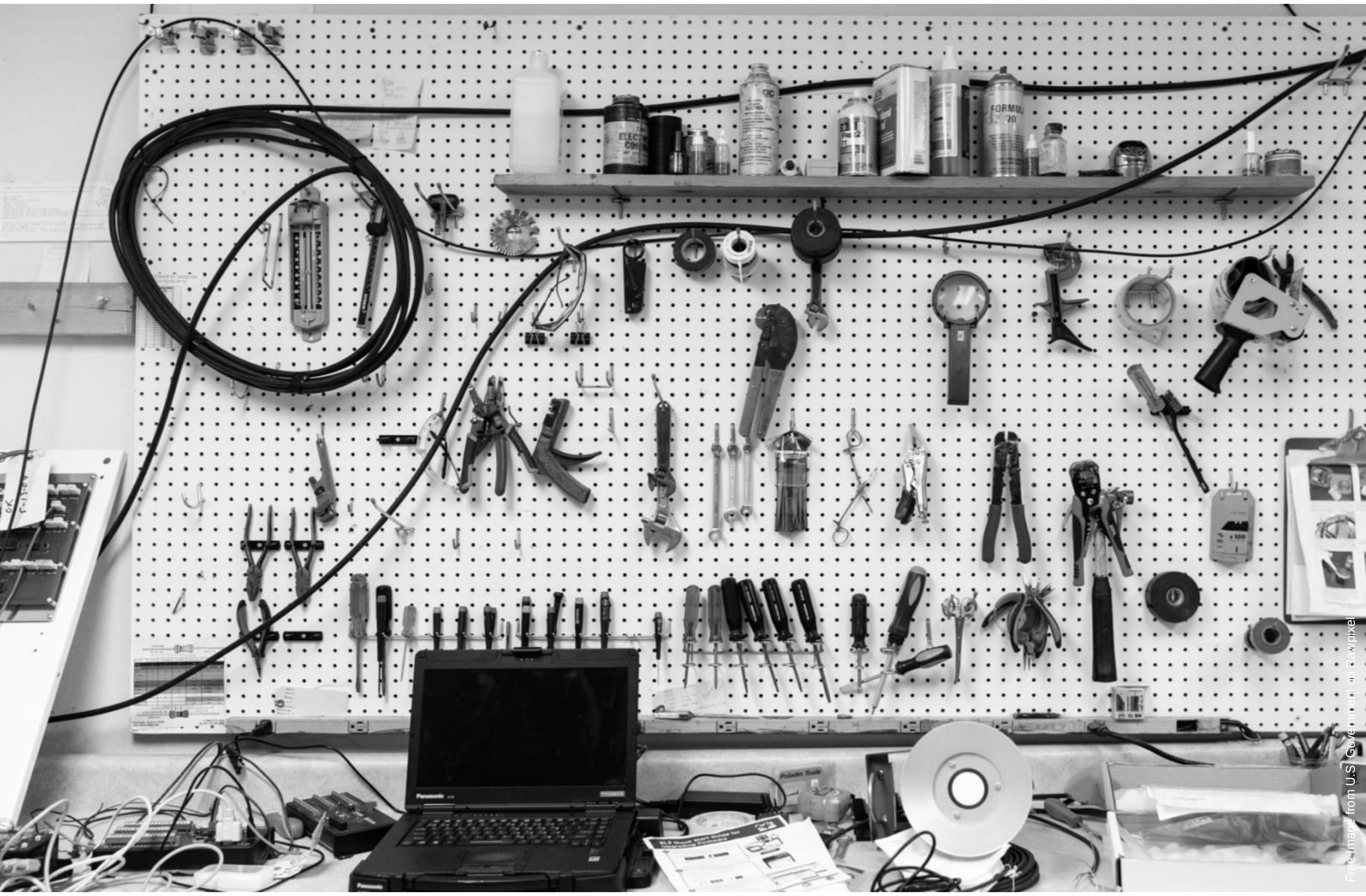
Designer's toolbox for Building LCA

A Contribution to IEA EBC Annex 72

April 2023



International Energy Agency

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Authors

Roberta Di Bari, Fraunhofer IBP, Germany (roberta.di.bari@ibp.fraunhofer.de)

Simone Bruhn, Aalborg Universitet København, Denmark

Rafael Horn, Fraunhofer IBP, German

Marcella R.M. Saade, Graz University of Technology, Austria

Regitze Kjær Zimmermann, Aalborg Universitet København, Denmark

Nicolas Alaux, Graz University of Technology, Austria

Alexander Passer, Graz University of Technology, Austria

Contributing Authors

Katrin Lenz, Fraunhofer IBP, Germany
Tajda Potrc Obrecht, Slovenian National Building and Civil Engineering Institute, Slovenia; Graz University of Technology, Austria
Bernardette Soust-Verdaguer, University of Seville, Spain
Alexander Hollberg, Chalmers University of Technology, Sweden
Harpa Birgisdottir, Aalborg Universitet København, Denmark

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Abbreviations and glossary

Abbreviations	Meaning
BIM	Building Information Modelling
BOM	Bill of Materials
BOQ	Bill of Quantities
EIA	Environmental Impact Assessment
GHG	Green House Gases
LCA	Life Cycle Assessment
LCC	Life Cycle Costs
LCI	Life Cycle Inventory
LOD	Level of Development
LOG	Level of Geometry
LOI	Level of Information
CAD	Computer Aided Design
CED	Cumulative energy demand
CO_2eq	CO_2 equivalent
EE	Embodied Energy
EOL	End of life
EPD	Environmental Product Declaration
GFA	Gross Floor Area
GWP	Global Warming Potential
IEA	International Energy Agency
IEA-EBC	Energy in Buildings and Communities Programme of the IEA
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LC	Life Cycle
LCIA	Life Cycle Impact Assessment
$LCCO_2$	Life Cycle CO_2 equivalent
NZEB	Nearly zero energy building or nearly zero emissions building
NRE	Non-Renewable Energy (fossil, nuclear, wood from primary forests)
NRPE	Non-Renewable Primary Energy
OECD	Organization for Economic Co-operation and Development
PE	Primary Energy
RSL	Reference Service Life
RSP	Reference Study Period
ZEB	Zero Energy Building
ZEH	Zero Energy House

ST1	Annex 72 Subtask 1: Harmonised methodology guidelines
ST2	Annex 72 Subtask 2: Building assessment workflows and tools
ST3	Annex 72 Subtask 3: Case studies
ST4	Annex 72 Subtask 4: Building sector LCA databases
ST5	Annex 72 Subtask 5: Dissemination

Term	Definition
CO_2 Intensity	The total CO_2 emission embodied, per unit of a product or per consumer price of a product. [kg CO_2eq /unit of product or price]
CO_2eq	CO_2 equivalent - a unit of measurement that is based on the relative impact of a given gas on global warming (the so-called global warming potential). [kg CO_2eq]
Contractor	Synonym: Service provider
Clients	Synonyms: financer, building owner, tenant, user
Cradle	Where building materials start their life
Cradle to Gate	This boundary includes only the production stage of the building. Processes taken into account are the extraction of raw materials, transport and manufacturing
Cradle to Site	Cradle to gate plus delivery to site of use.
Cradle to Handover	Cradle to site boundary plus the processes of construction and assembly on site
Cradle to End of Use	Cradle to handover boundary plus the processes of maintenance, repair, replacement and refurbishment, which constitute the recurrent energy. This boundary marks the end of first use of the building.
Cradle to Grave	Cradle to handover plus use stage, which includes the processes of maintenance, repair, replacement and refurbishment (production and installation of replacement products, disposal of replaced products) and the end-of-life stage, which includes the processes of demolition, transport, waste processing and disposal.
Embodied Energy	Embodied energy is the total amount of non-renewable primary energy required for all direct and indirect processes related to the creation of the building, its maintenance and end-of-life. In this sense, the forms of embodied energy consumption include the energy consumption for the initial stages, the recurrent processes and the end-of-life processes of the building. [MJ/reference unit/year of the RSP]
Embodied GHG emissions	Embodied GHG emissions is the cumulative quantity of greenhouse gases (CO_2, emissions methane, nitric oxide, and other global warming gases), which are produced during the direct and indirect processes related to the creation of the building, its maintenance and end-of-life. This is expressed as CO_2 equivalent that has the same greenhouse effect as the sum of GHG emissions. [kg-CO_2eq /reference unit/year of the RSP]
Energy Intensity	The total energy embodied, per unit of a product or per consumer price of a product. [MJ/unit of product or price]
Energy carrier	Substance or phenomenon that can be used to produce mechanical work or heat or to operate chemical or physical processes

Energy source	Source from which useful energy can be extracted or recovered either directly or by means of a conversion or transformation process
Gross Floor Area (GFA)	Gross Floor Area [m^2]. Total floor area inside the building external wall. GFA includes external wall but excludes roof. GFA is measured from the exterior surfaces of the outside walls.
Global Warming Potential (GWP)	A relative measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is measured against CO_2eq which has a GWP of 1. The time scale should be 100-year.
Greenhouse gases (GHG)	They are identified in different IPCC reports
Input and Output Tables	The Input-Output Tables are systematically present and clarify all the economic activities being performed in a single country, showing how goods and services produced by a certain industry in a given year are distributed among the industry itself, other industries, households, etc., and presenting the results in a matrix format.
Input and Output Analysis	The use of national economic and energy and CO2 data in a model to derive national average embodied energy/CO2 data in a comprehensive framework.
LCA	Life Cycle Assessment
PE_{nr}	Primary Energy non-renewable. Nuclear Energy is included.
PE_t	Primary Energy total. Renewable + Non-renewable Primary Energy. Nuclear Energy includes in the Primary Energy total.
Project commissioning	Synonyms: project commissioners, authority, policy makers
RSP	Reference Study Period. Period over which the time-dependent characteristics of the object of assessment are analysed (EN15978:2011)
Sustainability and certification expert	Synonyms: consultant, auditor

Summary

Introduction

The perception that life cycle impacts must be considered during the design of a building is common amongst practitioners (Roberts et al., 2020). The need to rely on Life Cycle Assessments (LCA) already in the early design stages drives practitioners to search for tools and data that might support the insertion of environmental performance information on their typical workflows (Nilsen and Bohne, 2019; Potrč Obrecht et al., 2020).

A survey performed within the activities of Subtask 1 showed that, generally, most architects and other stakeholders take environmental aspects into account (more than 90% of respondents), so almost all of them are familiar with the topic. The ones that actually rely on LCA, however, represent only 31% of respondents. 42% plan to use LCA in the medium term, and the remaining 27% do not plan to use it (Balouktsi et al., 2020).

In order to increase the number of design practitioners using LCA in their daily practice, two aspects must be addressed: (i) designers' basic knowledge about LCA and (ii) versatility and ease of use of building LCA tools. Regarding the former, the willingness to acquire knowledge to answer to the increased demand for buildings' environmental performance information will depend on design professionals themselves. A proper use of available tools requires a comprehension about the environmental mechanism measured by relevant indicators, which would allow the ability to interpret calculation results, and a good understanding of how design decisions influence the results (Balouktsi et al., 2020). The latter aspect, on the other hand, depends on the different goals of the tools' developers.

To ensure effectiveness, a tool must be tailored to the planning phase, the user's knowledge, and the concerns of the different stakeholders involved in the design process. Accordingly, either a wide variety of tools are needed, or each tool must be scalable and capable of adapting to the users' needs and knowledge (IEA-EBC, 2004; Millet et al., 2007). The focus of the report is to categorise available tools to make sure the designer can make an informed decision regarding what is (are) the best tool(s) to choose from, according to his or her specific needs.

Objectives

This document relates to activity 2.4 of Subtask 2. It aims to propose a categorisation for building LCA tools currently available for design decision makers.

While building tools number is raising and new products are under development, it is important to document and inform practitioners regarding the available features and options for LCA integration in typical designers' workflows. The report relies on the outcome of a questionnaire, which results are here presented. Within the survey, a group of current available tools participated. Even if the list of mapped tools is not exhaustive, based on this information, the survey activity allowed a building LCA tools' categorisation. The report is expected to help design practitioners in **selecting a building LCA tool** that would best fit their needs and their workflows, but also to provide an overview on **current general** and **ideal next generation tools**.

1. Tools and aids – a typology

LCA databases are used when evaluating the environmental impacts of specific building products, and it is therefore crucial when studying the environmental impact of a product. A various number of LCA databases exist nowadays, and it is acknowledged that the data in the databases varies from database to database because the modelled processes are based on the individual building product manufacturing characteristics (Takano et al., 2014)**Error! Reference source not found.**. A handful of the databases is being used as the underlying data basis in some LCA calculation tools (Soust-Verdaguer et al., 2017). Figure 1 illustrates a selection of databases used in building sector for LCA calculation.

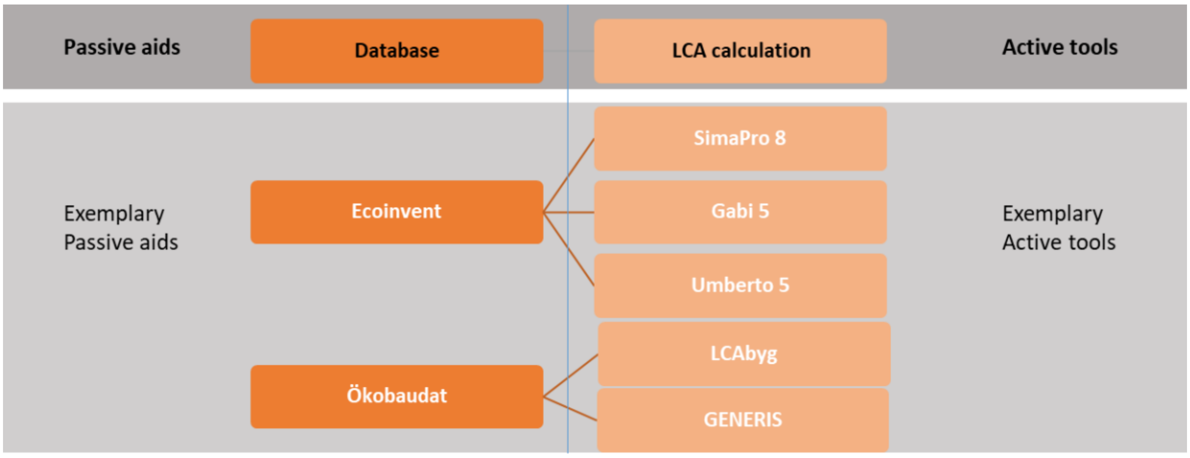


Figure 1 LCA databases used in LCA calculation tools. An example. **Error! Reference source not found.**

LCA databases are needed when calculating a building's embodied emissions. They however collect lifecycle information and document it, oftentimes not allowing the lifecycle modelling of complex processes and materials. Therefore, in this report they are claimed as **passive aids,** in which user is provided with lifecycle environmental information without performing a lifecycle modelling. The actual lifecycle modelling and environmental impact assessment often happens in a LCA calculation tool. LCA calculation tools are thus **active tools**, in which the user *actively* models buildings and buildings parts for deriving lifecycle information. Appropriate LCA calculation tools are needed to value the embodied GHG emissions not only, in a retrospective way, to assess the final environmental performance, but also, during the building design, for decision-making.

