Buildings LCA and digitalization

Designers' toolbox based on a survey

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Buildings LCA and digitalization: Designers' toolbox based on a survey

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Abstract. In a context of digitalization and increasing quality requirements, the building sector is facing an increasing level of complexity regarding its design process. This results in a growing number of involved actors from different domains, a multitude of tasks to be completed and a higher degree of needed expertise. New buildings are also required to reach higher performances in terms of environmental quality. To that regard, the exploitation of the full potential of digital tools can facilitate the integration of environmental aspects in the planning process, limit productivity shortcomings and reduce environmental impacts, which can result from an unaware decision making. Building environmental assessment can be performed through several Life Cycle Assessment (LCA)-based tools. "Pure calculation" tools quantify final buildings' environmental potential, while "complex tools" additionally support decision making during the planning process. It is often difficult to choose the best suitable tool, which strongly depends on the user's needs. Within the IEA EBC Annex 72, a survey was realized with the main objective of creating a comprehensive overview of the existing tools dedicated to buildings LCA. The questionnaire included the usability, functionality, compliance, data reliability and interoperability of the analysed tools. Lastly, based on the survey outcomes and their critical assessment, a procedure for the identification and selection of a tool has been proposed based on user's needs. As a result, this work outlines main features of currently available building LCA tools, for which there is a harmonized status in terms of usability and overall applied LCA methodology. Despite the need for more automatized workflows, tools' embedding is mostly not yet applicable in system chains or limited to a restricted number of tools.

Keywords: Building; Digitalisation; Life Cycle Assessment; LCA Tools

1. Introduction and context

There is a common perception amongst practitioners that life cycle impacts must be considered during the design of a building [1]. The need to rely on environmental sustainability assessment already in the early design stages drives practitioners to a search for tools that might support the integration of environmental performance information into their typical workflows.

The International Energy Agency–Energy Building and Community (IEA- EBC), Annex 72 "Assessing Life Cycle Related Environmental Impacts Caused by Buildings" focuses on the subject of embodied impacts related to building products and the integration of the environmental assessment into production process. This in order to allow an improvement of building processes and products in terms of environmental performance as well as provided characteristics and information [2]. The Annex 72 – Activity 2 is especially targeted to designers and reports recommendations on building information handling and guidelines for the assessment of building life cycle environmental performance [2].

The survey performed by Balouktsi et al. showed how most architects and other stakeholders (more than 90% of respondents) are familiar with the environmental aspects and take them into account. However, in their current practice, only around 30 % are able to use Life Cycle Assessment as a tool for the environmental impact assessment [3].

Over other environmental assessment tools, Life Cycle Assessment (LCA) is an acknowledged methodology that has numerous benefits. This method can provide a systematic assessment of the environmental consequences of a product and the information is based on the newest scientific advancements. As stated also in ISO 14040 – 14044 [4, 5], LCA has a flexible nature, which let it open to developments. Lastly, it quantifies the effects of emissions into the air, water, and land at each stage of the life cycle, avoiding therefore a shift of burdens [4]. Especially in buildings, LCA is a time and labor consuming task. In a context of stricter environmental policies, LCA is however an expertise, which cannot be set aside in the planning process. The introduction of digital instruments proved to facilitate collaborative design processes, in which a variety of actors with diverse expertise are making decisions. In the field of LCA, digitalization and digital tools can be an instrument to overcome such barriers. Nevertheless, the use of tools and digital instruments can be functional only in presence of proper understanding of the environmental mechanisms and a thoughtful interpretation of results [6]. To ensure effectiveness, a tool should be deemed suitable over the building design process, by targeting the user-specific knowledge and by considering the different stakeholders' concerns. Accordingly, tools' developer must either offer a wide variety of tools, or work on products' scalability and flexibility[7, 8].

While the market is still open and building LCA tools are being further developed to meet such requirements, this work aims to provide a possible toolset for the design phase and to inform designers and stakeholders on the best tool(s) to choose from, according to their specific needs. After the establishment of a typology for LCA tools, different products were mapped through a survey dedicated to developers and users. The collected information serves as a basis for the setup of a procedure, which could help stakeholders to identify a suitable tool from the toolset.

