

REVIEW

An Integrated Risk Management Framework for Digital Data Systems and Building Life Cycle Carbon Emissions

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Abstract: This paper examines the key risks associated with developing digital data systems for managing the carbon footprint of a building over its entire life cycle, or the total carbon dioxide emitted over a building's entire life cycle. The analysis suggests that these platforms need to integrate 3D building models (BIM), environmental data, and digital building records. As modern research increasingly focuses on the total impact of a building over its entire life cycle, rather than just the carbon dioxide required to manufacture the structures, ensuring data integrity and consistency across multiple devices is becoming increasingly challenging. The literature identifies several key risks, including poor data quality, limited interoperability between software environments, and confusing legal regulations. Currently, the connection between 3D models and most studies, which rely on proprietary software ecosystems, is not fully automated: one recent review found that while some parts are automated, most studies still require manual data reconciliation, and most are stuck using proprietary software rather than open systems. There are also gaps in how product data and building models are synchronized, leading to tracking errors. On the legal side, research into digital building logs shows that it is often unclear who actually owns the data or who has access to it. Addressing these issues requires more than technological improvements alone. We need a solid plan for how data is handled, based on five ideas: using standard data formats, double-checking quality, being clear about what we are measuring, validating results across different tools, and rolling the system out in stages with proper training. The best way forward is to build a platform that reuses existing reliable datasets and carefully adds new project info, rather than attempting to implement an entirely new system without incremental validation. Certification schemes like BREEAM are a primary thing driving the requirement for reliable, integrated whole-life carbon (WLC) data, but this also inherits the data quality and interoperability risks inherent in connecting BIM, LCA, and product declaration systems.

Keywords: Building Information Modeling (BIM), Whole-Life Carbon assessment, digital data systems, Life Cycle Assessment (LCA), risk management

1 Introduction

Current research shows that the carbon dioxide produced over the entire life cycle of a building is considered the total global warming impact of the building. The latest European guidelines emphasize that we need to take everything into account: the production of materials, the use of the building, its maintenance and even its demolition. This makes digital integration much more difficult, as everyone involved- from architects to engineers - has to use the same rules and units of measurement (Guzar Dena et al., 2026).

In practice, platforms for monitoring of LCA consists interconnected digital environments rather than a single application. It's a whole network connecting 3D models, carbon calculators, product data, and energy records. Digital logs act as a central hub for all this info, while open data standards are the best way to make sure different software programs can share information. Since certification systems need huge amounts of data from different experts, the increasing digitalisation of certification workflows offers significant benefits, but it also brings some risks (Olanrewaju et al., 2024).

The research also highlights why these matters. Case studies show that without a standard way of working, it's hard to compare buildings or trust carbon reports. Green building certifications now rely on technical product data (EPDs), but studies show these documents often miss key

information or don't fit the local area. Because of this, any platform trying to track whole-life carbon also inherits the flaws and risks of the fragmented and heterogeneous data environments (Almeida et al., 2023).

Furthermore, BREEAM's multi-criteria approach not only mandates Whole-Life Carbon (WLC) tracking but also integrates metrics for user health and well-being, demanding that digital platforms merge energy and LCA data with real-time sensor information, thereby significantly increasing the scope of digital data integration required for certification compliance (Olanrewaju et al., 2024).

2 Literature review

The report prioritizes recent systematic reviews, empirical studies and implementation papers that explicitly address the integration of BIM and Life Cycle Analysis (LCA), Building Design Lists (BDLs), Environmental Declaration (EAD) quality, life cycle carbon baselines, EPBD-related scope changes and the deployment of digital platforms (see Table 1).