This report distinguishes between two main **tool types** (see Figure 2):

- **"pure" calculation tools,** which are specific for LCA calculation. They can equal generic LCA tools for any product (e.g. GaBi and SimaPro).
- **complex planning tools**, which are tools that can be incorporated into the design process or software, such as CAALA, OneClick LCA.

Complex planning tools can be aimed also for a pure calculation.

These are further subdivided into two more: A) **connected** or B) **not to benchmarks** and assessments (see Figure 2). Some LCA calculation tools include also benchmarks to make it easier and help designers to make more informed decisions. Examples of tools, which include benchmarks are Pleiades, CAALA and

OneClick LCA. For insights on building environmental benchmarking, the reader is while referred to Reports "Case study Collection" (Birgisdottir et al., 2023) and "Benchmarking and Target-setting for the Life Cycle-based Environmental Performance of Buildings" of this Annex (Lützkendorf et al., 2023).

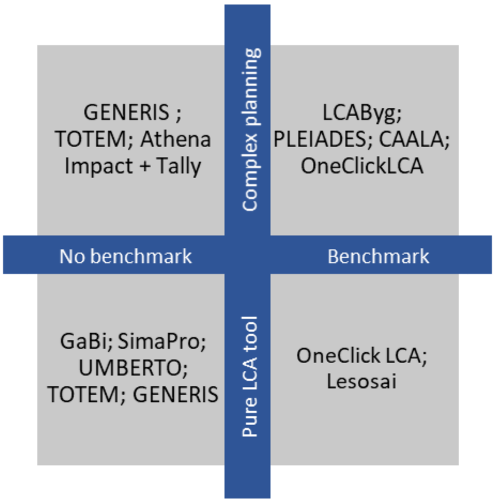


Figure 2 Mapping of the LCA calculation tools. E

When designers consider which LCA calculation tool is suitable for their needs, the following aspects should be considered (1) the designer's needs and constraints (2) the potential and limitations of a specific LCA tool**Error! Reference source not found.**. These factors are crucial when the designer choose the LCA calculation tool.

This report will focus on the selected tools listed in **Figure 3** and map the tools based on five categories, based on quality model standards for system and software products. The purpose of such a mapping is to make it easier for designers to choose between the various LCA calculation tools available on the market today. For a quality critical assessment, this report considers the quality categories, as here below defined and after described in the section 3.1. Definitions are based on ISO 25010 (International Standardisation Organisation, 2011) are adapted for LCA tools.

- **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 tools ability to exchange and make use of information"*
- **Conformity**, which means *"the degree to which the LCA tool compliance with standards"*.

Figure 3 Overview of the tools included in this report

2. Tools and aids examples

To obtain necessary information for the assessment of available tools in a clear and transparent way, a survey was prepared and submitted to tool providers and users. The main objective of the survey was to create a comprehensive overview of existing LCA software tools dedicated explicitly to buildings or building components and their features. The results have been further analysed, used for a critical assessment of the available tools regarding harmonized features and common issues.

Lastly, based on survey outcomes and their analysis, a procedure for tool identification depending on user needs and requirements will be proposed. The collected information can provide support to designers in the selection of the most appropriate tools for their specified use case and needs (see Figure 4).

Figure 4: Overview on provided activities and structure of the chapter

3.1 Methodology for investigating examples

The survey was conducted via the (free and open source) online survey application "Lime Survey" (LimeSurvey GmbH). It entailed 32 questions in six sections requesting:

- **general information,**
- **usability,**
- **functionality,**
- **reliability,**
- **interoperability and**
- **Conformity of the tool**.

The six sections refer to the five categories, as defined in Section 2, together with the **general information** (i.e., tool name and version), which is not a quality category.

A mix of different question types was used, such as dichotomous questions (with only yes or no as optional answers), open-ended questions, closed-ended questions or multiple-choice questions. Most of the questionnaire, i.e., functionality, reliability and interoperability would rather direct to tools' developers, which own the overview on tools features. However, it is also important to collect information from user's experience, especially in terms of tool's usability.

The questions were developed considering the evaluation framework for LCA-based EIA tools presented in Meex et al., 2018. Additionally, quality characteristics for evaluating the properties of a software product as described in ISO 25010 (International Standardisation Organisation, 2011) were taken into account.

The quality characteristics for evaluating the properties of a tool defined in ISO 25010 are represented by two quality models: the *quality in use model* and the *product quality model (International Standardisation Organisation, 2011)*. The models have a hierarchical structure subdividing some quality characteristics further into sub-characteristics.

The **quality in use model** is composed of five characteristics: effectiveness, efficiency, satisfaction, freedom from risk, and context coverage (Figure 5). These characteristics relate to the outcome of interaction in a particular context of use of the software product. The impact of the software product on stakeholders is described.

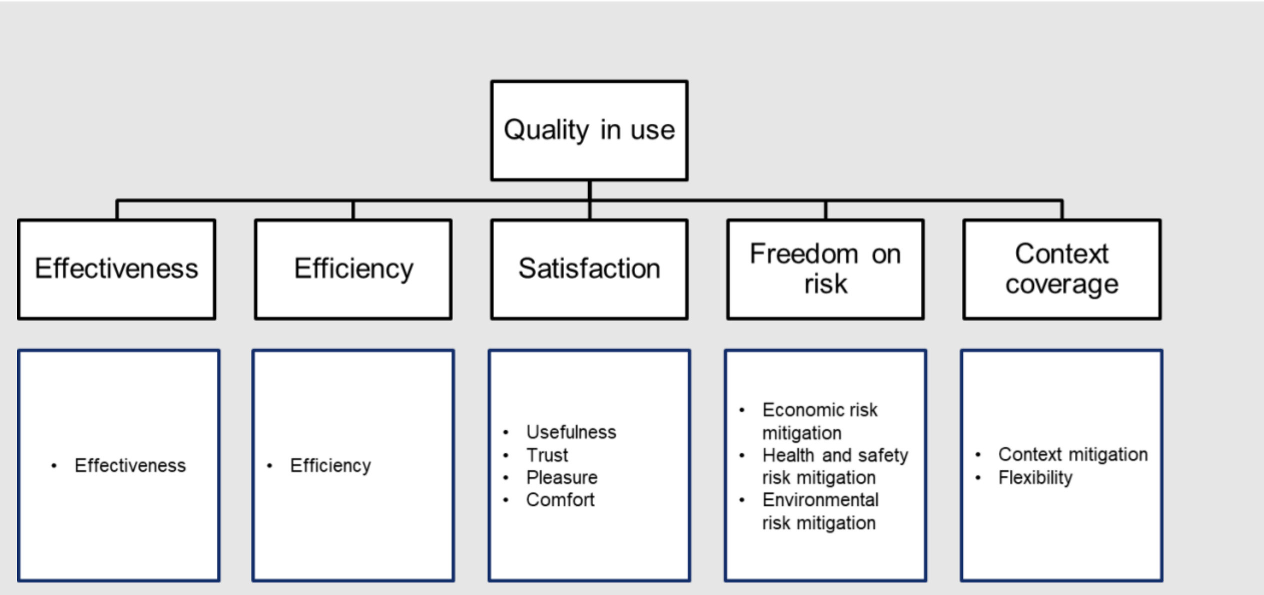


Figure 5 Quality in use model (based on ISO 25010:2011) (International Standardisation Organisation, 2011)

The **product quality model** includes eight quality characteristics: functional suitability, performance efficiency, compatibility, usability, reliability, security, maintainability and portability. These are further subdivided into sets of **sub-characteristics** (Figure 6).

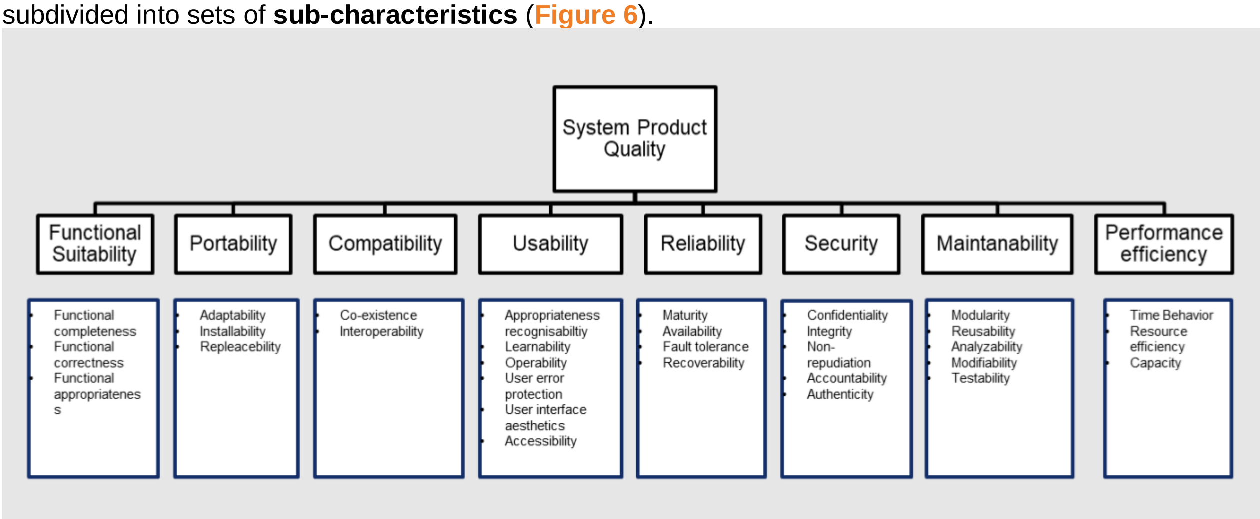


Figure 6 Product quality model (based on ISO 25010:2011) (International Standardisation Organisation, 2011)

Due to the goal of this Subtask in Annex 72 and the focus on the single tool, the quality assessment in use model was not considered in order to evaluate tools more in terms of features, functions and targeted user and applications.

With regard on product quality model, the six selected sections (general information, usability, functionality, reliability, interoperability and conformity) were selected for the survey (see Figure 7). **Usability** equals the definition in standard ISO 25010:2011. The **functionality** equals the functional suitability. Compatibility and portability characteristics are merged into the single **interoperability** characteristic. Differently, from abovementioned standard, **reliability** is defined here as "Reliability of the provided input and output". Lastly, **conformity** (with e.g., standards, guidelines) is considered.

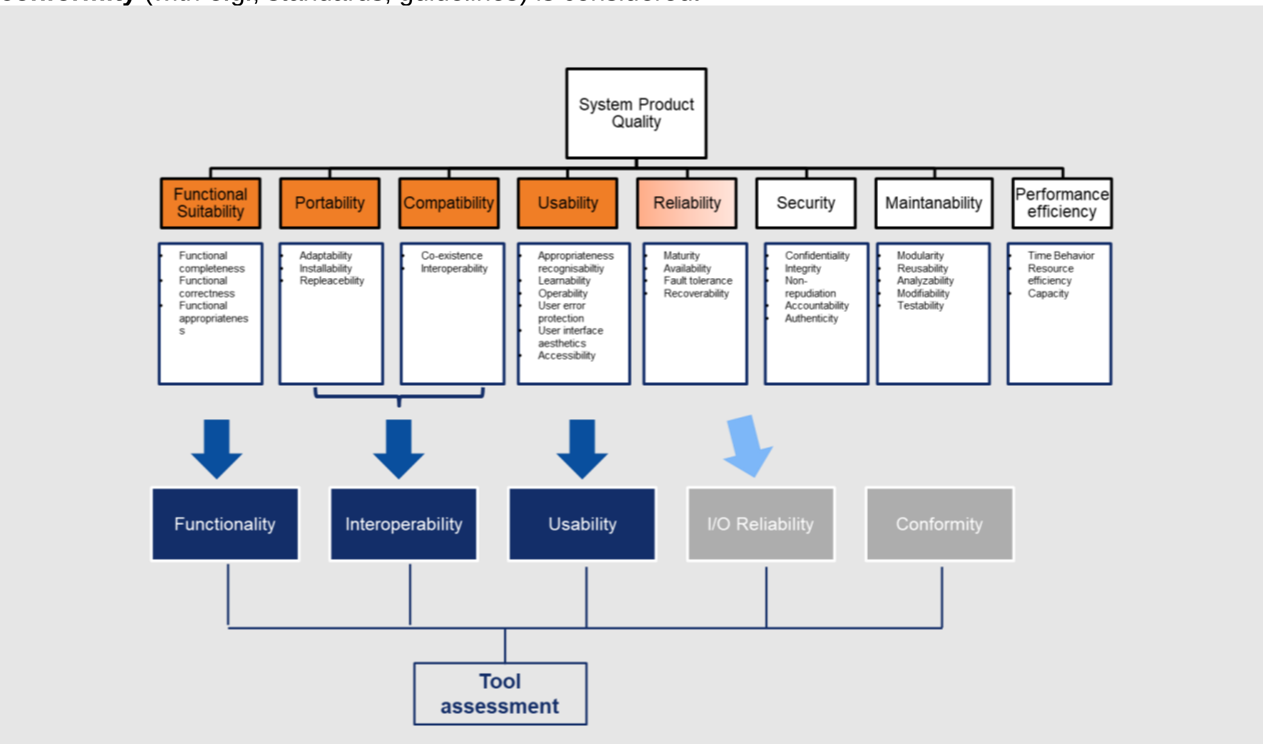


Figure 7: structure of the survey and assessment categories based on ISO 25010:2011 (International Standardisation Organisation, 2011)

Usability

In this section, the respondent was asked to provide information on the context of application. In Figure 8 are listed (on the left side) questions belonging to the "Usability" category. **Sub-categories** are listed on the right side and accompanied by an abbreviation, e.g., Operability (O). Questions in the survey allow the assessment of a specific subcategory. Therefore, each question is accompanied by the subcategory (-ies) (abbreviations) that can be potentially assessed.