2. Aids and Tools for Building LCA

The first part of this section provides a typology based on currently available instruments for building LCA. In the first subsection, Aids and Tools are defined and further specified. In the second part, a quality model for LCA tools is provided.

2.1. *Aids and Tool: Definitions and typology*

LCA databases represent the foundation for the evaluation of products' environmental impacts and are needed when calculating a building's embodied emissions. A various number of LCA databases exist nowadays, and it has also been proven that there is not a unique information source. Data in the databases vary from database to database because the modelled processes are based on the individual building product manufacturing characteristics [9]. As a common aspect, they collect lifecycle information and document it, by not allowing a lifecycle modelling of complex processes and materials. Therefore, in this work they are named *passive aids*.

The actual lifecycle modelling and environmental impact assessment often happens in a LCA calculation tool. LCA calculation tools are thus defined as *active tools*, in which the users provide entries and derive LCA results as an output. Active tools are here in turn distinguished in 2 main types:

- Pure calculation tools
- Complex planning tools

While pure calculation tools aim to provide LCA results in a retrospective way and without following the whole design process, complex planning tools are specific for the planning process and can be integrated into it. Complex planning tools can also be used for pure calculation (e.g. OneClick LCA, TOTEM or GENERIS). All active tools can also be: A) provided with environmental benchmarks and assessments or B) not provided (Figure 1).

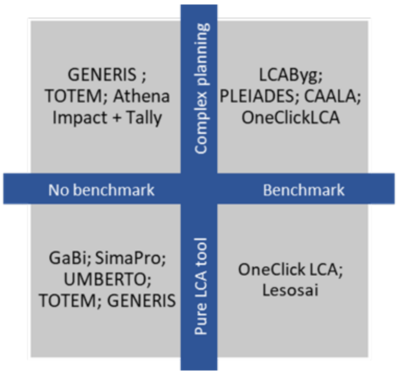

Figure 1. Active tools typology based on survey: examples of "complex planning" and "Pure LCA" tools. Tool provided and not provided with environmental benchmarks.

2.2. *LCA tool: a quality model*

When designers consider which LCA calculation tool is suitable, the following aspects should be considered: a) the designer's needs (intended application, design workflows, design requirements), and b) constraints (designer's LCA knowledge, environmental information availability) as well as the potential and limitations of a specific LCA tool.

For a better understanding and to make it easier for designers to choose between the various LCA active tools available on the market today, a mapping is necessary. For that purpose, a mapping-model has been established. Such a model is based on the previous work of Meex et al. [10] as well as quality model standards for system and software products [11]. With regard to the product quality model of ISO 25010 [11], five categories are considered and adapted for LCA:

- **Usability**, which means "the degree to which the LCA tool is able or fit to be used";
- **Functionality**, which means "the degree to which the LCA tool works well, is easy and convenient to use";
- **Reliability**, which means "the degree to which the result of a measurement, calculation, or specification in the LCA tool can be depended on to be accurate";
- **Interoperability**, which means "the LCA tool's ability to exchange and make use of information";
- **Conformity**, which means "the degree to which the LCA tool complies with standards".

3. Tool mapping from a survey

To obtain the necessary information for the assessment of available tools in a clear and transparent way, a survey was prepared and submitted to the free and open source online survey application

"LimeSurvey" [12]. 70 Tool providers, developers and users, inside and outside of the IEA EBC Annex 72, participated and submitted their questionnaires between May and September 2021.

To create a comprehensive overview of the existing LCA tools dedicated to buildings, 32 questions were prepared. Other activities and previous works already published within the Annex 72 were essential for the questionnaire preparation. IEA Annex 31" Energy Related Environmental Impact of Buildings" [8], investigated already LCA tools, focusing on, e.g., intended users, use cases, level of the analysis, and information needed for the evaluation of each building lifecycle stage. Hollberg et al. [6] provided insights on tools' results visualisation. Wastiels, Potrč Obrecht et al. [13, 14] described workflows for tools interoperability. The questions were divided in six sections, which equal the 5 abovementioned LCA tool quality categories, together with a general information (i.e. tool name and version).