Table 1 Main risk impact groups

Unspecified item	Assumption used in this report	Implication for the risk assessment	Sources
Target audience	Digital-platform architects, consortium leads, evaluators, and policy-facing technical stakeholders.ata	Risks emphasize governance, interoperability, and implementation.	Olanrewaju et al. (2025)
Jurisdiction beyond the EU	Jurisdiction beyond the EU	Jurisdiction beyond the EU	Olanrewaju et al. (2025); Parece et al., (2024)
Implementation timeline	Assumed to span pilot, validation, and scaled deployment phases.	Risks are assessed as lifecycle risks, not just design-stage risks.	Olanrewaju et al. (2025); Parece et al. (2024)
Data access model	Assumed to combine public registries, proprietary project data, and Manufacturer/product data, including BIM data, LCA databases, and EPD-related information.	Data ownership, licensing, provenance, and update duties are treated as material risks.	Li et al. (2023); Olanrewaju et al. (2025)
Platform development stage	Assumed not to be greenfield, because the topic concerns integration across fragmented BIM, LCA, certification, and product-data systems.	Mitigation emphasizes integration of fragmented existing systems.	Li et al. (2023)
Certification target	Treated broadly as an assessment/certification interface, including Level(s)-type indicators and green building certification workflows.	Findings are framed around Level(s), DGNB-type logic, and general green-rating workflows discussed in the literature.	Parece et al. (2024); Xu et al. (2022)
Specific KPIs and deliverables	The report relies on generic BIM-LCA, WLC, and certification-risk evidence.	This report assesses generic project risk.	Parece et al. (2024); Parece et al. (2025)

BREEAM, as a certification system, significantly influences the methodological framework of digital WLC assessment by setting specific requirements for functional units, reference service life, and the scope of life cycle modules (A1-D) that must be included in a compliant WLC calculation (Del Rosario et al., 2021; Olanrewaju et al., 2024). This dictates how BIM and LCA data must be structured and exchanged to ensure the final output is certifiable and comparable to other projects, aligning the technical process with market demands (Zavadskas et al., 2010; Olanrewaju et al., 2024).

BREEAM serves as a comprehensive framework for multi-criteria assessment, enabling project teams to evaluate, document, and demonstrate that a building fulfills advanced environmental and energy performance standards. By integrating BIM with BREEAM protocols, stakeholders can automate the collection of whole-life cycle data, ensuring that sustainability targets are met from the design phase through to operation. This digitalization of the certification process reduces manual data entry errors and provides a transparent audit trail for environmental compliance (Marsh et al., 2023; Lenkeviius & Tamoaitiene, 2026).

Specifically, BREEAM protocols define the required data granularity and submission procedures for key Whole-Life Carbon (WLC) assessment stages, spanning from design optimization (A1–A3 modules) and construction quality checks to in-use performance monitoring (B modules), highlighting its role in digitalizing green building certification (Olanrewaju et al., 2024).

Beyond environmental metrics, BREEAM increasingly incorporates data related to occupant well-being and health. Modern smart sensor platforms allow for the real-time monitoring of indoor environmental quality, which can be directly linked to BREEAM credits for user comfort

and health. This integration of high-resolution energy and well-being data within a unified digital platform allows for a more holistic approach to building certification, ensuring that energy efficiency does not come at the expense of inhabitant health (Li et al., 2025).

Technical limitations and interoperability constraints remain among the most significant implementation challenges (Lenkevicius & Tamoaitiene, 2026). Recent reviews show that calculating carbon from 3D models still involves a lot of manual work and is often limited to specific software. While open standards help, they don't solve the basic problem: carbon data and building models were created for different reasons and were developed using different semantic structures and data logics (Karami et al., 2025). Consequently, researchers emphasise the importance of creating translation layers and standardizing labels first. In fact, studies on connecting product data to building models found twenty different technical gaps that still need to be fixed (Aragn et al., 2025).

Data quality is an additional critical challenge. Information in product databases is often inconsistent and lacks clear proof of where the numbers came from. Studies show that these documents often don't cover everything needed for major certification schemes like Level(s). Plus, it's hard to be certain about carbon levels during the early design stage—even though that's when we can save the most carbon. Research warns that giving precise numbers without explaining the uncertainty can lead to bad decisions (Feng et al., 2022; Olanrewaju et al., 2025).

There are also legal and management risks because these platforms involve people, not just computers. Studies on digital logs show that data is often duplicated or inconsistent, and there are rarely clear rules on how to share it. The most common questions are: who owns the data, who can change it, and who keeps it up to date? When different regions do their own thing, this further increases fragmentation across digital workflows (Mda et al., 2024).