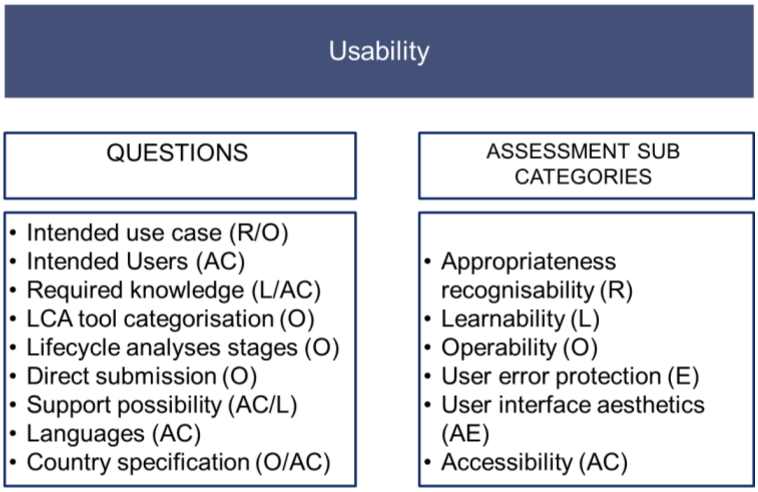


Figure 8: Structure of the survey and assessment categories based on ISO 25010:2011 – Usability section

First, the intended users (target group) should be specified. For example, the tool might be specifically designed to support architects in design phases or to aid LCA experts in the evaluation of a building after the design is completed. A list of intended use cases and users is provided based on the nomenclature of IEA Annex 31 (IEA-EBC, 2004). Please notice that, in the overall Building LCA tools can be addressed to a wider audience, which is not directly involved in the planning process. To get a comprehensive overview of all possible users and to not miss out any tools' target group, the survey included all potential tools users according to Annex 31 (IEA-EBC, 2004). With the intended use target, the questionnaire leads to the evaluation of tool recognisability and operability. By targeting the intended users, the survey evaluates tool accessibility. In this regard, intended use cases can be also outside the design process, e.g. marketing purposes. The questionnaire allows multiple choice, since many tool are targeted for several applications and users.

The list of intended uses based on IEA Annex 31 (IEA-EBC, 2004) entails:

- Assessment of products/building environmental profile
- Choice of products or technical solution
- Improvement of the overall environmental building performance
- Project comparisons
- Comparisons of building environmental profile with a provided reference building
- Marketing
- Labelling/certification
- Meeting standards.

The list of intended users based on IEA Annex 31 (IEA-EBC, 2004) entails:

- Authority
- Auditors
- Product manufacturers
- Building owners
- Building designers
- Consultants
- Financiers

- Tenants
- Researchers
- Service providers.

With the aim to further investigate the tool accessibility, the required level of LCA knowledge is indicated in a closed-ended question that allows respondents to choose between “none, basic or advanced” level of LCA knowledge from a dropdown-list. In this survey:

- "**None**" refers to no knowledge in LCA required,
- "**Basic**" refers to user with some experience in building LCA, and
- “**Advanced**" refers to users with expertise in LCA of building products and buildings. This question can furthermore identify the tool learnability and accessibility.

The tool operability is evaluated by indicating the tool type according to Section 2 and the planning phases, in which the tool can be applied.

The latter is carried out by a multiple choice question that refers to the intended phase(s) of application. The listed phases for selection are consistent with Annex 72 Subtask 2.1, who provided a generic definition of design steps and project phases:

1. Strategic definition
2. Preliminary studies
3. Concept design
4. Developed design
5. Technical design
6. Manufacturing and construction
7. Handover and commissioning
8. Operation and management
9. End of use, recycling

In case the listed design steps and project phases do not represent the intended/specific phase of application that is addressed with the tool, the respondent can add further phases (as a commentary).

The next question concerns the applicability of results delivered by the tool for certification purposes. For instance, the tool might be able to prepare results in a form that is demanded by a specific certification scheme. The tool reduces therefore time and effort for the user to request a certification. Direct submissions of LCA results increases in the final evaluation the tool operability.

Moreover, the respondent is asked to give information on available support options which increases tool learnability and accessibility. This multiple choice question can be answered by selecting one or more options: ***manual***, ***webinar***, ***tutorial***, ***FAQ*** and/or ***hotline***. Hereby, the respondent can specify other offered customer support.

The section on tool usability ends with questions on available languages and country specifications. Both questions are open-ended. The respondent should list the languages available in the tool. The question regarding country specifications aims at identifying the applicability of the tool across national borders and the ability to account for country specific conditions. For example a tool might be able to take into account national regulations, standards, databases or benchmarks. It should be specified whether these country specifications limit the use to only the respective country or whether they are optional (and the tool is generally designed for use across national borders). Both questions identify tool accessibility and operability (country-context operability).

Functionality

With the category functionality the tool input, output and further features for input and output are investigated (Figure 9). As previously, interrelations between questions and "Functionality" subcategories are presented.

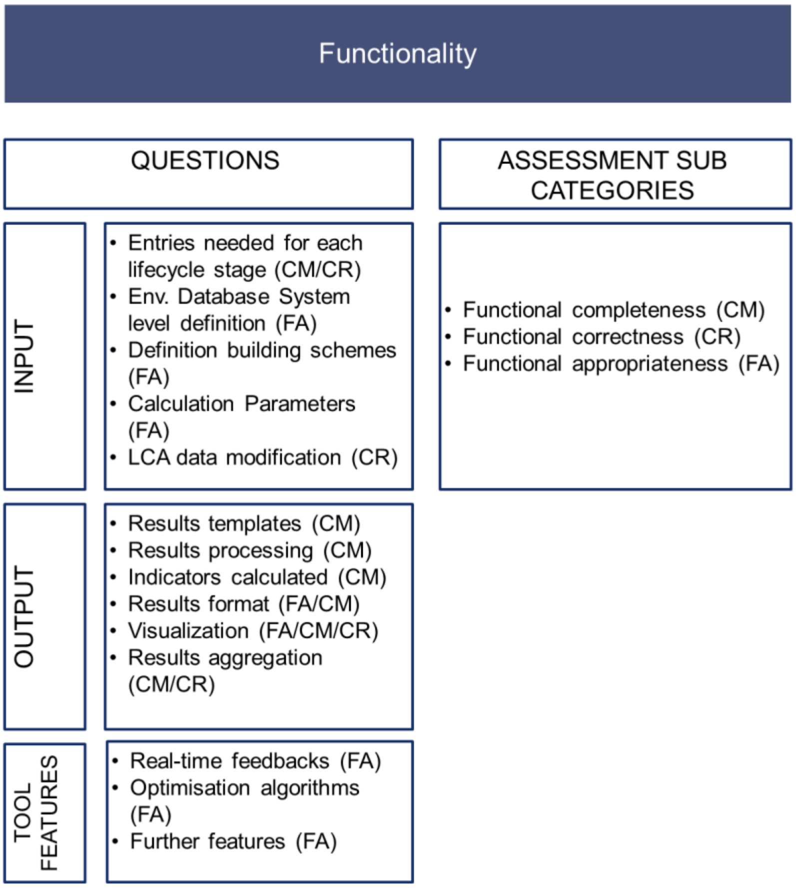


Figure 9: Structure of the survey and assessment categories based on ISO 25010:2011 – Functionality section

In a first instance, the **inputs** and all **required entries** are asked. According to IEA Annex 31 (IEA-EBC, 2004), entries for lifecycle analyses can vary in each lifecycle stage. The survey automatically identifies the considered lifecycle phases and for each of them prepare a list of standard entries. Requested inputs can influence the final completeness and correctness of the tool workflow and of results.

For phases, which entail building and construction elements productions (production phase, renovation and maintenance activities), the required entries can be represented by energy and mass flows. For renovation and maintenance, the tool may require the time interval for elements substitutions, building retrofit or refurbishment. The modelling of construction and erection activities occurs by providing average transport costs/extension and type and extent of building construction processes and use of machinery.

Building and urban systems operational phase requires information on energy performance, which can be provided manually, without any further aid systems with average energy calculations, by referring to building energy regulation, or carrying out energy simulation accounting climate context and daily variations. This information needs to be accompanied by source of necessary energy.

Lastly building end-of-life may require inputs on type and volume of building substances to be demolished, removed and/or destined to disposal, and the specification of recycling and re-use materials and systems.

Another topic, which influences tool functionality in terms of appropriateness, is the underlying data basis. Environmental databases and their version can affect the appropriateness of analysis in specific geographical/temporal contexts. All these issues need to be considered together with designers' need and requirements for building lifecycle analysis. Within the questionnaire, the main and mostly used environmental databases are listed. These encompass Environmental Product Declarations (EPD), which are product- and producers' specific, as well as generic databases, such as Ökobau.dat (building specific) and Ecoinvent and GaBi databases (not building specific).

Further inputs that can specify the LCA analyses are, e.g., characterization methods for the Life Cycle Impact Assessments (LCIA) and parameters for unit conversion. For instance, the user will be supported within the quantity calculation and unit conversions through conversion factors. The functional appropriateness and completeness can be thus increased.

LCA data sources can finally been modified, selected or complemented for a higher correctness of results. An example can be provided by tools, which derive or exploit statistical records for buildings and constructions. The provided inputs are in this case internally processed before the results generation.

The second part of the Functionality category investigates the **output provision**. In this regard, the questionnaire asks about the results data format (spreadsheet document, PDF, Extensible Markup Language - XML, dashboards, HTML document browser). This aspect may dictate user-friendliness and the required informatics knowledge for the tool utilisation, the immediacy of results provision and the visualization flexibility. Visualization possibilities in the context of building LCA is a widely discussed topic. Hollberg et al., 2021 and this Annex, Subtask 2.6 (see Background Report Subtask 2.6), carried out investigation on it. As a results, a list of possible visualisation charts and diagrams was generated. Each possibility must be connected to a specific analysis goal and investigation level. The here abovementioned issues influence the tool appropriateness as well as correctness and completeness of the provided results documentation.

The formal output investigations have been followed by the results contents, i.e., the presented environmental indicators. For many applications, e.g., building environmental certification, more than one single indicator is required, by increasing results completeness. Most of the tools provides core indicators according to European standards EN 15804 (European Commitee for Standardization, 2020).

Last part of the investigation analysed **tools features for design optimisation**. The questionnaire asks about real time feedbacks on design changes and use of optimisation algorithms for solutions suggestions, which enhance the functionality of the tool for proper purposes.

Reliability

As the complexity of models increases, issues on LCA results reliability arise. During recent years a range of tools presented improvement in terms reliability in LCA with the integration of approaches for data quality management, sensitivity and uncertainties analyses.

Such approaches aim to improve data quality and transparency, which in turns enhance the decision-making process. Among all issues related to data reliability, we can mention (Björklund, 2002):

- Data inaccuracy: empirical accuracy of measurements that are used to derive the numerical parameter values
- Data gaps: Missing parameter values in lifecycle modelling
- Unrepresentative data: Data gaps may be avoided by using unrepresentative data (Martínez-Rocamora et al., 2016), typically, data from similar processes, but of unrepresentative age, geographical origin, or technical performance.
- Model uncertainty: Model uncertainty is due to simplifications of aspects that cannot be modelled
- Uncertainty due to choices: Choices are unavoidable in LCA
- Spatial and temporal variability.

Even if such uncertainties can be reduced in a LCA study, some of them still can persist and, due to their effects on LCA results, cannot be neglected. They can involve LCA inventory, which relies on imperfect data, in addition to further uncertainties created by the assessment process itself. It is necessary therefore to evaluate the effects that data and process uncertainty have on the LCA results. Applications of methods coming from statistics, e.g. Bayesian or Monte Carlo Simulation, proved to be effective strategies to track and measure the propagation of uncertainties (Raynolds et al., 1999). Insights on LCA Uncertainties are available in the Background Report 2.3 of this Annex.

Based on such considerations, within the questionnaire asked about possibility of the inclusion of results deviation with sensitivity analysis or uncertainties analysis. When an uncertainties analysis occurs, error propagation possibilities are asked (Figure 10).

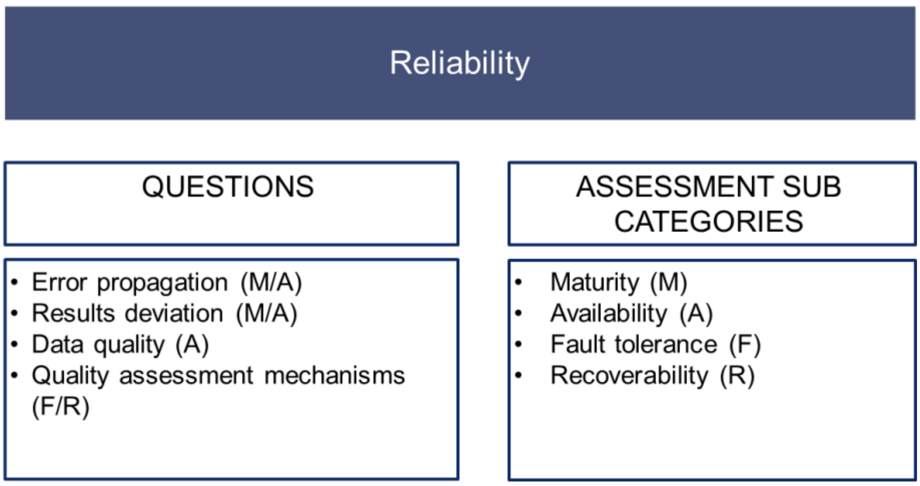


Figure 10: Structure of the survey and assessment categories based on ISO 25010:2011 – Reliability section

Following, data quality is investigated. The participant can declare the data quality (none, regional, verifies, independent) of the tool.

Finally quality assessment mechanisms are asked, e.g., automatic quality check of the information entered for LCA study or certification submission.