Each question was developed in order to assess a quality category and, more specifically, quality subcategories. In Figure 2, on the right side of each section, quality sub categories are listed, according to ISO 25010 [11]. Each of them is afterwards associated to an abbreviation (e.g. Appropriateness recognisability (R)). On the left side of each section, the information asked through the question is presented. Each of them is then accompanied by respective sub categories (abbreviation).

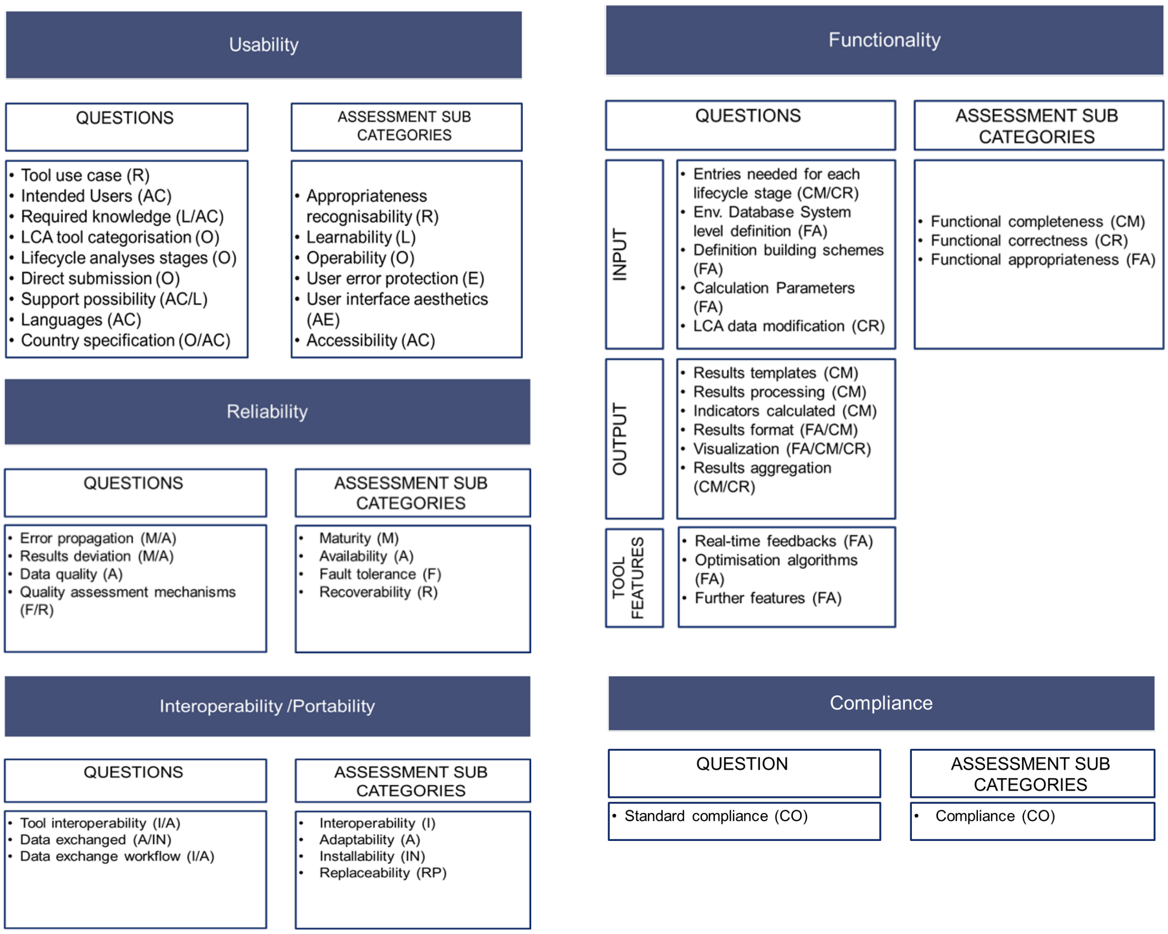

Figure 2. Structure of the questionnaire and assessment sub-categories based on [11].

