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Assessment of Digital Tools for Climate Change Mitigation in the Built Environment: Early Insights from IEA EBC Annex 89

Bernardette Soust-Verdaguer [1*], Maria Balouktsi [2], Alexander Hollberg[3], Thomas Lützkendorf[5]

[1] Departamento de Construcciones Arquitectónicas I, Escuela Técnica Superior de Arquitectura, Universidad de Sevilla, Spain
[2] Department of the Built Environment, Aalborg University, Denmark
[3] Department of Architecture and Civil Engineering, Chalmers University of Technology, Sweden
[4] Institute of Structural Design, Working Group Sustainable Construction, Graz University of Technology, Austria
[5] Karlsruhe Institute of Technology (KIT), Centre for Real Estate, Germany

* E-mail: bsoust@us.es

Abstract. In light of the urgent need for climate change mitigation in the construction and real estate sectors, it is crucial to implement effective measures that will drive meaningful progress. Digital tools that support the assessment of buildings' whole-life carbon emissions play a key role in this effort. However, the successful implementation of these tools relies on their effective and efficient use by various stakeholder groups, each of which has different decision-making needs and workflows. Notably, integrating diverse perspectives into tool quality and service, particularly those of users and developers, remains an under-explored area. This study presents key findings from an international survey conducted across participating countries as part of the IEA EBC Annex 89 project, which focuses on implementing net-zero whole-life carbon buildings. The survey, which is part of a broader set of Annex activities, maps existing tools and analyses aspects such as their capabilities (e.g. the environmental indicators assessed by the tool), information management (e.g. databases) and practical integration (e.g. the format of the data output). This paper presents the survey methodology and focuses on analysing a subset of the results in order to evaluate whether current tools meet the needs of stakeholders and address the challenges of integrating them into design and decision-making processes.

1. Introduction

The construction and real estate sectors – sometimes also called field of action "construction, maintenance and operation of buildings" - are among the leading sources of global greenhouse gas (GHG) emissions, making it a key area for climate change mitigation efforts (1). Achieving meaningful progress in this sector requires the adoption of effective strategies. In this regard, tools that help assess and influence the whole-life carbon (WLC) emissions – sometimes also called "life cycle global warming potential" - of buildings are particularly important.

The International Energy Agency's–Energy Building and Community (IEA-EBC) project, Annex 89 "Ways to Implement Net-zero Whole Life Carbon Buildings" (2) focuses on the pathways and actions needed by various stakeholders and decision-makers to implement whole life cycle-based net-zero GHG emissions from buildings in policy and practice. In this vein, the implementation of tools and aids to achieve these objectives remains relevant.

At present, a larger and fast-growing number of tools are in use worldwide to quantify and assess the GHG emissions of buildings throughout their life cycle (3,4). While these tools are essential to support the decarbonisation of the construction and real estate sector (2). However, their full potential remains untapped. This is due to a range of challenges such as variable accessibility, inconsistent stakeholder engagement, and insufficient integration into real-world decision-making workflows (5). Notably, current research (4,6,7) has overlooked the importance of incorporating the perspectives of both active users of tools and developers of software into the design and service quality of these tools.

Previous studies have addressed this topic (4–10), by analyzing existing tools using different approaches. For example, Säwén et al. (5) developed a meta-review of the literature evaluating tools for life cycle building performance assessment and from this field. They find that a practice-centric perspective is lacking in the available literature reviewing tools. The study concludes that tools should be assessed based on their use in real design processes within specific local contexts, rather than in hypothetical test cases. This finding underscores the need for evaluation frameworks that consider the perspective of the intended end users. Another study conducted by Säwén et al. (9) reviews thirteen life cycle assessment (LCA) tools using a characterization framework; however, it only includes tools with a connection to the parametric design software Grasshopper. Another relatively recent study by Karunaratne & Dharmarathna (4) focuses on the comparative assessment of nine software tools used for whole-building environmental LCA selected from scientific literature. Their analysis employed questionnaires to compare the data inputs, database, tool structure, output and results, as well as data analysis and interpretation. However, the study is limited in scope, both in the number of analysed software and its primary reliance on technical experts' perspectives, thus, without a broader stakeholder input base.