Interoperability

An increasing degree of digitalization in construction planning offers significant potential for building life cycle assessment: it reduces the efforts related to data collection as well as barriers (Figure 11). European countries are asked to require and apply digital instruments, especially in the context of public works (European Parlament, 2014).

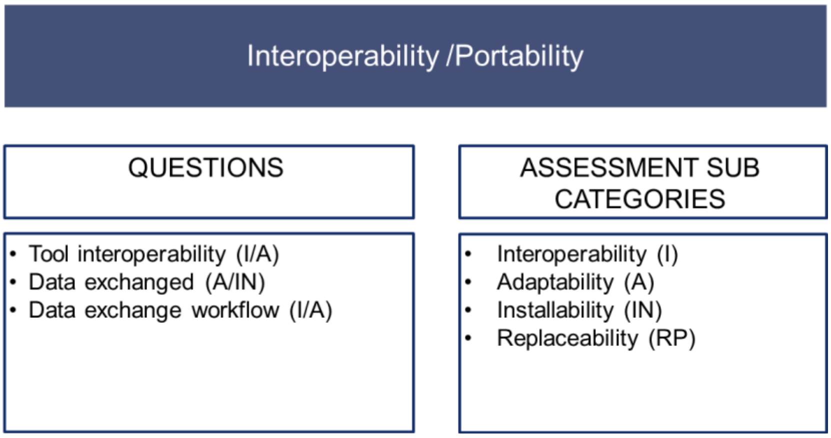


Figure 11: Structure of the survey and assessment categories based on ISO 25010:2011 – Interoperability/Portability section

In the context of the digital planning, BIM is a widely applied and promising workflow in the building sector that aims to enable the collaboration of all involved actors in the planning and design process, through providing accessibility for all, to one single digital building model (European Construction Sector Observatory, 2021; European Parliament, 2014; Horn et al., 2020).

In this sense, the integration of environmental assessment into BIM or any digital integrated planning process or design tool, gained attention. This integration process is also inclined to become continuously more complex resulting in the need for standardization and harmonization of approaches. The application of standardized formats for data exchange enables interoperability throughout the planning and design process and aids the challenge of integrating LCA with BIM through space for implementing environmental impacts information in the overall data structure.

Wastiels and Decuypere, 2019 provided a comprehensive classification scheme of the current strategies and workflows for the interoperability between digital models and LCA tools. Insights on digital workflows for design process are while presented in the background report of this Annex, Subtask 2.5.

Due to the relevance of the topic, the questionnaire includes a section for the investigation of tool interoperability with other tools. Compatibility with other design tools is asked. When this occurs with a specific software, the participant can specify which file format can be exchanged (IFC, gbXML, etc.). This helps the investigation on the tool adaptability. The more tools can be interoperable and the more file can be easy to adapt, the more tools are adaptable and can be installed in different interfaces). As a next step, this portability should be described in detail, particularly with regard to the underlying workflow, by referring to the classification of Wastiels and Decuypere, 2019.

Conformity

The last section of the questionnaire is dedicated to the compliance of the surveyed tool with standards, (International Organization for Standardization, 2006a, 2006b), LCA guidelines and other specific building assessment frameworks (e.g. Level(s) in the European context).

3.2 Overview on tools described by experts

The survey started on the 3rd May and was concluded at the end of September 2021. The collected answers were originally 70 and were analysed, filtered and afterwards selected in order to collect comprehensive results and avoid repetitions. Whereas the same tool was presented more the once in the survey, the provided answers were analysed, in order to check answer inconsistencies, and merged. All results and documentation of the survey can be found in the attached Annex.

As a result, the following tools were investigated.

List of investigated tools

- PLEIADES
- FCBS CARBON
- TOTEM
- GPR Buildings
- CAALA
- LCAbyg
- OneClick LCA
- SimaPRO
- Lesosai
- PHribbon
- GENERIS
- Greg
- BIMELCA
- The ZEB tool
- LCA US
- Enerweb
- Energy Plus; eQuest +Tally
- Athena Impact
- SBToolCZ,
- Envimat
- Sphera GaBi

Usability

Intended Use

Most of the analyzed tools aim to assess product and building environmental performance and improve it. Highly relevant for the final decision-making process is the comparison of products, constructions and projects as well. When the comparison is carried out with a reference building, the tool allows to meet more easily standards. Survey participants declared marketing use case only for the tool “SBToolCZ” (Figure 12).

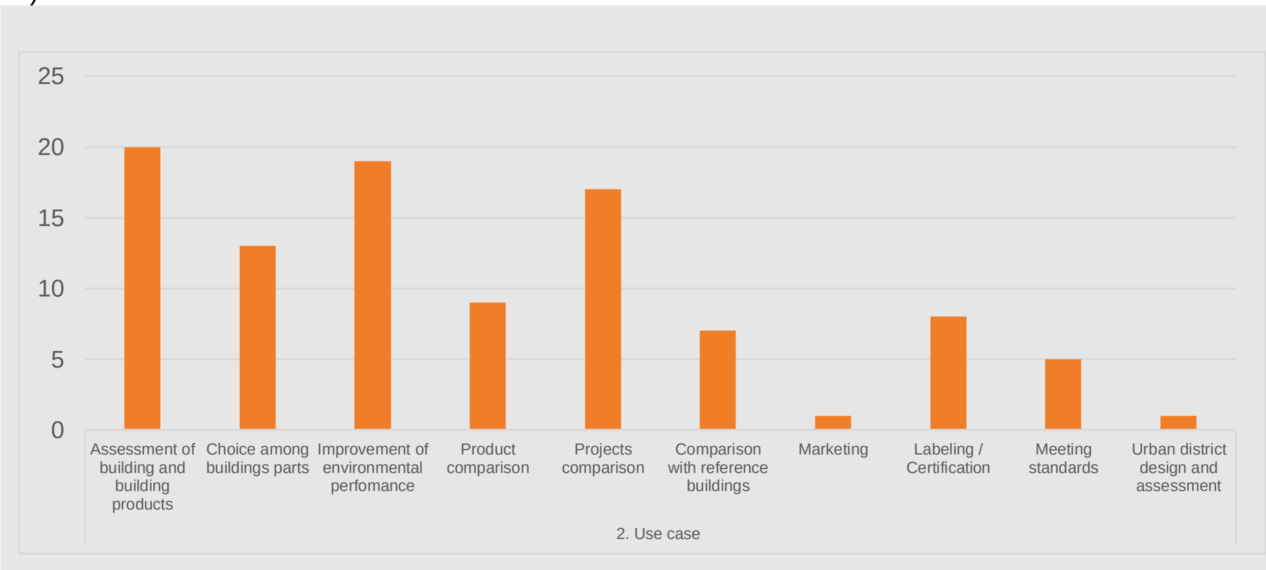


Figure 12: Survey outcomes. Question 2 on intended use case.

Users and Users' Knowledge

In the overall, all tools are intended to be used by building designer or sustainability consultants. Especially in the context of building certification and standards, tools can be used by authority such as auditors. Users belonging to the group of product manufactures, building owners, financiers, tenants and service providers and not prioritized but however included in up to 4 examples (Figure 13). For a proper use of the analyzed tools a basic knowledge in field of LCA is required (Figure 14). However, there are tools (19%), which are easy-to-understand also for an audience, who does not have experience in LCA.

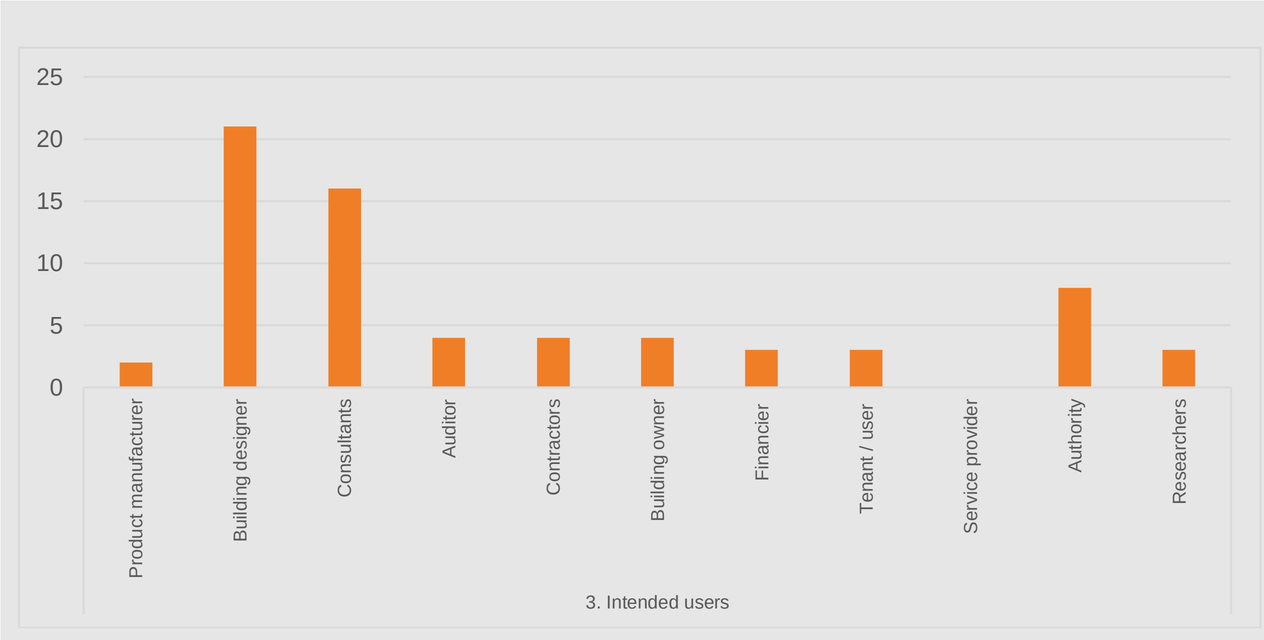
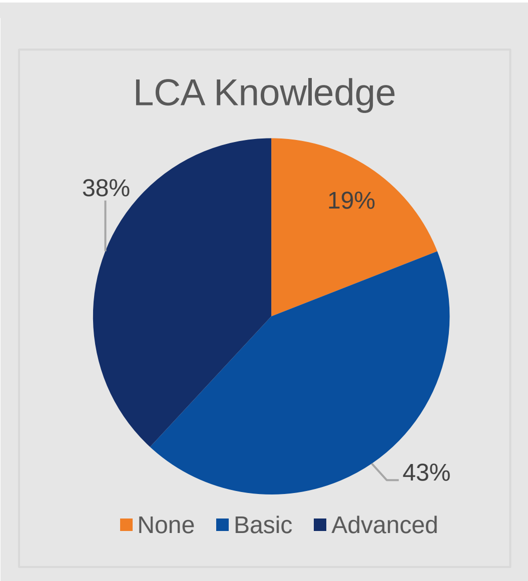


Figure 13: Survey outcomes. Question 3 on intended users.



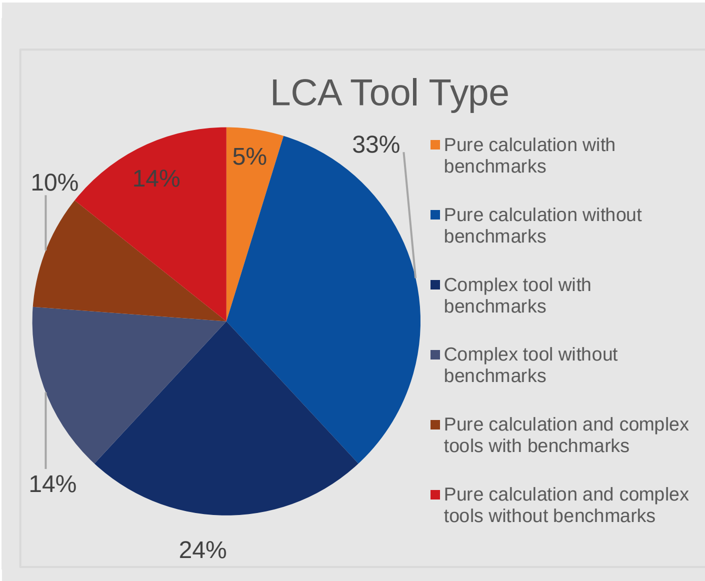


Figure 14: Survey outcomes. Questions 4-5 on required LCA knowledge (left) and tool type (right).

Tool Typology

Most of the tool examples are complex tools for building LCA, which can work also for a pure calculation. More than half of them is accompanied by benchmarks. Pure calculations tool (only) cover totally 40% of the investigated tools and 85% of them are without benchmarks.

By carrying out a cross-reference among all results, it can be noticed that complex tools with benchmarks are targeted for audience with basic knowledge in LCA. When a tool is working as pure calculation tool, sustainability experts and consultants are included in the targeted users. Since the most targeted user is the building designer, not surprisingly the main use case of all exanimated tools is the evaluation and the improvement of the building profile.

Considered LCA Stages

The majority of the analysed tools aim to carry out "cradle to grave" LCA analyses. In this sense, all lifecycle phases are included in the system boundaries. Whereas the tool provides analyses of urban system (2 tools counted), the operational phase will include additional information (**Figure 15**).