The increasing automation of WLC data collection to meet BREEAM and similar certification requirements introduces a risk of over-reliance on automated calculations (Olanrewaju et al., 2024). This technological shift demands specific mitigation for the 'Human Factor' risk, as staff require specialized training not only in BIM-LCA tools but also in interpreting BREEAM's nuanced environmental and well-being criteria to avoid misapplication of automated results (Olanrewaju et al., 2024).

Finally, there are human and financial hurdles. Many industry stakeholders still lack sufficient technical training, and there often aren't enough financial reasons for smaller companies to switch to these new tools. A platform can have technically advanced platforms, but it will fail if it's too much work for users or if they don't trust the results. Security is also a concern; as construction goes digital, it becomes a bigger target for hackers. This means we need a culture of safety and good management, not just better IT (Železná et al., 2024).

3 Methodological basis and materials

The proposed risk management framework is designed for the modern data platforms that incorporate whole life carbon into building assessments, certifications, and information toolstopic, which focuses on advanced digital data platforms for integrating whole life carbon data into building information tools, assessment systems, and certification schemes. The main purpose of the framework is to support transparent, auditable, and technically consistent carbon-related decision-making across BIM-based design, LCA calculation, EPD data use, digital product passports, and certification workflows (Otero et al., 2023). The topic explicitly aims to increase the use of digital data exchange platforms and improve the reliability of EU-aligned life cycle inventory data for construction materials and products (see Figure 1).

Within the structured risk management package, BREEAM serves as the ultimate benchmark for the reliability of the entire data workflow (Olanrewaju et al., 2024). Achieving BREEAM certification for WLC requires that all risks—from incomplete BIM data (R1) to insufficient traceability (R10)—are managed to produce an audit-defensible calculation chain that proves compliance with stringent environmental and, increasingly, occupant well-being standards (Olanrewaju et al., 2024).

The framework begins by defining the project vision and whole-life carbon (WLC) objectives. Clear goals help align sustainability targets with project decision-making throughout the building lifecycle (Pomponi & Moncaster, 2016). The next stage establishes system boundaries, including life-cycle modules (A1-D), building type, and certification targets. These parameters strongly influence the consistency and comparability of LCA results (Finnveden et al., 2009). The framework then checks whether the scope, boundaries, and performance indicators are clearly

defined. This step reduces ambiguity and helps avoid methodological inconsistencies (Heijungs & Suh, 2002). If necessary, the process returns to refine indicators and data requirements.

Afterward, data sources and platform architecture are identified. The framework combines BIM models, EPD databases, IoT systems, digital building logbooks, and certification data to support interoperability between BIM, digital twins, and LCA platforms (Lu et al., 2020; Li et al., 2025; Kookalani et al., 2026).

The next step screens key risk categories, including data quality, interoperability, governance, methodological consistency, and user-related risks. These issues are critical in integrated digital construction systems (Sacks et al., 2018). Each risk is then assessed according to its probability and impact. This method helps prioritize the most significant threats within the project environment (Zou et al., 2007; Tamoaitien et al., 2021). The framework then evaluates whether the risk level is acceptable. If not, mitigation measures are introduced, such as data validation rules, IFC-based standards, version control, audit trails, compliance checks, and staff training (Hillson, 2002).

Validated WLC data are then integrated into BIM-based workflows (Zou et al., 2026). This improves data consistency and supports environmental impact analysis across the building lifecycle (Volk et al., 2014). The assessment stage generates outputs such as whole-life carbon results, scenario comparisons, certification evidence, and reporting dashboards, providing a basis for sustainable decision-making (Cabeza et al., 2014). The framework also verifies whether the results are transparent, traceable, and suitable for certification. Reliable documentation of data sources, assumptions, and calculations is essential for scientific validation and compliance with certification schemes (ISO 14044, 2006). If issues remain, assumptions and calculation logic are reviewed again (Hatefi et al., 2025).

Finally, the platform is deployed for monitoring, reporting, and continuous improvement during the operational phase of the building (Opoku et al., 2021). The outcome is a reliable WLC-based decision-support system for design, assessment, and certification processes (Dixit, 2019). So based on the model the risk management matrix for advanced WLC data platforms was established (see Table 2).