De Wolf et al. (10) establish a set of criteria to characterize software tools and databases, grouped into comprehensiveness, robustness, and operability, but focused only on tools and databases developed for the European context. On the whole, the field still lacks comprehensive and up-to-date analyses encompassing a large number of tools currently available on the global market, including those developed by local governments and scientific institutions, which are actively employed in current practice across different countries. To address these gaps, IEA-EBC Annex 89 (2) has launched a global survey amongst experts targeting both tool users and software developers within the participating countries and the broader network. Unlike previous studies, this survey intends to offer a wider scope and a more inclusive, multi-stakeholder perspective. The aim is to identify outstanding examples across various contexts, as well as analyse critical aspects of their performance in supporting WLC assessment, from different perspectives. To the authors' knowledge, this represents the most extensive global survey conducted on this topic recently.

2. Survey design and implementation

The survey aims to identify and assess digital tools used across different contexts worldwide, evaluating them against key criteria defined in previous research (5). The survey consisted of 45 questions, predominantly multiple choice. The scope of the survey was:

a) software-based technologies such as standalone software, CAD plug-ins, spreadsheet-based models, digital data collection tools and analytics,

b) tools intended for various stakeholders, including designers, engineers, building owners, policymakers, or educators,

c) open-source, commercial, or in-house tools,

d) tools for new construction, refurbishment/renovation, or education purposes for training of the next generation of design professionals, building owners, construction product manufacturers and other key stakeholders,

f) analysis levels ranging from building, component, to product level.

To collect responses effectively, an online questionnaire was developed using Microsoft Forms.

The survey was distributed among IEA-EBC Annex 89 participants (2) and through various channels to increase visibility, including mailing lists related to relevant tools. The questionnaire was administered in English. Data was collected between April 9 and June 24, 2025, yielding 35 responses to date. The questionnaire focused on two possible profiles: (a) active user of the tool and (b) developer of the software. The survey had five parts, as illustrated in Figure 1. The survey's objective is to capture perspectives from both respondent groups on overlapping and distinct issues. The viewpoints of the different stakeholders involved contrast to gaining a more comprehensive understanding of the subject matter. The color coding used in the graphics (section 3) corresponds to the specific topics addressed in the questionnaire.

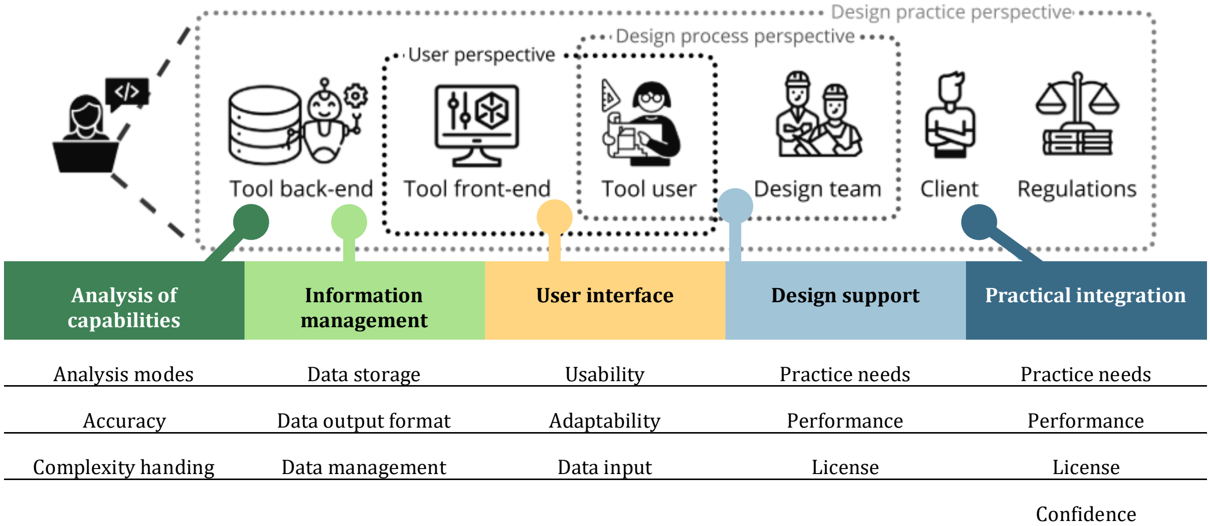

Figure 1. Main topics and subtopics addressed in the survey (adapted from (5)).