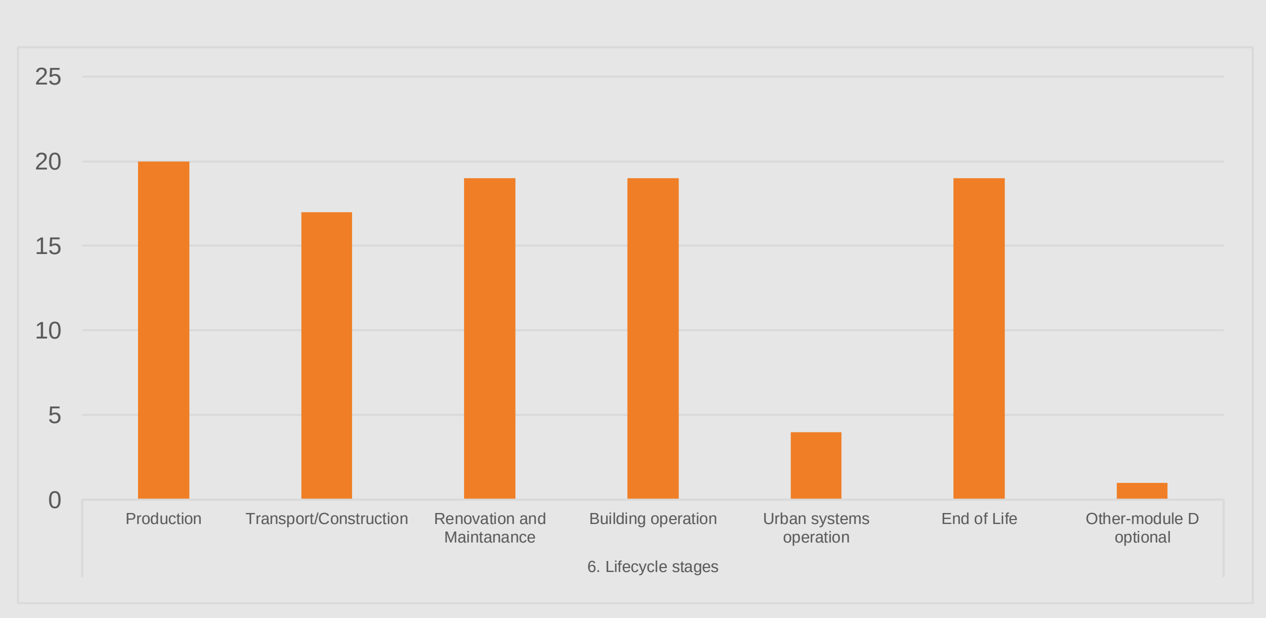


Figure 15: Survey outcomes. Question 6 on considered lifecycle stages.

Intended Design Phases

As a results of this question, most tools are increasingly applicable starting from the preliminary study until the handover. All tools are intended to be applied during the developed design, namely during the latest design stages. The high interest in the application during strategic definition and preliminary studies can be claimed relevant. In this context, the tool needs to derive environmental values starting with few buildings' information. Only 6 tools were intended for Operation and End of Use (**Figure 16**).

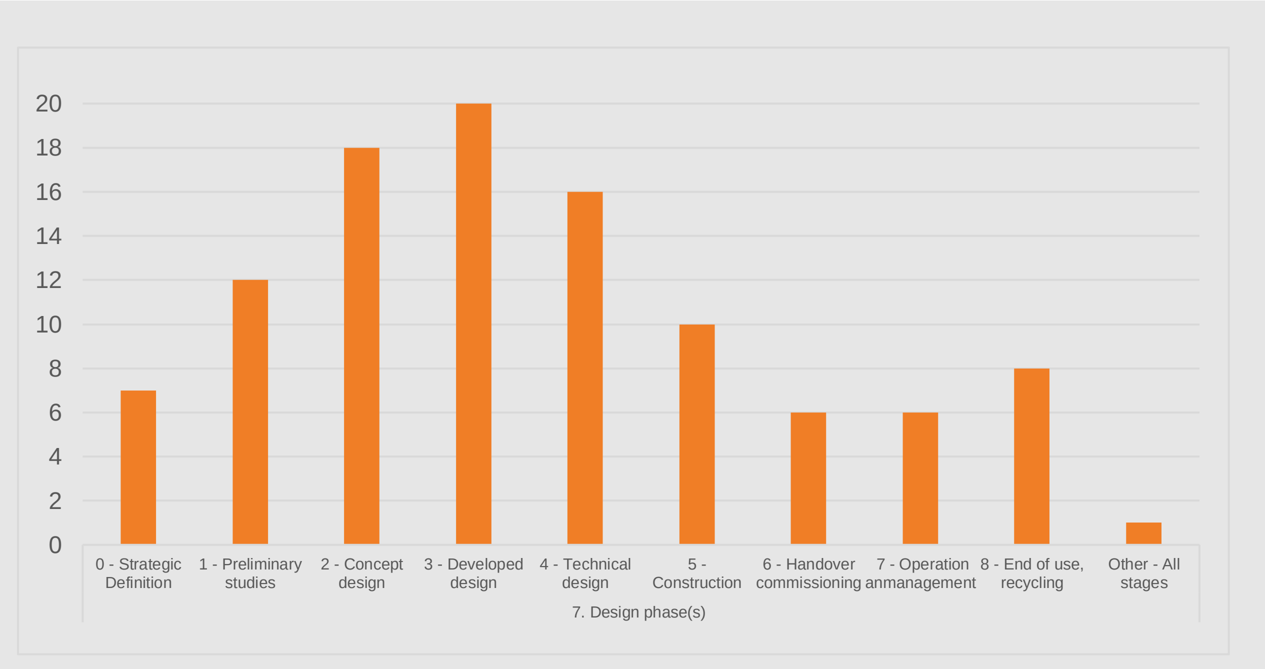
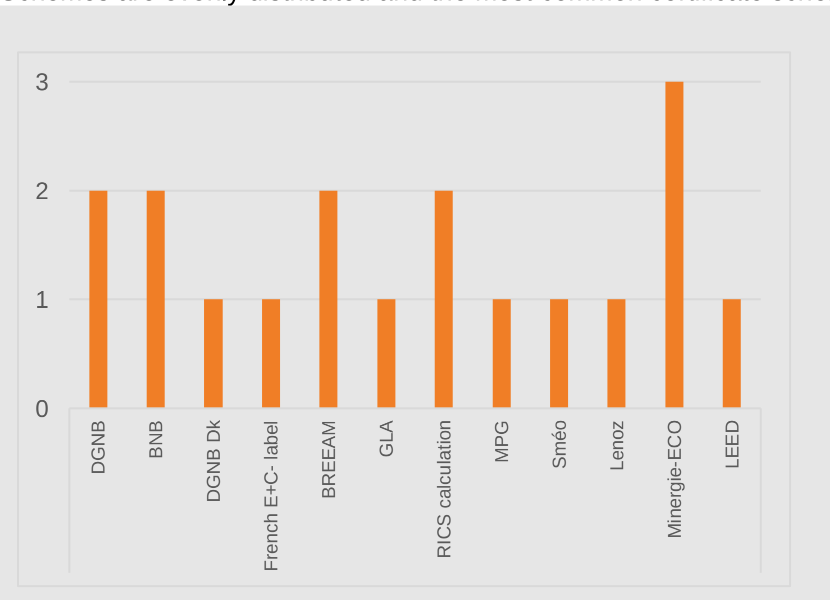


Figure 16: Survey outcomes. Question 7 on intended design phases of tool application.

The cross reference between results on Tool typologies and intended Design phases, showed that tools with link to benchmarks can be at least applied starting from the concept design. Tools like Pleiades, FCBS Carbon, CAALA and OneClick LCA are provided with benchmarks and, according to survey participants, can be applied already during the strategic definition.

Prepared for Submission – Certification schemes

Roughly half of the tools surveyed were intended to help with Submission Preparation. The Certificate Schemes are evenly distributed and the most common certificate scheme is Minergie-ECO (Figure 17).



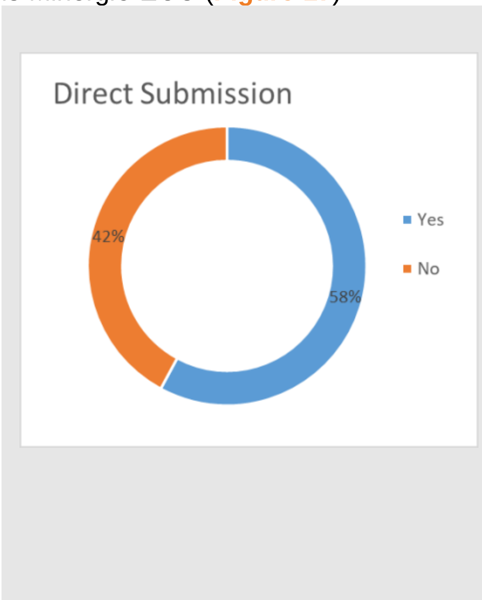


Figure 17: Survey outcomes. Questions 8 on availability of certification schemes and direct submission for building certification.

Support Options Available

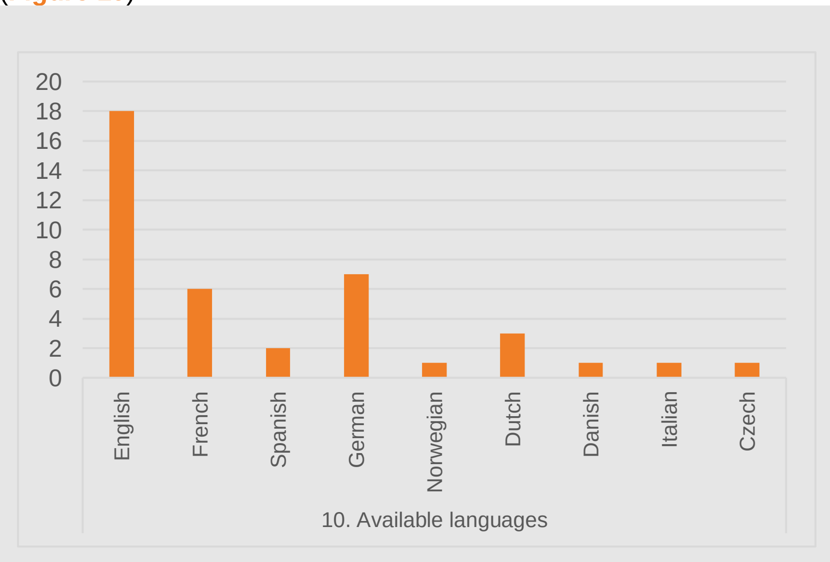
The most common Support Option available is the product's manual and online video Tutorials. Roughly half of the products have Webinars, FAQs and Trainings. Only 5 of the products offer Online Support /a Hotline. In this sense "*live support*" is still not for all tool developers manageable (**Figure 18**).

Figure 18: Survey outcomes. Question 9 on support options

Languages Offered

All of the products offered their services in English in order to be fully accessible also outside their country.

This leads to the investigation on tools' country specification. Roughly half of them are country-specified. The cross reference with results on tool typology, confirmed that pure calculation tool (see Section 1) are mostly not country specified. Such tools, in fact, allow higher level of flexibility during the lifecycle modelling (**Figure 19**).



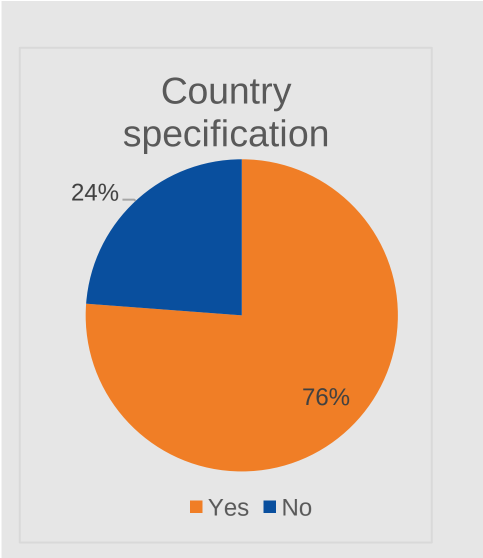


Figure 19: Survey outcomes. Questions 10-11 on available languages and country specification.

Functionality

Production Phase entries

Almost all tools require energy and mass flow of manufacturing, i.e., type and quantities of building materials (Figure 20). Four calculation tools allow the possibility of entering energy and mass flow due to provision and manufacture of technical services. Whereas the tool can be linked to a digital model, the building form and the model can be provided as input. The tool will either recognize type and quantities of materials, or this information needs to be entered manually.

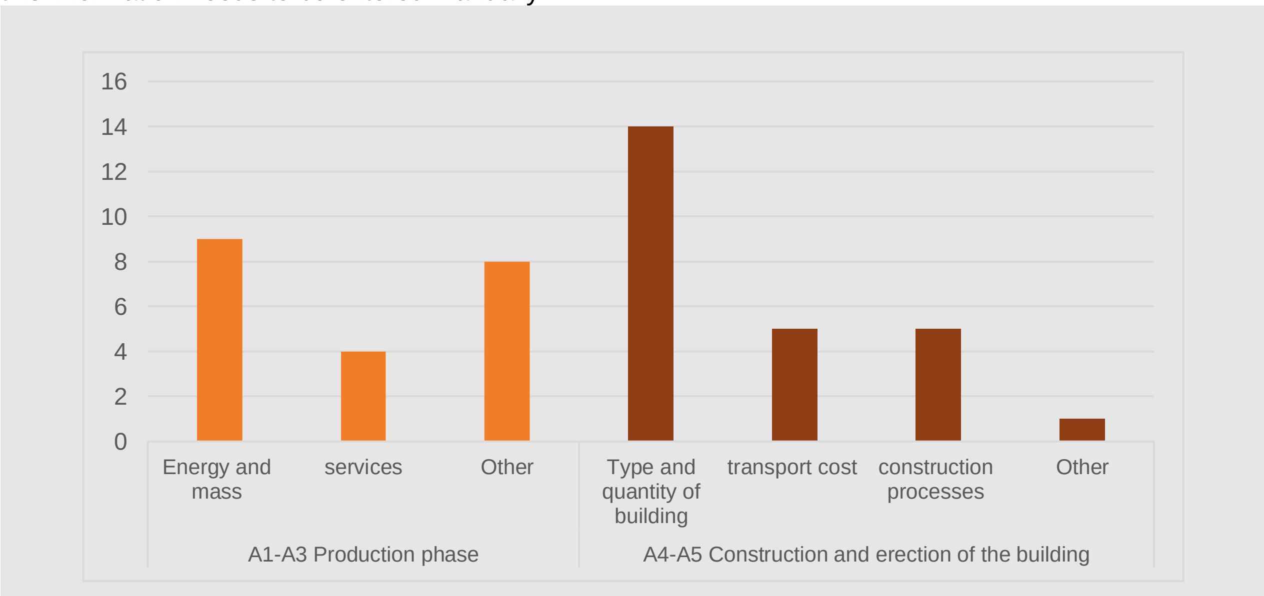


Figure 20: Survey outcomes. Question 12 on required entries for building production and construction process.

Regarding the construction phase, the evaluation is mostly based on type and quantity of building products. Few tools allow the inclusion of transport information and extended specifications about construction processes and machinery use.

Maintenance Phase Considerations

Half of the products consider Time Interval for Maintenance Activities, more than half consider Time Interval for Renovation Activities and less than half consider Mass / Energy Flow for Maintenance or Renovation Activities. If the time interval is not manually entered, the tool can suggest automatically time interval for all renovation and maintenance activities, depending on the building element.