After the survey's closure, the originally 70 collected answers were analysed, filtered and selected in order to avoid repetitions. When the same tool was presented more than once in the survey, the provided answers were analysed, inconsistencies were checked, and the information was merged. 25 tools were totally mapped. Even if the market offers a higher number of tools, which could theoretically still be investigated, the survey covered a significant group.

For the critical assessment of the results, the answers were finally counted and classified as:
A) **Harmonized** when there is an agreement/alignment on such issue;
B) Relevant issues **handled in different way** by tool developers;
C) Open issues for which there is an **improvement potential**.

4. Results

4.1. Survey outcomes
Some interesting insights (e.g. tool type, intended users, tool interoperability) of the questionnaire are reported in the Appendix, while a full outcome of the survey will be further published in the context of the IEA EBC Annex 72 activities.

The survey reported a harmonized status of the available tools in terms of *usability* and overall applied *LCA methodology*. All tools target similar intended applications, i.e. the assessment and/or comparison of buildings and building parts, environmental certification and improvement of building's environmental performance. Intended users are also similar, i.e. planners, sustainability consultants and authorities. In terms of LCA knowledge, pure calculation tools require a more advanced expertise level, while complex tools try to support more the user during the lifecycle modelling. Furthermore, the survey showed that there is a consensus on applying cradle-to-grave analyses, with few variations for tools that do not consider transport, construction processes, the whole building maintenance and renovation activities. There are tools that work on the building's energy simulation and therefore their focus is on the building operation. With regard to the calculated environmental indicators, there is a high level of harmonisation. Most of the tools are able to provide a Life Cycle Impact Assessment (LCIA) with the full set of core indicators according to the EN 15804 [15].

In terms of tools *functionality*, the survey recorded a higher variety in terms of requested inputs, provided templates, visualisation possibilities, results aggregation and tool features. More interesting is the difference between tools that allow *advanced features*, such as LCA data source modification, real-time feedbacks and optimisation algorithms. Such a difference lies on the tool maturity and the technical advancement. A similar outcome can be found in the *interoperability*. Most of the investigated tools allow data import and export from digital models but prefer working with Bill of Quantities and Spreadsheets. A tools' coupling is limited to a restricted group. In this respect, there are also differences in terms of automation levels and BIM-LCA coupling workflows.

4.2. Procedure for tools identification
Based on the considerations made in the previous section, a procedure for identifying a tool, which can satisfy specific designers' or users' needs, is here proposed.

The procedure consists in a systematic and pyramidal selection (Figure 3). Requests belonging to the lower part have higher priority for the tool identification process, but provide a low filtering. Requests on the higher part select the proper tool with a higher level of personalisation. Such requests are related to the survey outcomes that showed more differences and discrepancies.

a) **Use/User Identification**: the application and the intended user need to be targeted. The country of application can be declared in order to filter automatically tools with respective country-specific environmental databases. Furthermore, a language preference and LCA knowledge level can be optionally provided (Table 1).
b) **Tool type selection**: pure calculation or complex tools for the building assessment are chosen. A preference regarding benchmarks provision is given (Table 2).
c) **Tool features and user's preferences for building design**: this targets more advanced specific users' needs, such as provision of results during the early design stages, optimisation algorithms, and interoperability with digital planning or tool coupling possibilities (Table 4).
d) **Tool features and user's preferences for LCA**: where deemed useful for the potential user, preferences about deviation analyses and quality assessment mechanisms are asked (Table 5).