Each risk is assessed by likelihood and impact on a five-point scale, where the risk score is calculated as Likelihood x Impact. The highest-ranked risks are related to incomplete BIM model data, inaccurate or outdated EPD/LCI datasets, BIM–LCA interoperability limitations, insufficient traceability, and lack of user competence. These risks are consistent with the literature, which identifies data quality, interoperability, harmonised EPD formats, model granularity, and stakeholder capacity as recurring barriers in BIM-LCA implementation (Ghasemi et al., 2018; Teng et al., 2022; Almeida et al., 2023; Bolognesi et al., 2025).

The risk ranking in Table 2 is also relevant for certification-oriented use. Whole life carbon declarations require not only a calculated result, but also a defensible calculation chain, including the functional unit, reference service life, included life cycle modules, database version, EPD validity, and assumptions used in the model. Recent studies show that BIM-based LCA screening can support faster design decisions, while detailed external LCA validation remains necessary for final reporting and certification evidence (Guzar Dena et al., 2026).

Table 3 presents the 3×3 risk matrix, where likelihood and impact are grouped into low, medium, and high categories. This visual matrix helps identify priority areas for management attention. Risks located in the high-probability and high-impact zone require immediate mitigation, particularly those associated with missing BIM attributes, unreliable emission factors, inconsistent LCA boundaries, and weak platform interoperability. The matrix is useful for proposal-level risk communication because it translates technical BIM-LCA risks into a management-oriented decision format.

The inclusion of real-time data and IoT-related risks is justified by recent research showing that BIM-IoT platforms can support embodied carbon tracking and dynamic carbon monitoring. However, such systems also introduce additional risks related to sensor calibration, data security, real-time interpretation errors, and over-reliance on automated results. Therefore, the workflow in Table 1 and the controls in Table 2 include calibration, anomaly detection, access control, audit logs, and expert validation as key mitigation measures.

Overall, the tables form a structured risk management package for advanced whole life carbon data platforms. The workflow defines the process logic, the risk register defines specific threats and mitigation measures, and the 3×3 matrix supports prioritisation. Together, these tables provide a practical framework for managing technical, methodological, regulatory, in-