3. Results and discussion

3.1 Response rate and coverage

The total of 34 responses collected reflects a balanced distribution between the two target respondent profiles: 20 from tool developers and 14 from users. The tools reported originate from or have been applied in a diverse set of 15 countries. The "Country" column indicates either the respondent's location or the country where the tool was developed. The "Type" column specifies the format of the tool. "Accessibility" describes how users can access the tool, and "Target Users" identifies the intended audience for whom the tool is designed.

Table 1. Summary of the general information about the tools collected. Note: "E" = engineer; "D"= designer; "BO" = building owner; "P" = policymaker

Tool name	Country	Type	Accesibility	Target users	Respondent : user	Respondent: developer
BIM-ZEN	Spain	LCA plug-in in BIM	In-house tools	*D, E*	X	X
openLCA	Germany	Desktop-based	Free-to-use	*D, E*	X	
Pléiades LCA	France	Desktop-based	Free-to-use and commercial	*D, E*		X
LCAbyg	Denmark	Web application	Free-to-use	*D, E*		X
LCAlive	Denmark	Web application	Free-to-use	*D, E*		X
SIDAC	Brazil	Web platform	Free-to-use	*D, E*	X	
One Click LCA	Spain / México	Web application	commercial	*D, E*	X	X
CECarbon	Brazil	Web platform	Free-to-use	*D, E*	X	
GBDI Global Building Data Initiative.	Switzerland	Web platform	Free-to-use	*D, E*		X
SIA 390/1 Rechenhilfe	Switzerland	Excel sheet	Free-to-use	*D, E*	X	

LCA4G-SEED	Republic of Korea			*D, E*	X	
eLCA	Germany	Specific software	Free-to-use	*D, E*	X	
EnOB:LezBAU	Germany	Web application	Free-to-use	*D, E*	X	X
EVAMED	Mexico	Web application, LCA plug-in in BIM	Free-to-use	*D, E*		X
C.Scale	Switzerland	Web application	Free-to-use and commercial	*D, E*		X
2050 Materials	Switzerland	Web platform	commercial	*D, E*		X
LEGEP	Germany	Desktop-based	Commercial	*D, E*		X
Preoptima CONCEPT	United Kingdom	Desktop-based	Free-to-use	*D, E*		X
TOTEM	Belgium	Web platform	Free-to-use	*D, E*		X
Athena Impact Estimator	Canada	Desktop-based	Free-to-use	*D, E*	X	
Structural Element GWP Atlas	Germany	Comprehensive database	Free-to-use	*D, E*	X	
Reduzer	Norway	Web application	Free-to-use	*D, E*		X
Klimapfadfinder (IW.2050)	Germany	Excel sheet	Free-to-use	*BO, P*	X	
CEVEI	Uruguay	Excel sheet	Free-to-use	*D, E*	X	X
Tally	USA	Plug-in BIM	commercial	*D, E*	X	
CAALA	Germany	Plug-in of different BIM software	commercial	*D, E*		X
Czech national tool for simplified LCA	Czech Republic	web application;	Free to use	*D, E*		X
Vizcab	France	web application;plug-in of one software;	Freemium or pro	*D, E*		X
GREG - Graue Energie von Gebäuden	Switzerland	desktop-based	Annual fee	*D, E*		X
EcoTool	Switzerland	web application;	- Free Version - Pro Version (soon)	*D, E*		X

3.1 *Summary of selected responses*

The questionnaire includes several questions that are shared by both users and developers. This section presents a selection of nine key questions (paying attention to include both multiple-choice and open-ended ones), each belonging to one of the five broad topics (Figure 1) to highlight some of the main preliminary findings of the survey. The selection of questions analyzed in this paper is based on identifying the broader scope of tools' analysis to indicate some potential gaps in addressing full WLC and for various building types, how easy the tools are to use and how well they meet the needs and requirements for providing a consistent and representative evaluation. The questions presented are shown in Figure 2.