Operational Phase Considerations

Half of the products surveyed consider Building Energy Regulation and Average Energy Calculation (such as “degree day method”) in the Operational Phase. When a link with digital planning is allowed, the tool can consider daily variation (hourly variation) in energy consumption simulation. Totally, five of the investigating tools can derive the quantity automatically. This can be done also, for instance, by calculating the U-values for building constructions and deriving an average value of energy consumption (Figure 21).

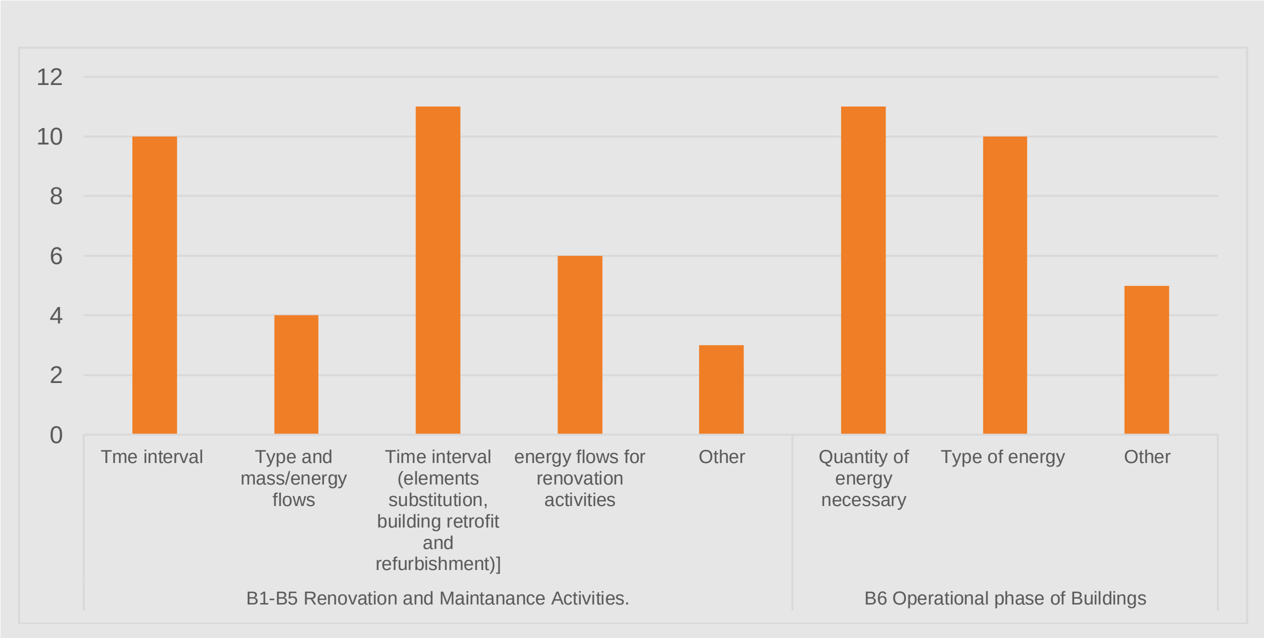


Figure 21: Survey outcomes. Question 12 on required entries for building operational phase.

Urban Systems Considerations

The investigated tools that allow analyses on urban system level have similar entries for the operational phase calculation. Among all the information, water mains leakage, waste sorting system, streets, district heating characteristics, pipes, parks with water needs can be specified (**Figure 22**).

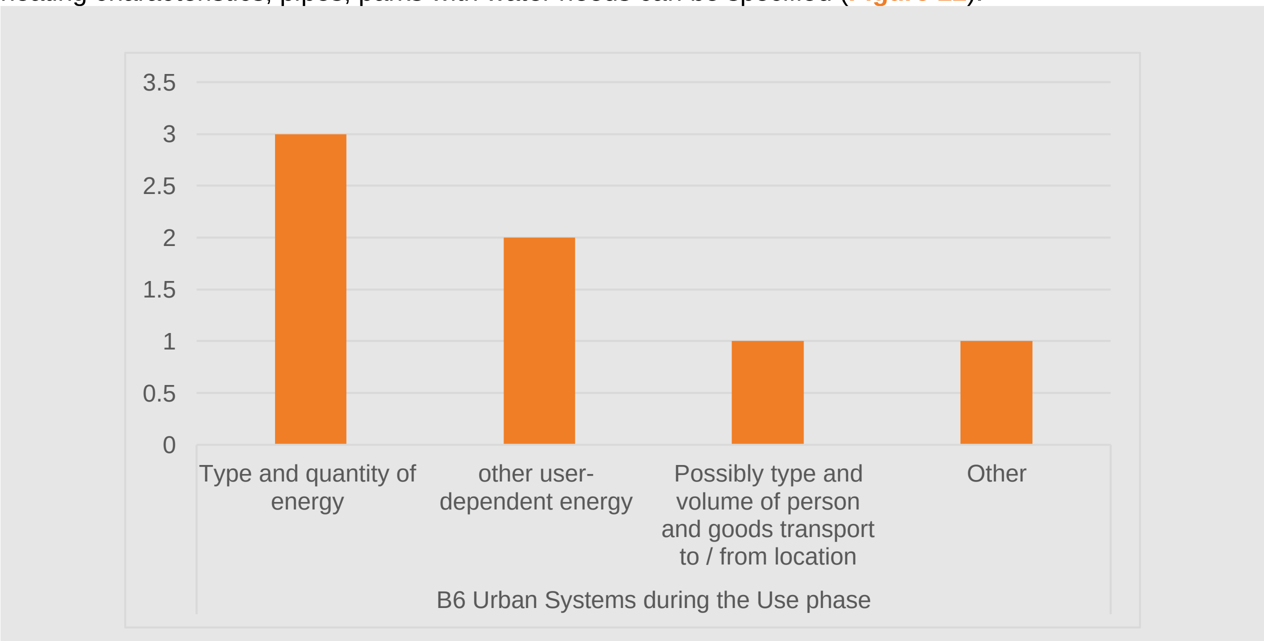


Figure 22: Survey outcomes. Question 12 on required entries for urban system operational phase.

End of Life Considerations

Most products surveyed consider the Type and Volume of Building Substance to be demolished during the removal of the building. Less than half of the products consider Possible Re-Usable Materials / Systems or Possible Recyclable Materials / Systems (**Figure 23**).

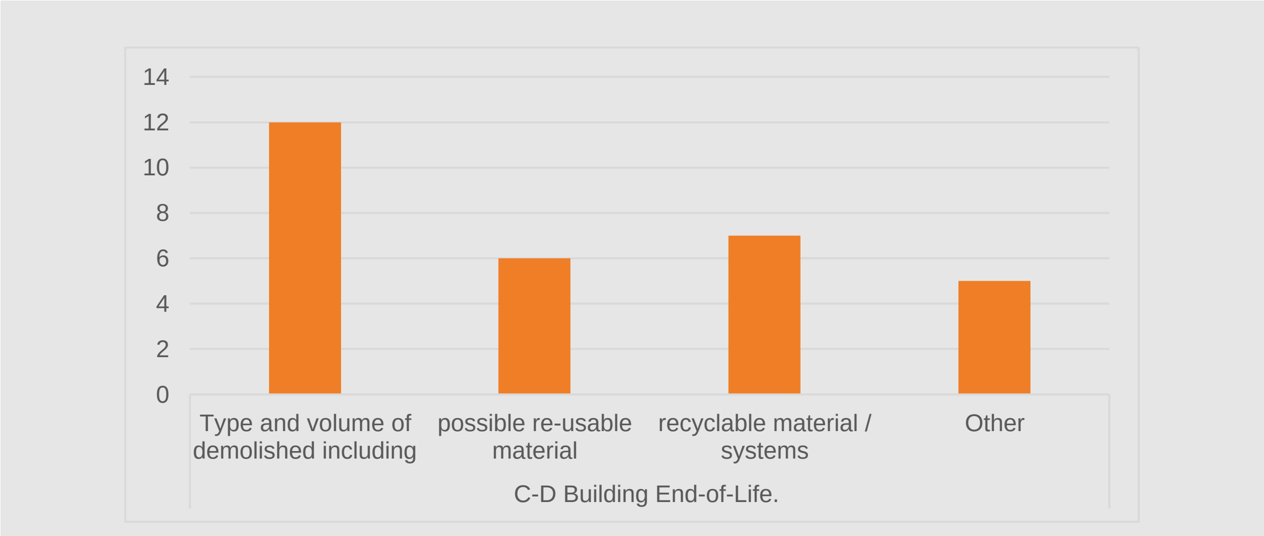


Figure 23: Survey outcomes. Question 12 on required entries for maintenance and renovation activities (left) and building end of life (right).

Environmental Databases

Most of the investigated tools are based on product or manufacturer specific datasets. EPDs and Ecoinvent are prevalent (**Figure 24**). Tools that are country specific in the German context can provide results based on Ökobau.dat, while other tools use ICE database, NMV (for Netherland), ESUCO, kbob list (valid in Switzerland) or envimat.cz (for Czech Republic).

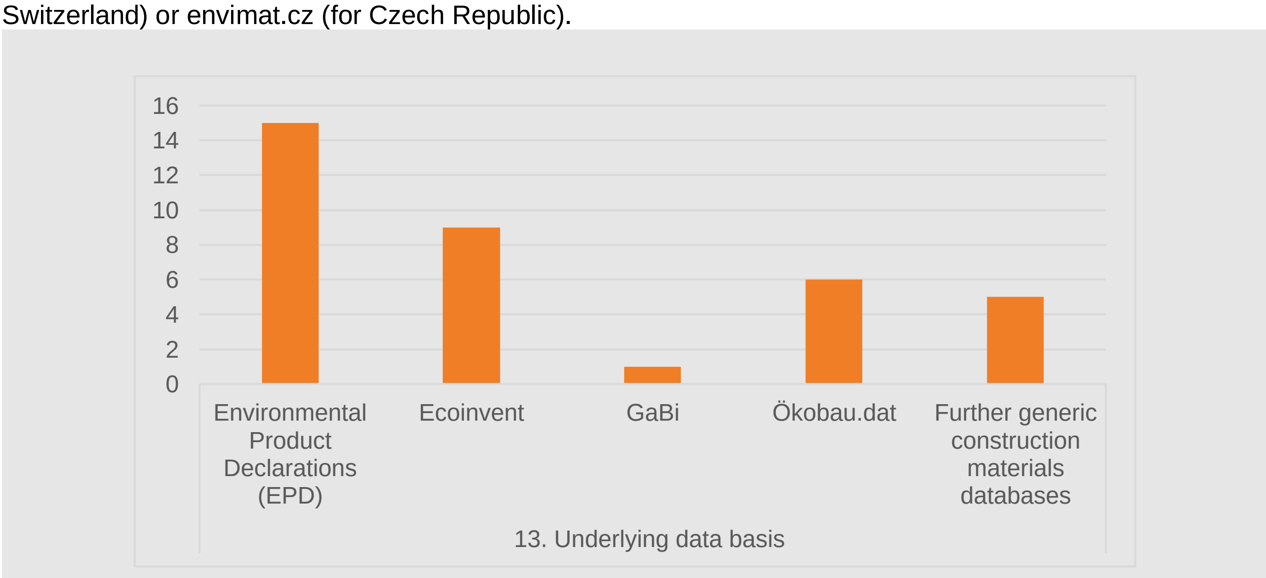


Figure 24: Survey outcomes. Question 13 on underlying databases.

System level

As already noticed in the questions, analyses are mostly carried out for buildings and building elements. Building stock and urban districts are not on focus of the currently available tools (**Figure 25**).

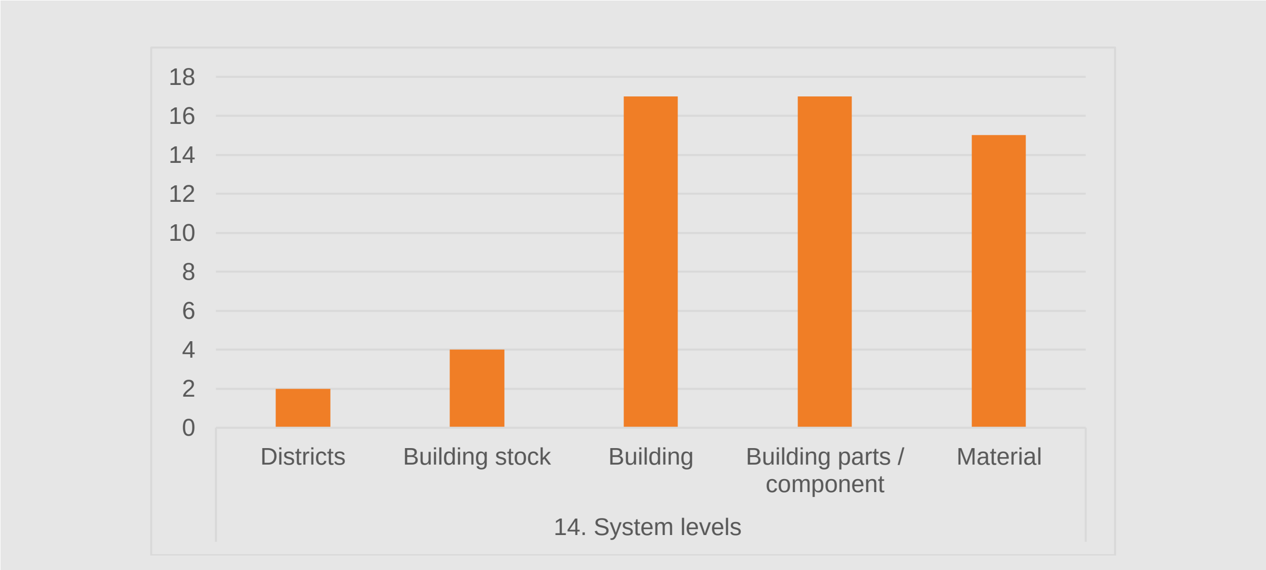


Figure 25: Survey outcomes. Question 14 on system levels.