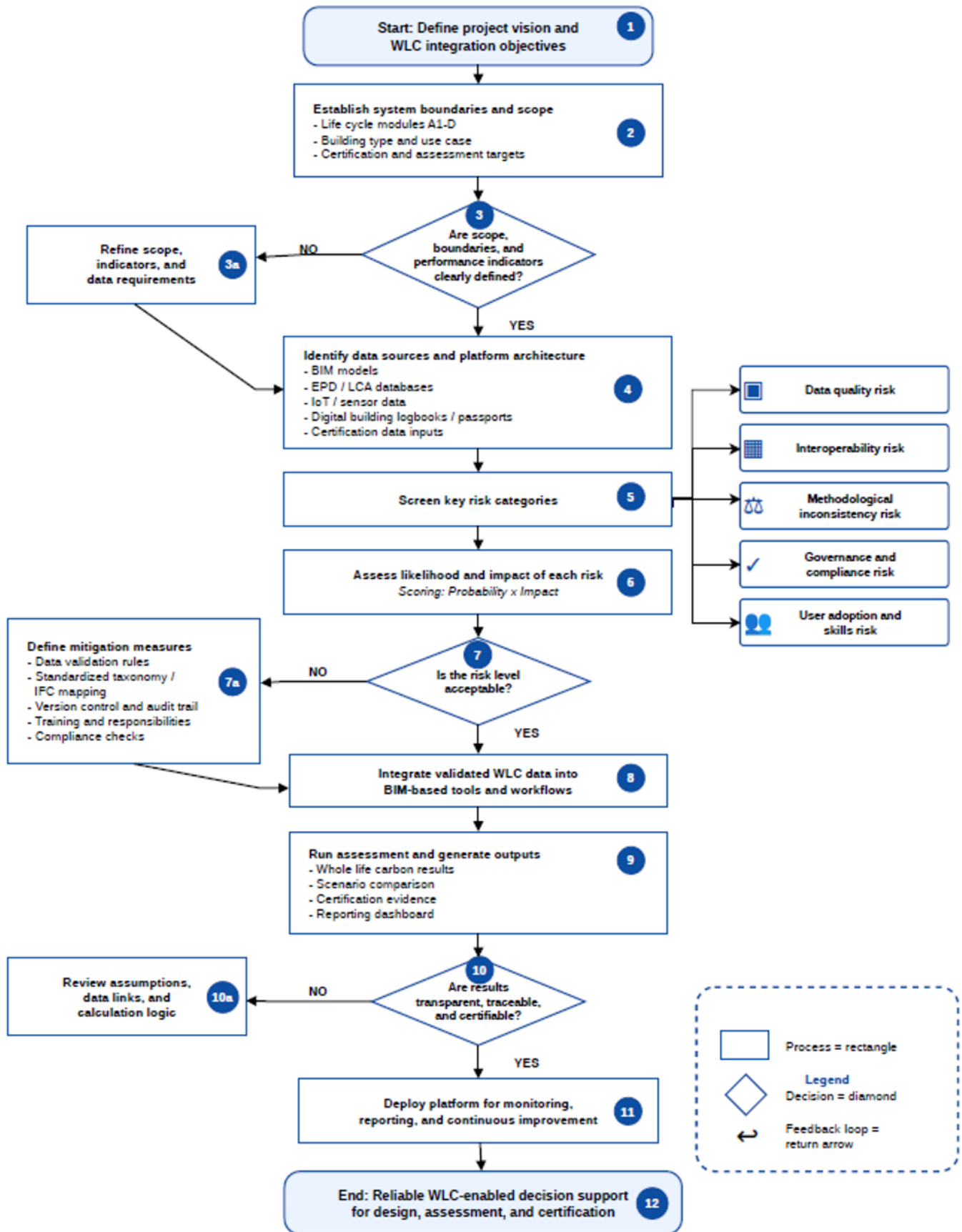


Figure 1 Risk assessment flowchart for advanced data platforms integrating whole life carbon into building information tools, assessments, and certification.