Analysis capabilities	Question I: Why are you using this tool? Question II: Which types of projects are supported by the tool? Question III: Can whole life carbon calculations or analyses be performed or does the tool focus on certain stages?
Information management	Question IV: What is the geographic scope covered by the data integrated (data representativeness)?
User interface	Question V a): Have you needed previous expertise to use the tool? Which type of experience was sufficient for starting using it? – question to users Question V b): Is previous expertise (e.g. training, courses, any expertise or previous experience) required by the user? – question to developers
Design support	Question VI: Is it possible to compare alternative designs inside the tool? Question VII: At which level is it possible to compare alternative designs?
Practical integration	Question VIII: Provide two examples of the most relevant attributes of the tool for your workflow. – question to users Question IX: What do you think are the two biggest challenges you are facing in your tool development? – question to developers

Figure 2. Selected questions included in this paper.

Analysis of capabilities: One of the most essential questions targeting users seeks to understand the motivations behind their choice to use the specific tool they reported, as well as to determine the assessment scopes being performed. The responses were diverse and broadly fell into two categories: the ones highlighting the tools' ability to adapt data or scenarios to specific contexts, and the ones focusing on the overall tool's suitability for assessing WLC impacts in buildings. The latter emerged as the most common reason, cited by over 50% of respondents (Figure 3).

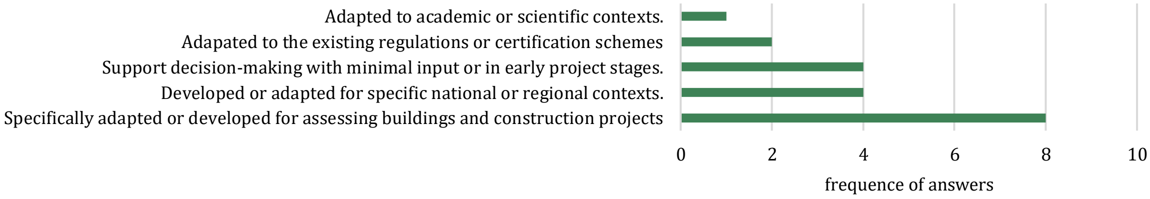

Figure 3. Summary of answers on why the users are using the tools (Question I).

When it comes to selected aspects of tools' coverage assessed in the survey, Figure 4 shows a primary focus on assessing new buildings, which reflects the current emphasis of many national and regional regulatory frameworks and certification schemes. This alignment is understandable, as new construction projects often serve as the starting point for implementing and testing emerging WLC assessment methods. However, a growing number of tools are beginning to accommodate renovation and refurbishment projects. This shift indicates a rising level of readiness to extend WLC methodologies to existing buildings, potentially paving the way for their inclusion in both voluntary frameworks and future regulatory requirements. The importance of renovation is particularly pronounced in regions with aging building stock like Europe, where upgrading existing structures is critical to meeting climate targets.

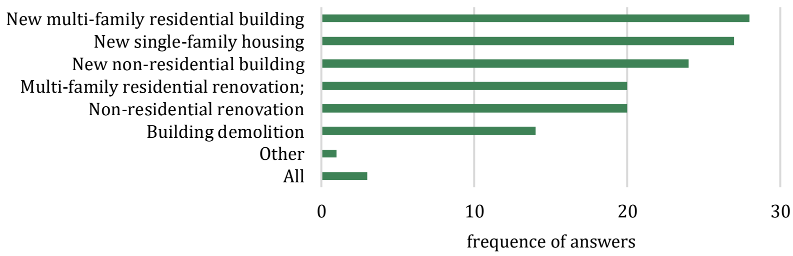

Figure 4. Answers about the type of project that can be assessed (users and developers, question II).

