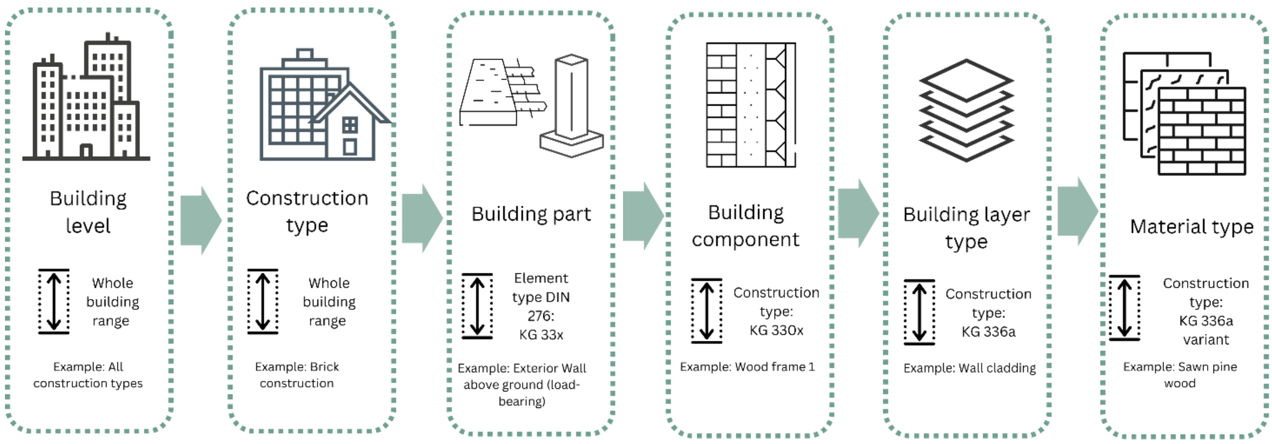

Figure 2: A sample approach to address early phase uncertainty: Stochastic modelling using German standard DIN276 (Staudt et al., 2023).

Chamber of Architects (BKI, 2023) can serve as valuable libraries for common construction types, providing structured reference data that support the derivation of typology-specific default values in BIM-based life cycle assessments. Component-based data can be derived using building element classification systems, such as the German standard DIN 276, which enables the creation of structured reference data even in early design stages.

By linking these classifications with typology-based component libraries, it becomes possible to generate more context-sensitive LCA results, even with limited planning information.

Additionally, simplified decision frameworks and adaptive LOD strategies, supported by template-based assumptions and fallback mechanisms using generic datasets like ÖKOBAUDAT, can enable consistent and comparable results even with low-detail models (Dalla Mora et al., 2020; Lützkendorf, T., 2019; Staudt et al., 2023; Rezaei et al., 2019; Cavalliere et al., 2019; Tam et al., 2022; Prideaux et al., 2024) (Figure 3).

Conclusion

This contribution highlights three of the most pressing challenges that hinder the effective integration of LCA into early-phase BIM workflows: Limited interoperability, lack of intuitive feedback, and inadequate support for uncertainty and low-LOD models. While these issues stem from both technical limitations and process fragmentation, they are not insurmountable. Emerging developments in open standards, real-time visualization, and uncertainty-aware modelling frameworks show promising potential to bridge these gaps. By addressing these shortcomings, the BIM-LCA integration can become more accessible, reliable, and informative, particularly during the conceptual stages when design decisions have the highest potential to affect the environmental impact. These challenges are grounded in practice-oriented insights from small- to medium-sized design firms in Germany, which differ from current, predominantly research-driven approaches. Future research and development efforts should focus on translating these solutions into scalable, user-friendly tools that align with real-world design practices, ultimately encouraging broader adoption across the architecture, engineering, and construction (AEC) industry.

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