Table 2 Extended risk management matrix for advanced WLC data platforms

ID	Risk Description	Category	Lik. (1-5)	Imp. (1-5)	Risk Score	Risk Level	Mitigation Strategy	Owner	Evidence Basis	Reference
R1	Incomplete BIM model data	Data Quality	4	5	20	High	Validate LOIN, IDS, quantities, and carbon attributes before LCA export	BIM Coordinator	Missing BIM attributes distort GWP calculations	Ferreira et al. (2026)
R2	Outdated or inaccurate EPD / LCI data	Data Quality	4	5	20	High	Apply version-controlled databases and traceable emission factors	LCA Specialist	EPD/LCI inputs strongly affect carbon calculations	Li et al. (2023)
R5	Lack of BIM–LCA interoperability	Interoperability	4	4	16	High	Test IFC/API exchange and use mapping rules	BIM / LCA Specialist	Interoperability gaps reduce data reliability	Lima et al. (2024)
R7	Lack of user competence and acceptance	Human Factor	4	4	16	High	Provide role-based training and simplified workflows	Project Manager	Knowledge gaps limit platform adoption	Železná et al. (2024)
R14	Methodological gap between BREEAM credits and social targets in Materials and Methods	Methodology	4	4	16	High	Map BREEAM credits to UN SDGs	BIM Coordinator	BREEAM credits do not fully align with social sustainability targets	Adewumi et al. (2024)
R3	Inconsistent LCA system boundaries	Methodology	3	5	15	High	Align modules with EN 15978 and Level(s)	LCA Expert	Inconsistent boundaries reduce comparability	Železná et al. (2024)
R8	Regulatory uncertainty	Compliance	3	5	15	High	Monitor WLC requirements and maintain compliance logs	Compliance Officer	Evolving regulations increase uncertainty	Guzar Dena et al. (2026)
R10	Insufficient traceability of WLC results	Data Management	3	5	15	High	Maintain audit trails and version-controlled workflows	Data Manager	Poor traceability weakens certification reliability	Guzar Dena et al. (2026)
R15	Inadequate quantification of social targets in BREEAM certification	Certification	3	5	15	High	Apply social sustainability evaluation matrices	Certification Expert	Social impacts are often insufficiently assessed	Olanrewaju et al. (2025)
R4	Non-comparable certification results	Certification	3	4	12	Medium	Standardize functional units and validate across tools	Certification Expert	Different tools produce inconsistent outputs	Parece et al. (2024)
R6	Over-reliance on automated calculations	Process Control	3	4	12	Medium	Include expert review and sensitivity analysis	Project Team	Automated workflows still require validation	Guzar Dena et al. (2026)
R12	Platform misalignment with design and certification workflows	Adoption	3	4	12	Medium	Conduct pilot testing with certification processes	Product Owner	Workflow incompatibility reduces adoption	Lima et al. (2024)
R13	Lack of unified social sustainability definitions	Methodology	3	4	12	Medium	Standardize terminology through literature review	LCA Expert	Diverse frameworks create inconsistency	Dempsey et al. (2011)
R17	Non-actionable discussion findings due to resource-focused analysis	Process Control	3	4	12	Medium	Apply capability-based sustainability assessment	Product Owner	Resource-focused analysis limits practical applicability	Janssen and Basta (2022)
R9	Data security breaches	Security	2	5	10	Medium	Use encryption, access control, and audit logs	IT Manager	Security failures may affect certification audits	Zhao et al. (2026)
R11	Sensor and real-time data errors	IoT / Real-time Data	3	3	9	Medium	Implement calibration and anomaly detection plans	IoT Engineer	Sensor gaps reduce monitoring reliability	Xu et al. (2023)
R18	Failure to operationalize social sustainability in conclusions	Adoption	2	4	8	Medium	Develop practical operationalization models	Data Manager	Theoretical findings lack implementation value	Larimian and Sadeghi (2019)
R16	Stakeholder communication barriers in transdisciplinary collaboration	Human Factor	4	5	20	High	Implement a transdisciplinary stakeholder engagement framework	Project Manager	Lack of participation protocols limits collaboration efficiency	Larimian and Sadeghi (2019)

Table 3 Likelihood and impact 3 × 3 risk summary matrix

		Impact		
		Low	Medium	High
Probability	High	Low	Medium	High R1, R2, R5, R7, R14, R16
	Medium	Low	Medium R11	Medium R3, R4, R6, R8, R10, R12, R13, R15, R17
	Low	Low	Low	Low R9, R18

Note: Likelihood and Impact are grouped as Low = 1–2, Medium = 3, High = 4–5. Risk IDs are shown inside each cell.

teroperability, and adoption-related risks in BIM-enabled WLC assessment and certification environments.

4 Results

The risk assessment identified 18 valid risks related to the integration of whole-life carbon data into BIM-based tools, WLC/LCA data systems, assessment workflows, and certification processes. Each risk was assessed using the formula $S = \text{Likelihood} \times \text{Impact}$, where the final risk score was used to classify risks into high, medium, and low categories.

As presented in Figure 2, the mean risk score was 14.17, while the maximum individual risk score was 20. Out of the 18 risks, 10 risks were classified as high risks with scores of $S \geq 15$, and 8 risks were classified as medium risks with scores between $S = 8–14$.