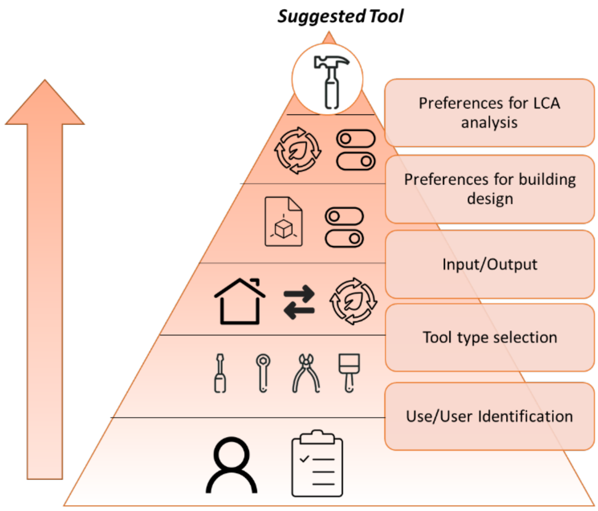

Figure 3. Procedure for the identification of a tool from toolset.

Here below, an exemplary application of the procedure is shown. With this first selection (Table 1-Table 2), it is possible to narrow down the tool search, but, according to the survey outcomes, this may still lead to different possible tools.

Table 1. Use and User identification based on developed procedure.

Request	Example
User Type	Designer
Preferred Tool Language(s)	English
Use case	Improvement of environmental performance
Country specification for use case	No
Suggested Tools	Pleiades; FCBS CARBON; GPR Building; CAALA; One Click LCA; SimaPro; PHribbon; LCAUS; BIMEELCA; TOTEM tool; Energy Plus; eQuest; Athena Impact + Tally; GENERIS

Table 2. Tool type selection based on developed procedure.

Request	Example
Calculation tool (Y/N)*	Y
Complex tool (Y/N)*	Y
With link to benchmarks? (Y/N)*	Y
Suggested Tools	Pleiades; CAALA; One Click LCA; PHribbon; BIMEELCA; Lesosai

*Y = Yes; N = No

Table 3. Tool's Input and Output preference based on developed procedure.

Request	Example
System level(s)	Building
LCA database	Environmental Product Declaration
Output for selected lifecycle stages	Template Report (.doc ; .pdf)
Results aggregation	Elements; Lifecycle stages aggregation
Suggested Tool(s)	Pleiades; CAALA; One Click LCA; Lesosai

The further selection (Table 3) provides a better picture of the needed tool. The last filtering allows selection with a unique tool that is suitable to all user's needs (Table 4-Table 5).

Table 4: Preference for building designers based on developed procedure.

Request	Example
BIM Coupling: Workflow for data exchanges	5 BIM object enrichment
Results provision during design early stages (Y/N)*	Y
Suggested Tool	Pleiades; Lesosai

*Y = Yes; N = No

Table 5: Advanced preferences for LCA analysis based on developed procedure.

Request	Example
LCA Deviation analysis (Y/N)*	Y
Quality assessment mechanisms for LCA (Y/N)*	N
Suggested Tool	Pleiades

*Y = Yes; N = No

5. Discussion and outlook

The survey on building LCA tools outlined features and aspects for which a harmonization has been mostly reached. However, certain challenges still remain. While previous investigations focused mostly on the general usability and functionalities [8, 16], the presented survey included additional aspects related to informatics advancement, such as optimisation algorithms or data exchange. This allowed for the deduction of a general LCA tool and an "ideal" next generation tool (Figure 4).