Regarding the covered life cycle stages (Figure 5), the results indicate that most tools still primarily focus on life cycle modules A1–A3 (production stage), and secondarily C3-4 (main end-of-life stage modules) assumingly largely due to the widespread availability of data from Environmental Product Declarations (EPDs) and established databases, which are structured around these modules. However, there is increasing recognition of the importance of including modules A4 and A5 (construction process stage) as they may significantly contribute to upfront carbon emissions depending on context. Despite this, relatively few tools provide detailed or flexible functionality for assessing these stages. The reason could be that these stages can be highly project-specific, depending on supply chains, construction methods, and logistics, and therefore require more contextualized data, which is not always readily supported by existing databases. Furthermore, coverage of embodied use-stage modules remains limited, except accounting for B4 (replacement), which is a combination of A and C modules. In general, expanding the scope of tools to a more comprehensive WLC assessment is key to improving the accuracy and relevance of assessments, particularly for long-term policy alignment towards more holistic carbon regulations.

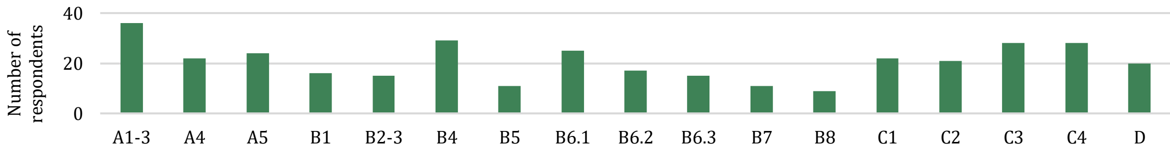

Figure 5. Answers about the scope of the assessment (users and developers, question III).

Information management: One specific question focused on the geographical scope of tool application (Figure 6). The most frequent answer for both users and developers was the national scope. This is reasonable as the development of LCA tools must include data that is representative of the location of the assessed building. Only a few tools were reported as having regional or international applicability. Understanding the tools' geographical coverage is essential, as the accuracy and relevance of the results heavily depend on the regional representativeness of input data (e.g., energy mix, transportation emissions, construction practices, and material availability). Whereas national tools may ensure greater alignment with local regulations and data, broader regional or international tools may offer greater flexibility and comparability across borders, an important feature for multinational stakeholders or cross-border benchmarking efforts with the precondition that data consistency is maintained across different regions.

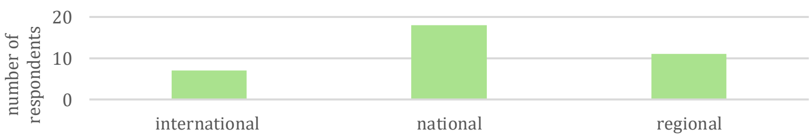

Figure 6. The geographical representativeness of the surveyed tools (users and developers, question IV).

User interface: Having low-threshold tools, i.e. those that are accessible to users with varying levels of expertise, is crucial for broadening the adoption and impact of WLC assessment. When tools are easy to use, they enable a wider range of stakeholders, including those without advanced technical backgrounds, to engage in assessments and decision-making processes. As shown in Figure 8a, most respondents indicated that they did not need a high level of expertise to use the tools reported. However, the most common response was that users still required some guidance, typically in the form of manuals or instructional videos. By contrast, Figure 8a reflects the developers' perspectives, suggesting that, in most cases, the tools are designed to require little or no prior expertise.

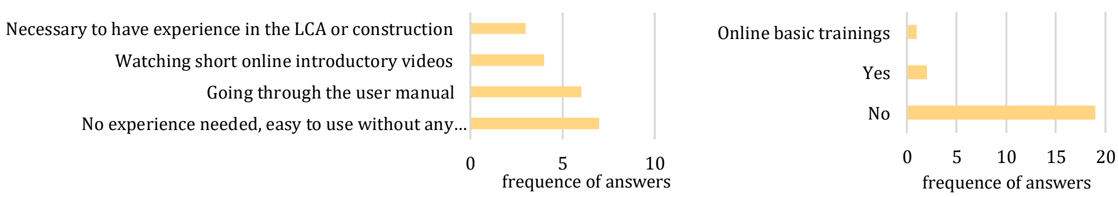

Figure 7 a) (left): level of expertise needed by users (Question Va); **b) (right):** level of expertise needed by developers (Question Vb).