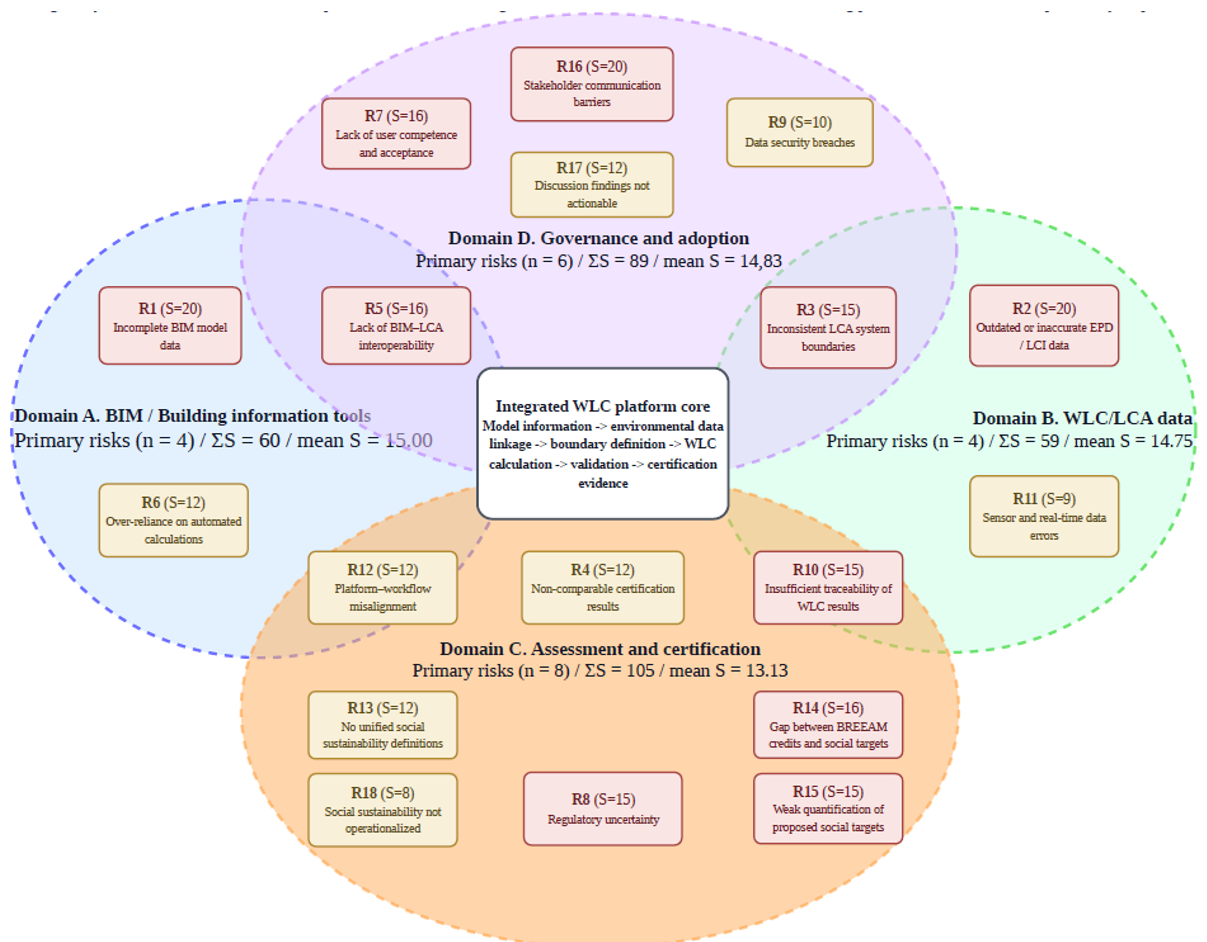


Figure 2 Quantified risk logic of advanced data platforms for integrating whole-life carbon into building information tools, assessment workflows, and certification systems.

The diagram in Figure 2 presents the distribution of risks across four interacting platform domains: BIM / building information tools, WLC / LCA data, assessment and certification, and

governance and adoption. According to the domain burden summary in the [Table 4](#):

Table 4 Distribution of risks across interacting platform domains

Domain	N (quantity)	Σ S (sum)	Mean S (average)
A. BIM tools	4	60	15.00
B. WLC / LCA data	4	59	14.75
C. Assessment / certification	8	105	13.13
D. Governance / adoption	6	89	14.83

5 Discussion and mitigation strategy

The findings indicate that the assessed WLC-BIM platform environment contains a high concentration of risks with medium and high impact. These findings align with earlier BIM-LCA integration studies on BIM-LCA integration, which report that data completeness, interoperability, classification mapping, and environmental data reliability remain persistent barriers in digital carbon assessment workflows ([Almeida et al., 2023](#); [Aragñ et al., 2025](#); [Parece et al., 2024](#); [Teng et al., 2022](#)).