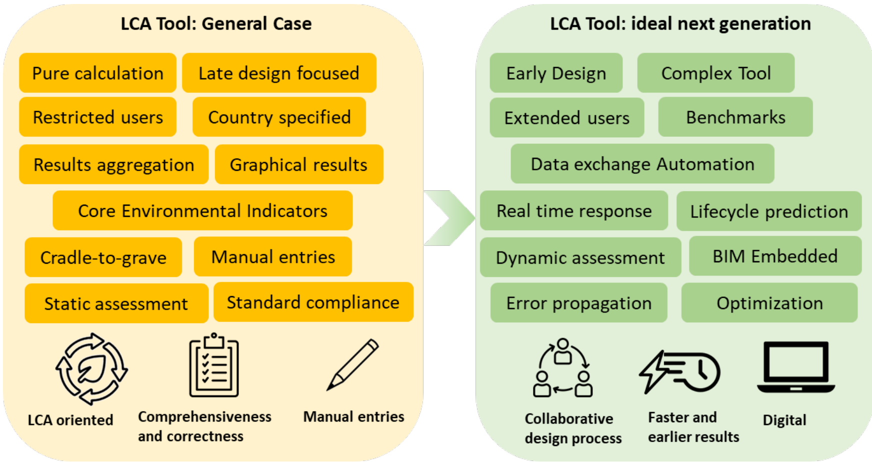

Figure 4: LCA Tools. Synthesis of "general" and "ideal" next generation tools.

In current LCA tools, the input of data is not automatized. A data exchange is possible between tools but users are usually requested to provide some entries manually, which may lead to re-entering data or possible errors [17]. Outputs are provided in form of reports, pre-formatted templates and with both numerical and graphical options. Results are aggregated in several ways, by considering different level of details or lifecycle stages. Bar charts and pie donuts are the most frequent visualization possibilities[6].

Advancements in tools entails the implementation of functions for earlier and faster evaluation of environmental profiles. These requirements are in line with the increasing collaborative design and digitalization in the building sector. Next-generation "ideal" tools should support more the early decision making. Consequently, the intended users should include all stakeholders involved in the building planning, even who may not have knowledge in the field of LCA to increase all stakeholders' awareness towards environmental quality. The usability of the LCA tools needs to be increased with consideration of more environmental information, i.e. including transport, construction processes and renovation/end-of-life scenarios. Tools' databases need to be extended with statistical records, in order to allow for benchmarks derivation. It is important to communicate variations and uncertainties on LCA analysis in a transparent way. This may be feasible with the implementation of results deviation and error propagation. As a next generation tool will be faster, it is also important to implement a real time feedback procedure and workflows with higher level of automation, e.g. plug-in or IFC object enrichment and import/export, as presented e.g. in Horn et al., 2020 [17]. Concluding, high efforts need to be addressed to BIM portability, which increases collaborations between the different fields.

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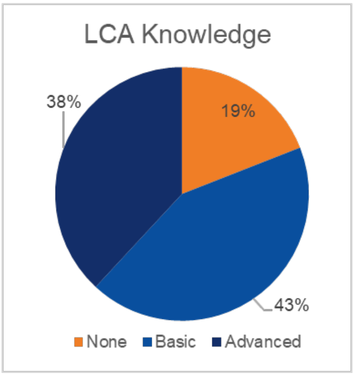
Appendix



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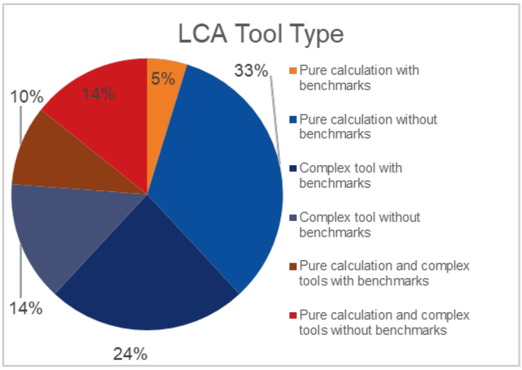