Templates / Predefined building schemes

All tools' providers agree on the compilation of templates for the collection of LCA results and include predefined building schemes. However, each tool presents several typologies with different features and level of flexibility. Some examples present standard building elements that can be modified by the user. Users can also copy elements from the library and modify or delete existing layers. There are templates for the constructions' comparison or comparison with reference buildings. Some tools are entirely based on standard components and materials, enabling quick design choices to be made at early stages. Direction and magnitude of decision impact is key at the early stages.

Parameters Used for Calculation

Among the 15 investigated tools, nine tools allow a higher level of flexibility through the selection a proper LCA characterisation method. Nine tools provide conversion factors (**Figure 26**). This can be also done with help of an algorithmic generation of building quantities based on basic building parameters (height, footprint, etc.).

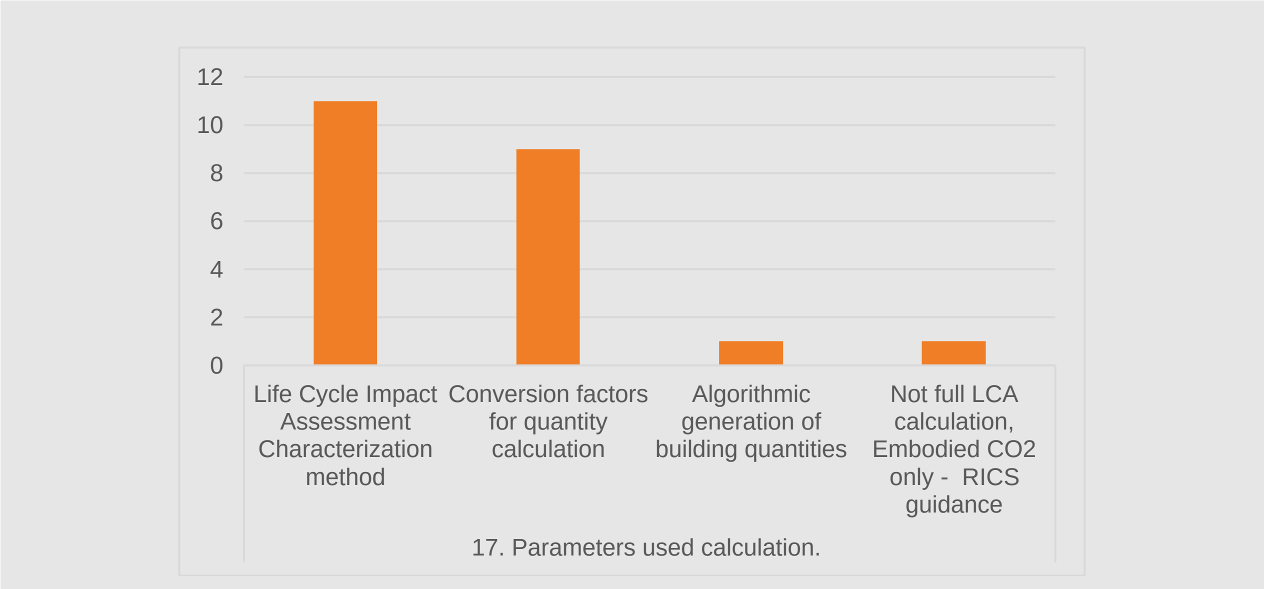


Figure 26: Survey outcomes. Question 17 parameters for calculation.

LCA Modification

Almost 60% (7 tools) of the products surveyed modify the original LCA Data Sources before making them accessible to the users. Contextualisation of products that are mainly national (e.g., concrete), calculation of some indicators not provided in ecoinvent (e.g., CO2 including biogenic according to forest management for wood) are possible. Standard information from EPD can be modified in 2 tools. Units in the EPDs vary widely and can be awkward for the praxis, which allows a crosscheck for consistency too. Sometimes materials are in other units, e.g., per m^2 if the thickness is not generally known, e.g., for carpet, or per m for I-beams. They can also be per kg or per kWh for ASHPs, these are not generally converted from the EPD.

Available Results

The most common visualisation of the LCA Analysis is in a PDF Report. Over half of the products offer Spreadsheets and Dashboards while only a few offers Mark-up Language or HTML/json files. BIMELCA allows a unique visualisation directly in the BIM model (Figure 27).

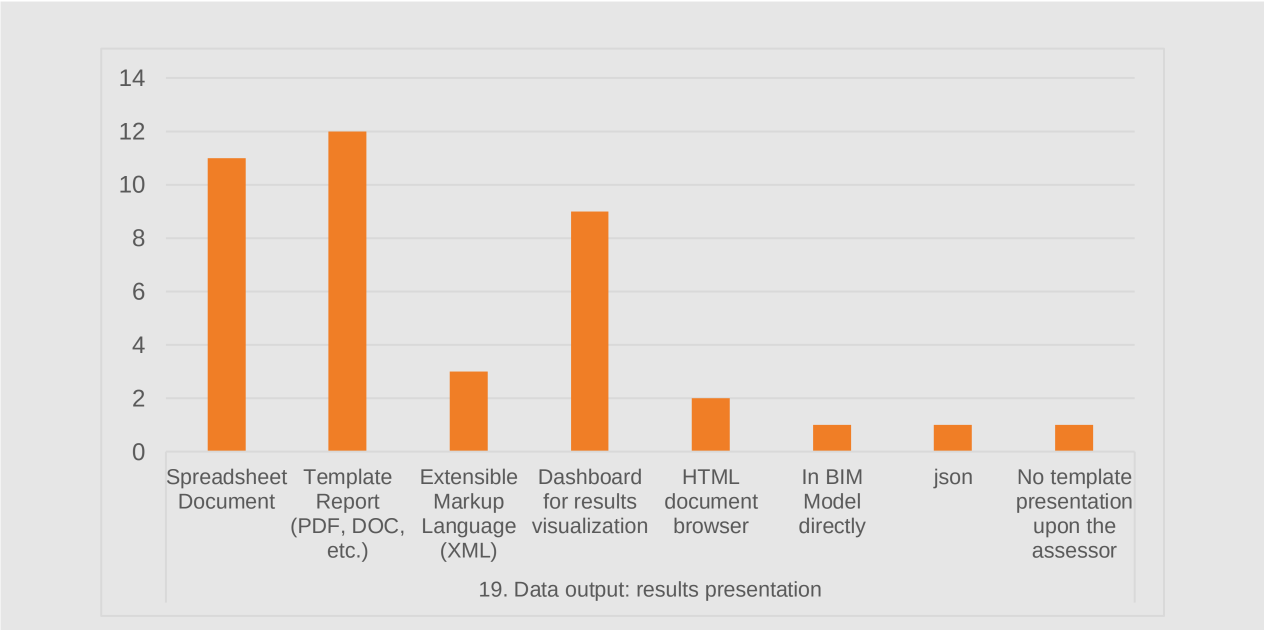


Figure 27: Survey outcomes. Question 19 on data output and results presentation.

Result Visualisation

The most common visualisation available in the products is the Bar Chart, followed by the Pie Chart, the Stacked Bar Chart and Line Chart. However, as shown here in **Figure 28**, there is a variety of uncommon visualisation possibilities that are not considered (see Section 3.1 – Functionality and background report 2.6 of this Annex), such as scatter plat, cluster and colour map. They are in fact to be related to further applications, which are not intended in the investigated tools.

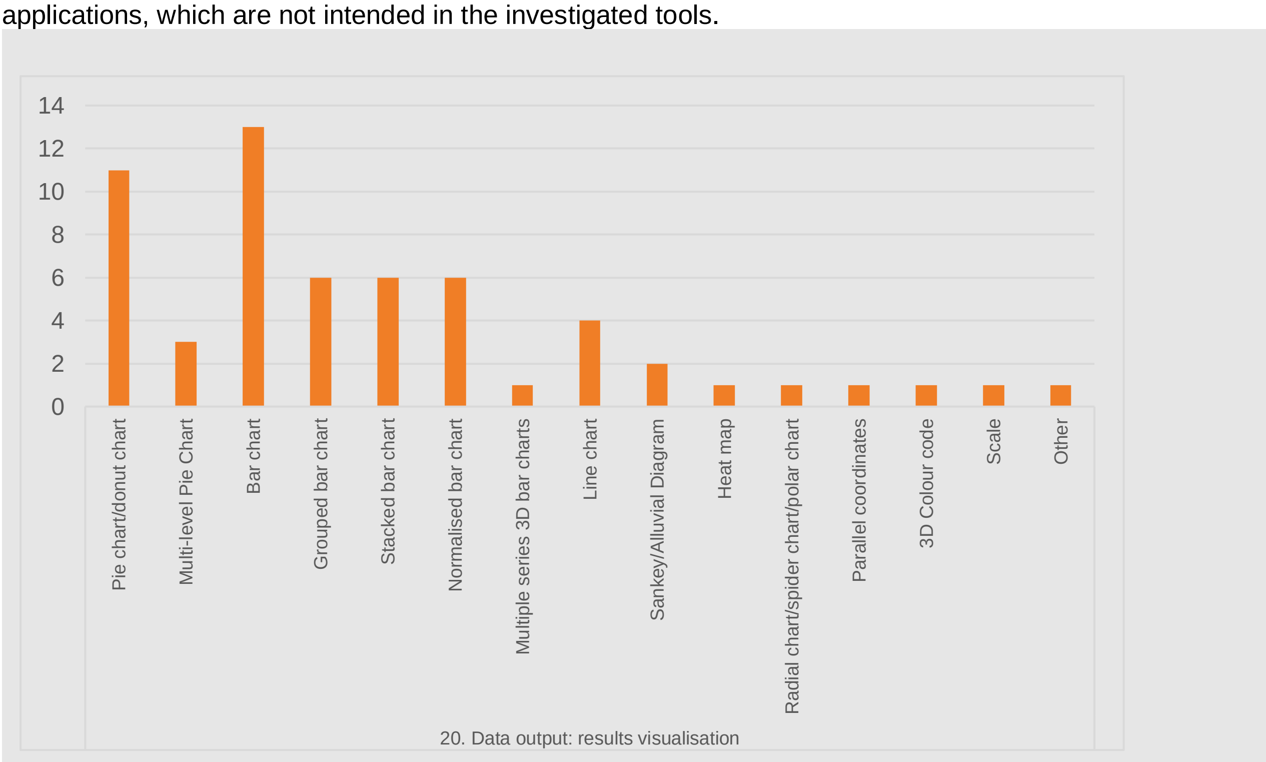


Figure 28: Survey outcomes. Question 20 on data output and results visualisation.

Result Indicators

All tools, except for Enerweb, provide GWP results. Most of the tool calculate all indicators relevant for building environmental certification purposes. Four participants declared a possible derivation of the full set of core indicators according to EN 15804 (**Figure 29**).

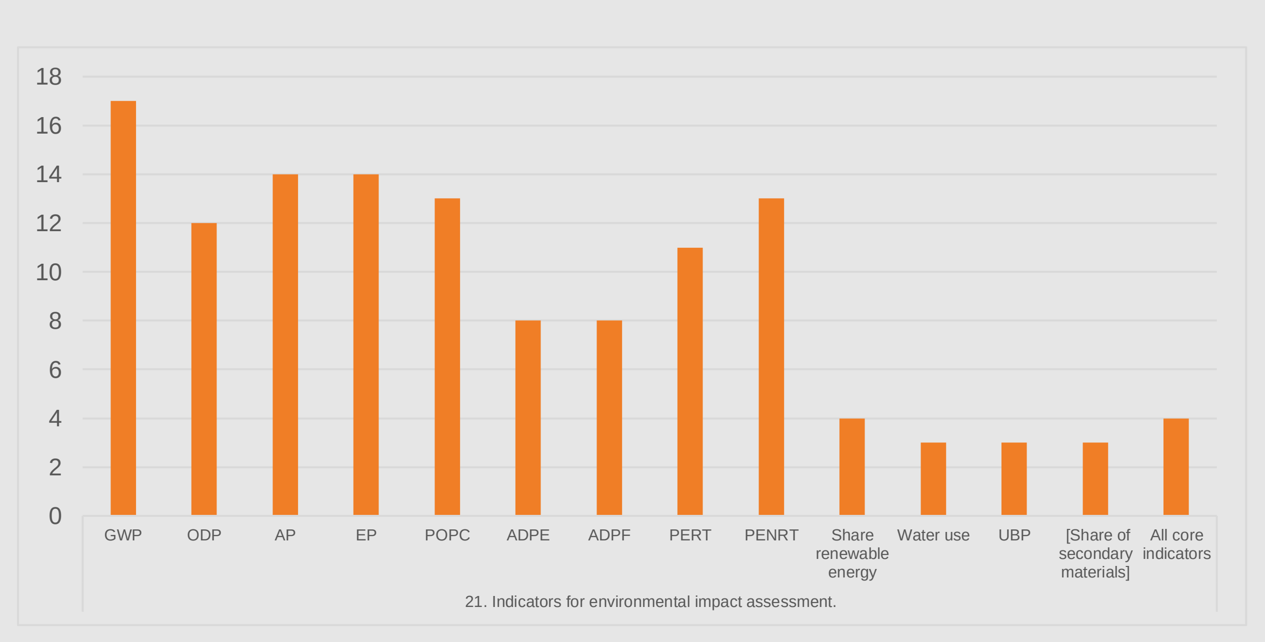


Figure 29: Survey outcomes. Question 21 on calculated environmental indicators.

Aggregation

All the products surveyed aggregate their results in building elements or in the several lifecycle stages. In this sense, results aggregation is an important instrument for allowing different granularities of the lifecycle environmental information and support better the user (**Figure 30**).