R1, R2, R16 risks represent three different dimensions of platform reliability. R1 relates to the completeness and usability of BIM model information. If material layers, quantities, classifications, or object attributes are missing, the carbon assessment can be affected from the first stage of data extraction. R2 concerns the reliability of EPD and LCI datasets, which directly influence emission factors and WLC calculation outputs. R16 highlights the organisational side of the platform, where weak communication between stakeholders can reduce the effectiveness of even technically well-designed workflows. The distribution therefore shows that all identified risks had either medium or high potential impact within the assessed WLC-BIM platform context.

The domain-level results also indicate that risk is not concentrated in one isolated platform component. The assessment and certification domain suggests that certification-related evidence, comparability of results, reporting assumptions, and methodological consistency require particular attention. This aligns with studies showing that certification frameworks and whole-life carbon assessment require clear system boundaries, functional units, reference service life assumptions, and transparent evidence trails ([Olanrewaju et al., 2024](#); [Guzar Dena et al., 2026](#); [Olanrewaju et al., 2024](#)).

The BIM tools domain indicates that data quality is a critical technical dependency. A WLC platform can only produce reliable outputs if the model contains structured and verifiable information suitable for quantity extraction and environmental data mapping. This finding supports previous research arguing that BIM-LCA workflows require purpose-driven information requirements, model checking, classification alignment, and controlled exchange mechanisms ([Ferreira et al., 2026](#); [Olanrewaju et al., 2024](#); [Strelets et al., 2025](#)).

The probability-impact matrix further shows that several risks with medium likelihood still have high impact. This is relevant for mitigation planning because such risks may not occur in every project, but when they do occur, they may reduce the reliability and comparability of WLC outputs, traceability, or certification readiness. Therefore, mitigation should not focus only on the highest scores, but also on risks located in the medium probability / high impact zone.

Based on these findings, the mitigation strategy should follow the WLC data chain. First, BIM information requirements should be defined before calculation begins. This includes model granularity, material attributes, object classifications, and mandatory carbon-related parameters. Second, EPD and LCI data should be checked for validity, database version, regional relevance, and methodological consistency. Third, LCA system boundaries should be fixed before results are generated, including life-cycle modules, reference service life, functional units, and scenario assumptions. Finally, WLC results should be supported by audit trails, expert review, sensitivity checks, and certification-ready documentation.

Governance-related controls are also needed. Studies on digital building logbooks, BIM adoption, digital twins, and cybersecurity indicate that platform implementation depends on data ownership, user competence, access control, stakeholder trust, and long-term maintenance procedures ([Alonso et al., 2023](#); [Burgess et al., 2026](#); [Gmez-Gil et al., 2023](#); [Prn et al., 2024](#); [Seddiki & Bennadji, 2026](#); [Yao & Garca de Soto, 2024](#)). Therefore, the proposed workflow should

combine technical validation with organizational measures such as role-based responsibilities, user training, communication protocols, and periodic review of data quality.

6 Conclusion

This study assessed the main risks affecting advanced WLC–BIM data platforms designed to integrate whole-life carbon information into building information tools, assessment workflows, and certification systems. WLC–BIM platform reliability depends on the quality of the full data chain. BIM model completeness, environmental data validity, LCA boundary consistency, result traceability, and certification evidence all influence whether platform outputs can be considered reliable and defensible. The domain-based results further show that assessment and certification carry the largest cumulative risk burden, while BIM tools represent the strongest average technical dependency.

Overall, the study indicates that WLC platform implementation cannot be approached solely as a software automation problem. Reliable integration requires structured BIM information requirements, verified EPD / LCI data, transparent LCA assumptions, auditable workflows, and clear governance responsibilities. The proposed risk logic provides a framework for identifying and prioritising platform-level risks.

Future research should test the proposed risk framework in real project environments. Further studies could validate the risk scores through expert panels, apply the framework to different building types and certification schemes, and compare results across national regulatory contexts. Additional research is also needed to improve BIM–LCA data exchange, EPD-to–BIM mapping, digital building logbook integration, and quality assurance procedures for WLC reporting.

Conflicts of interest

The authors declare that they have no conflict of interest.

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