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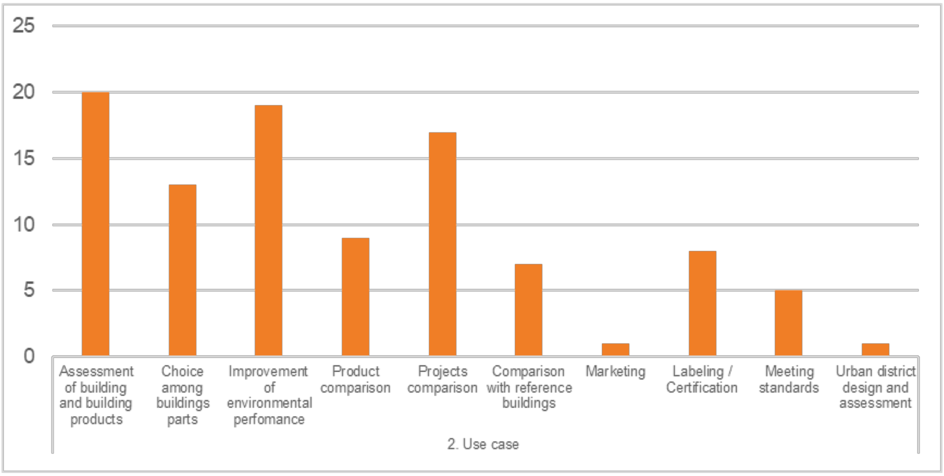

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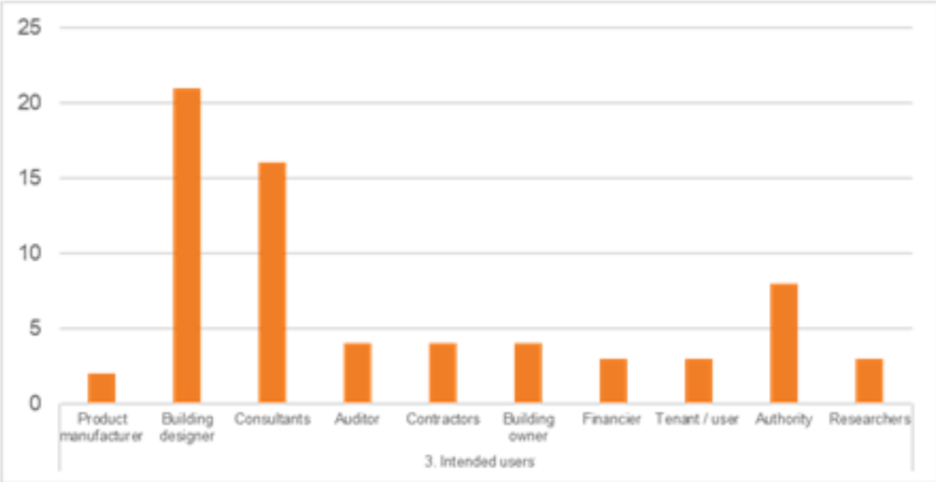
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Product manufacturer
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Auditor
Contractors
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Financier
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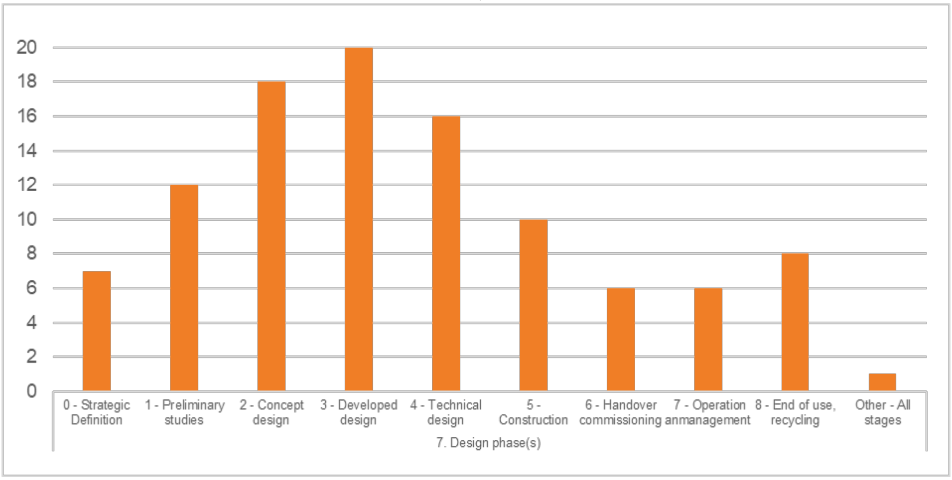
Researchers
3. Intended users