Design support: How a tool supports decision-making and guides the user to make better decisions remains an important aspect to consider. Throughout the design process, there is often a dynamic interplay between creative, qualitative exploration and quantitative evaluation. Figure 8a includes the answers of users and developers to the question that focuses on detecting if it is possible to compare alternative designs inside the tool. Figure 8b provides a deep overview of the specific level at which this comparison can be conducted.

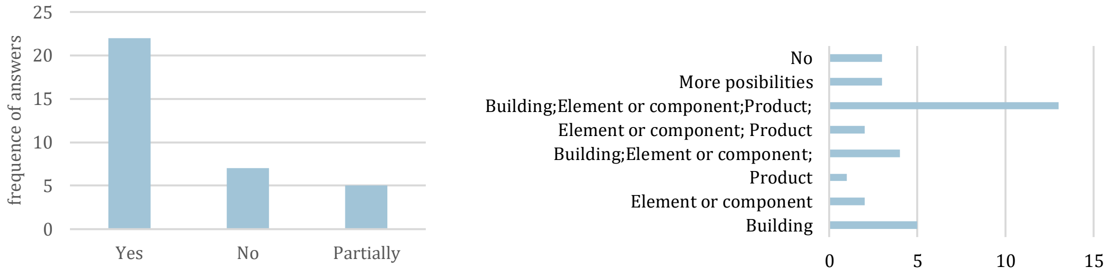

Figure 8: a) (left): Possibility of comparing alternative designs inside the surveyed tools (Question VI); **b) (right):** Level at which the comparison can be conducted (Question VII).

Practical integration: This section of the survey aims to assess the practical implementation of the tool, including the key stakeholders it targets, the areas where improvements are needed, and the benefits associated with its use. Figure 9 summarizes selected responses from users regarding the most relevant attributes of the tools within their workflow. The feedback highlights key aspects such as simplicity and ease of use, effective data visualization, as well as the fast evaluation and the use of predefined building elements as one of the most relevant attributes of the tools. Here, more than one type of attribute has been detected in the answers.

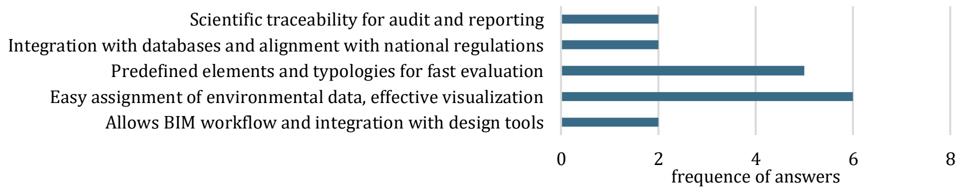

Figure 9. The most relevant attributes of the surveyed tools within the user's workflow (Question VIII).

From the side of developers, they were asked to indicate the two biggest challenges they are facing in the tool development. The answers show that the most important challenge to address remains the integration of the tools into the design process and current practice of professionals, as well as the simplification of the process involved in the evaluation (Figure 10 includes the main typologies of answers). Here, more than one option was possible to select by the respondent.

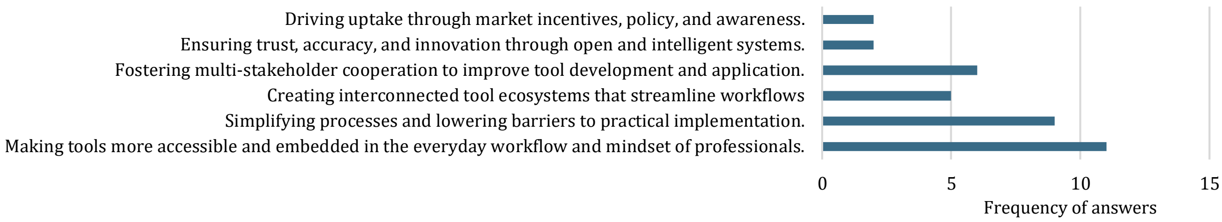

Figure 10. Summary of type of answers on the challenges detected by developers (Question IX).

4. Conclusions

The preliminary survey results reflect a diverse range of countries and varying levels of maturity in the practical implementation of tools supporting the Net-zero WLC Buildings and sectoral decarbonisation. Both users and developers of related tools highlight the simplicity of use and the effective understanding of results as important aspects. For users, these are among the most highly valued features, while for developers, they represent key challenges to address in the future. Notably, one of the most persistent challenges remains the integration of the WLC assessment processes in the construction and real estate sectors. The insights gathered on future challenges and desired tool attributes provide valuable guidance for future development and innovation. The survey will remain open in the coming months to gather additional responses and ensure its broader coverage. Efforts will also be made to maintain a balanced participation between users and developers, enabling direct comparison of responses from both profiles regarding the same tool. The extended dataset is also expected to support the identification of best practice examples and an improved classification of the tools collected.

5. Declaration of generative AI and AI-assisted technologies

During the preparation of this work, the authors used GPT-4 for supporting the grouping and summarizing of open-question answers, as well as for enhancing the language and clarity in selected parts. After using this tool, the author reviewed the generated results and corrected them accordingly. The authors edited the content as needed and hence take full responsibility for the publication's content.

6. Acknowledgements

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References

[1]. United Nations Environment Programme, Global Alliance for Buildings and Construction. Global Status Report for Buildings and Construction 2024/2025. 2025.
[2]. Passer A. (Operating Agent). IEA-EBC Annex 89. Ways to implementation of whole life cycle base net zero greenhouse. 2023.
[3]. Berges-Álvarez I. Integración de criterios ambientales y económicos en fases tempranas de diseño de edificaciones a través de Building Information Modeling [Magister Thesis]. Universidad del Bío-Bío, Chile; 2022.
[4]. Karunaratne S, Dharmarathna D. A review of comprehensiveness, user-friendliness, and contribution for sustainable design of whole building environmental life cycle assessment software tools. Build Environ [Internet]. 2022;212:108784. Available from: https://www.sciencedirect.com/science/article/pii/S0360132322000336
[5]. Säwén T, Kalagasidis AS, Hollberg A. Critical perspectives on life cycle building performance assessment tool reviews. Renewable and Sustainable Energy Reviews. 2024;197(114407). DOI: 10.1016/j.rser.2024.114407.
[6]. Arvizu-Piña VA, Armendáriz López JF, García González AA, Barrera Alarcón IG. An open access online tool for LCA in building's early design stage in the Latin American context. A screening LCA case study for a bioclimatic building. Energy Build. 2023;295:113269. DOI: 10.1016/j.enbuild.2023.113269.
[7]. Sartori T, Drogemuller R, Omrani S, Lamari F. International Survey of the Usage of Whole Building Life Cycle Assessment Software. Buildings. 2022;12(8).
[8]. Bari R Di, Horn R, Bruhn S, Alaux N, Ruschi Mendes Saade M, Soust-Verdaguer B, et al. Buildings LCA and digitalization: Designers' toolbox based on a survey. In: IOP Conference Series: Earth and Environmental Science, Volume 1078, sbe22 Berlin D-A-CH conference.
[9]. Säwén T, E Magnusson A, Kalagasidis S, Hollberg A. Tool characterisation framework for parametric building LCA. In: SBE BERLIN 2022. 2022. p. 12.
[10]. Wolf C De, Cordella M, Dodd N, Byers B, Donatello S. Whole life cycle environmental impact assessment of buildings: Developing software tool and database support for the EU framework Level(s). Resour Conserv Recycl. 2023;188(106642). DOI: 10.1016/j.resconrec.2022.106642