d)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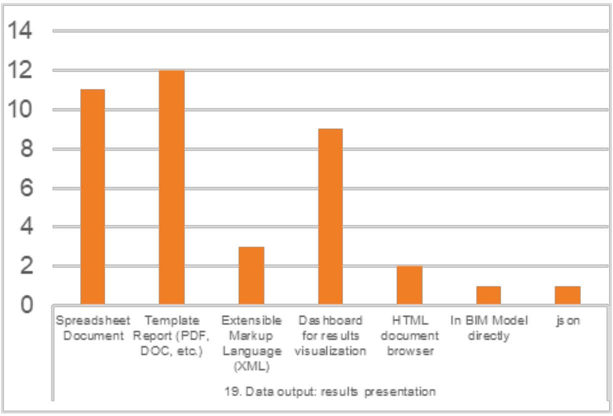
0 - Strategic Definition
1 - Preliminary studies
2 - Concept design
3 - Developed design
4 - Technical design
5 - Construction
6 - Handover commissioning
7 - Operation anmanagement
8 - End of use, recycling
Other - All stages
7. Design phase(s)

e)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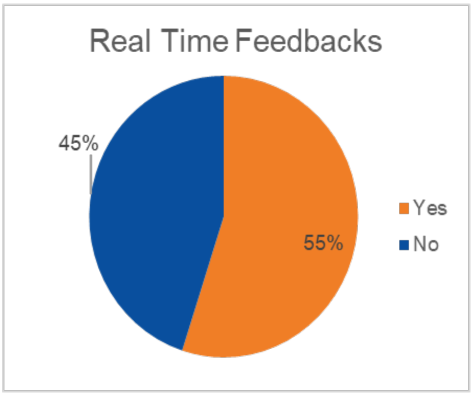
Spreadsheet Document
Template Report (PDF, DOC, etc.)
Extensible Markup Language (XML)
Dashboard for results visualization
HTML document browser
In BIM Model directly
json
19. Data output: results presentation

f)


Real Time Feedbacks
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55%
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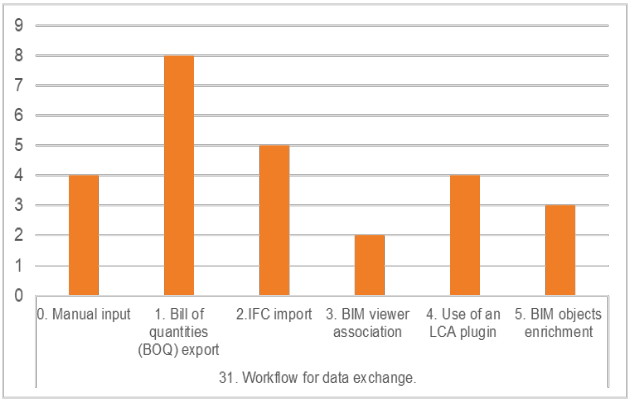
No

g)



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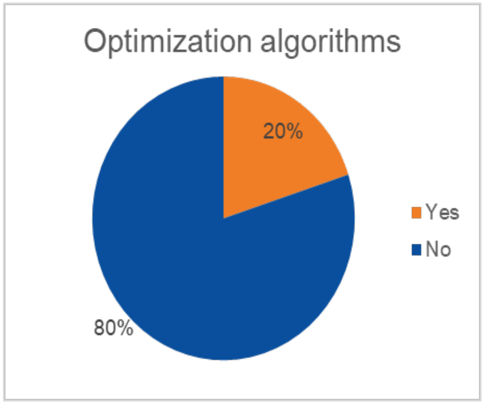

i)

Figure 5: Relevant outcomes from the survey regarding: **a)** required LCA knowledge; **b)** Tool types; **c)** intended use cases; **d)** intended users; **e)** design phases for tool application; **f)** Results file format; **g)** tool's real-time feedbacks; **h)** workflows applied for data exchange; **i)** optimization algorithms.