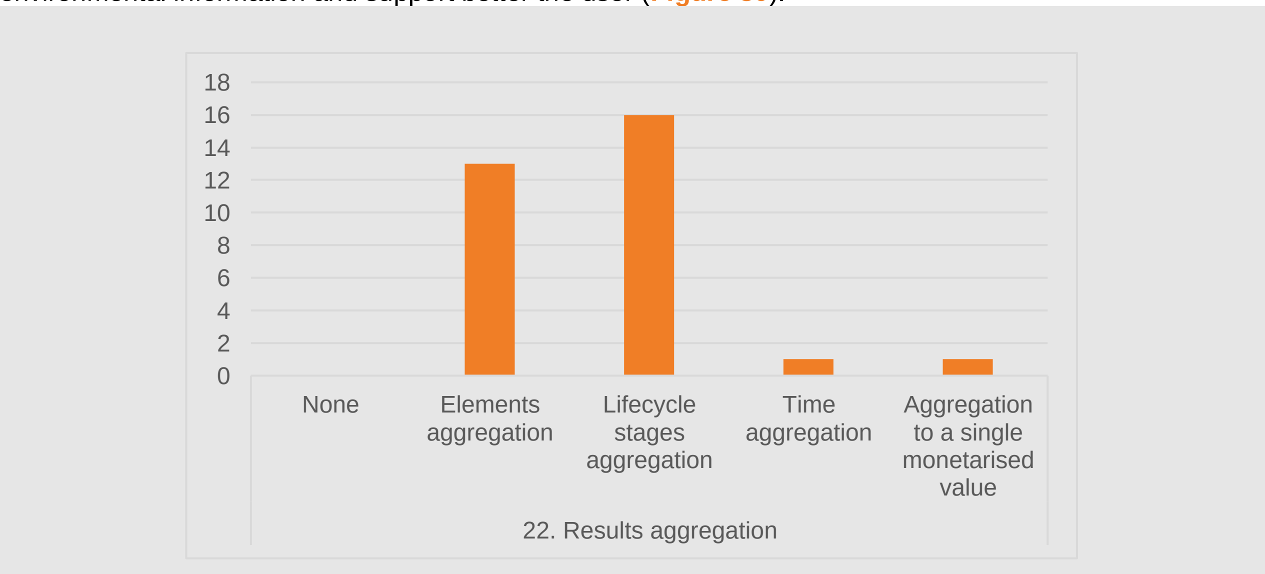
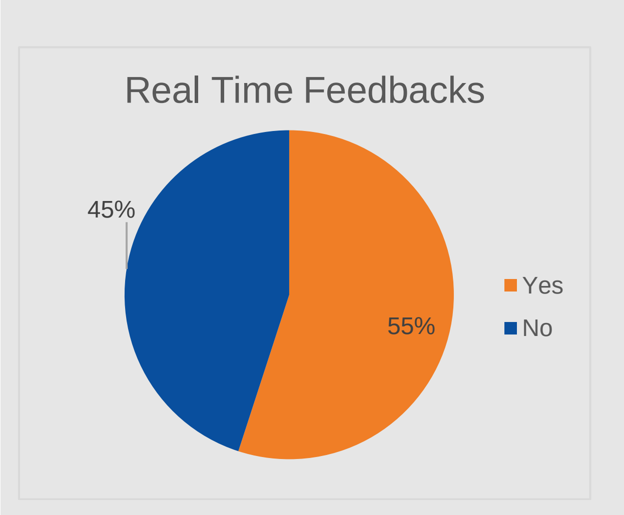


Figure 30: Survey outcomes. Question 22 on results aggregation.

Real-Time Design Feedback / Optimization Algorithms

Due to the different tool maturities, not all products offer Real-Time Design Feedback. For any of them it is not feasible because external energy simulation data are needed. According to participants' answers, some products declare that it is possible, but they have not incorporated it yet (Figure 31).



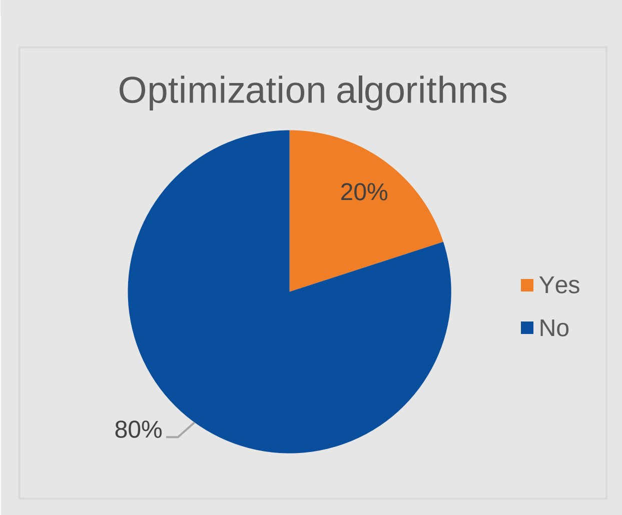


Figure 31: Survey outcomes. Questions 23 -24 on real time feedbacks and optimization possibilities.

With regard on Optimization Algorithms to propose building solutions, only a few of the products are provided with enough resources. Some of the products can be linked to visual programming software like Dynamo and use their results as an objective in optimization.

Other tool features

The FCBS CARBON tool is designed to provide early estimates of the embodied carbon of building at an early stage, when bills of quantities are not yet available. Instead, it uses a standardised algorithm to provide guidance during design about better or worse material/form choices. Components are based on standard build-ups, modelled using EPD and ICE data. Within 30 minutes, it is expected that a building whole life carbon analysis can be undertaken, and then iterated on to find lower carbon solutions.

CAALA links to CAD/BIM model, import and export of gbXML, simplified LCC calculation for variants comparison.

PHribbon integrates with PHPP, the Passivhaus Planning Package. From PHPP, materials and quantities are extracted; operational data serve for the generation of combined Embodied and Operational graphs.

BIMEELCA can work via Revit API and integrates in this way the BIM tool.

The ZEB tool can be used on its own to calculate embodied emissions for materials and has an input to link with simulated emissions from operation. Due to it being excel based, it can be used to model different life cycle modules depending on the availability of generic and, or specific data (EPD). Norwegian EPD are collated and linked in the EPD library in the tool and the user can use a drop-down menu to choose different materials (linked to the EPD). The ZEB Tool can be connected to REVIT using Dynamo plugin.

Reliability

Deviation Analysis

Most of the investigated tools, cannot provide instruments like deviation analysis (Figure 32). Pleiades provide both sensitivity and uncertainties analyses only for energy calculation. SimaPro can carry out sensitivity analyses.

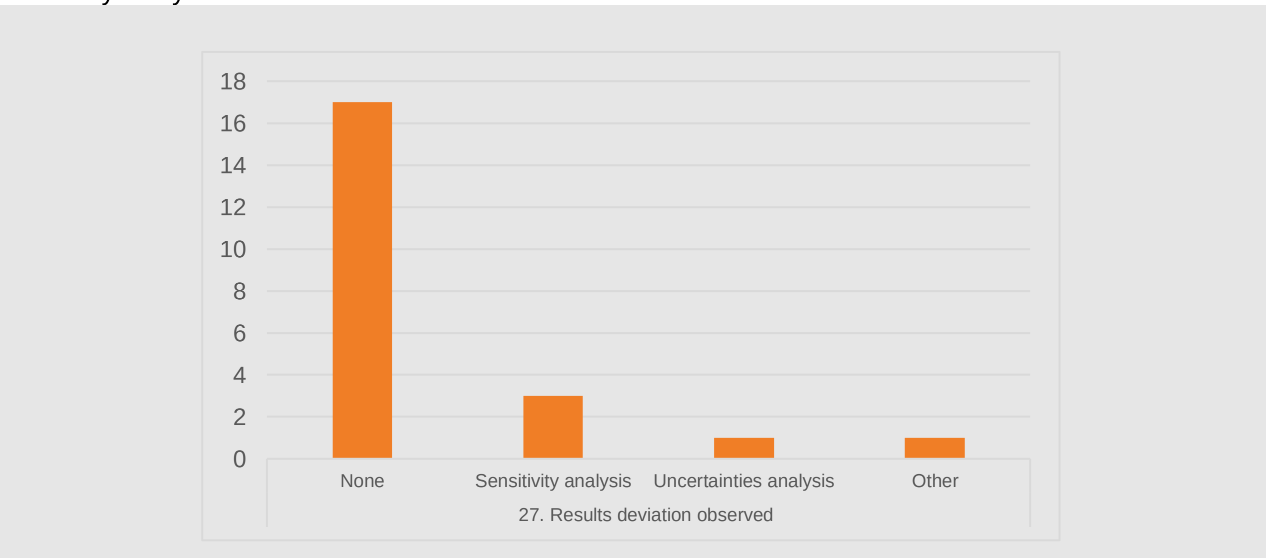


Figure 32: Survey outcomes. Question 27 on tool-observed results deviations.

Data Quality

Most of the products consider data quality. According to underlying databases, roughly half of the products consider Regional and Verified data quality, while only five consider independent data quality (Figure 33). Three tools do not specify the dataset quality.

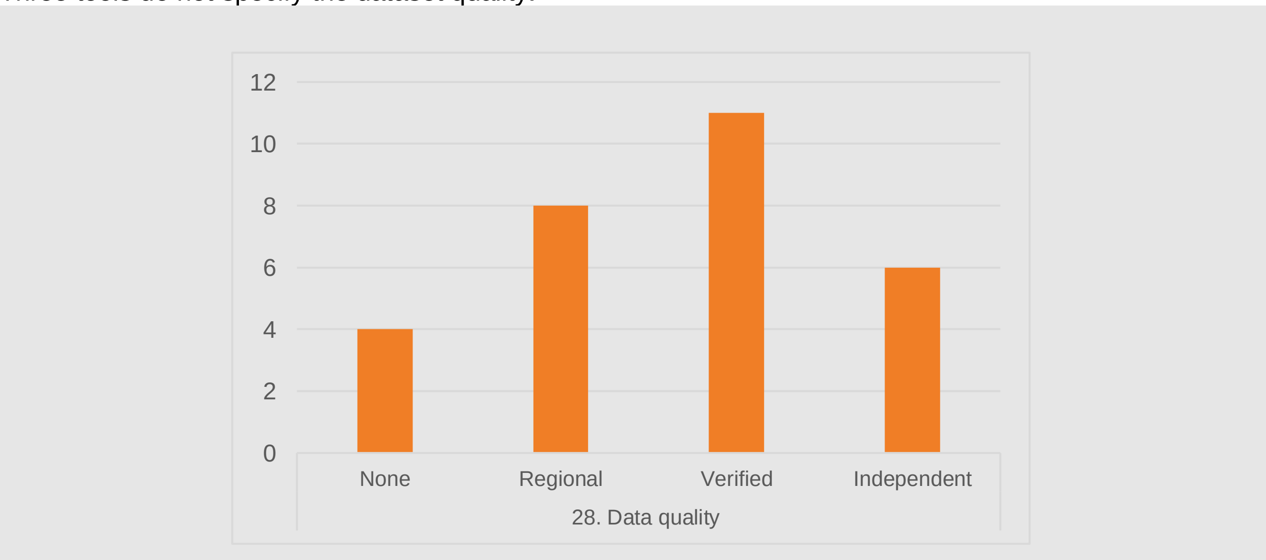


Figure 33: Survey outcomes. Question 28 on data quality.

Quality Assessment Mechanism

Quality assessment is offered only in few products, i.e., only a third of the products offer a Quality Assessment Mechanism. Mechanisms can however strongly differ. GPR Building provides an optional independent review, in order to receive certificate (GPR certificate). CAALA has a simple model checker to check quantities taken over from CAD/BIM model. Quite similar is the mechanism in GENERIS, which verifies user entries for building environmental certifications. If data are changed, Lesosai shows it in report and checks that all materials are filled with values.

Interoperability

Tool Interoperability

The survey showed a still missing tool interoperability with other products. Most of the tools are able to work with Excel, half of the tools can work with Revit and only 3 can work with other more advanced tools. If the products can work with Excel, other software such as Revit are indirectly accessible (Figure 34).

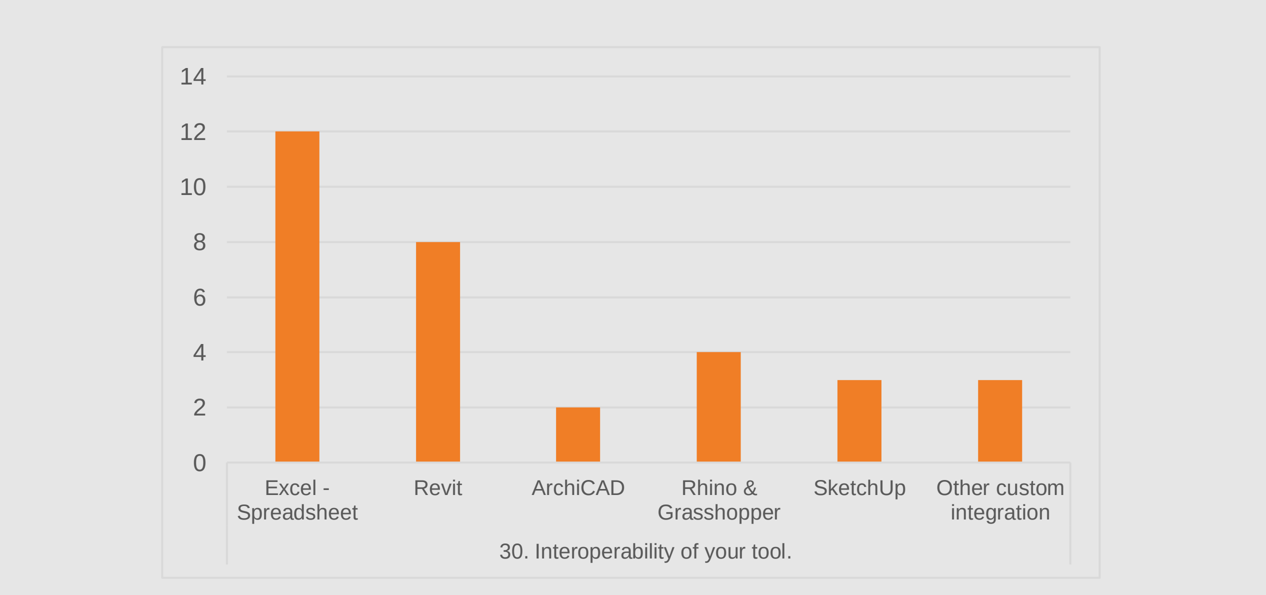


Figure 34: Survey outcomes. Question 30 on tool interoperability.

Workflow

As referenced previously, tools operability occurs mostly with an Excel Spreadsheets. More than half of the products have the ability to produce Bill of Quantities but only a few can work directly within other software (Figure 35). Other more sophisticated and automated workflows, such as LCA plugin application or BIM object enrichment) are not widespread.

Instead of IFC, Pleiades and CAALA can possibly use gbXML import/export. Generally, for the PHribbon version the quantities come from the PHPP, the Passive Haus Planning Package model, though additional info is needed for items that are not part of that thermal model, e.g. internal walls, intermediate floors, services, roof finishes etc.

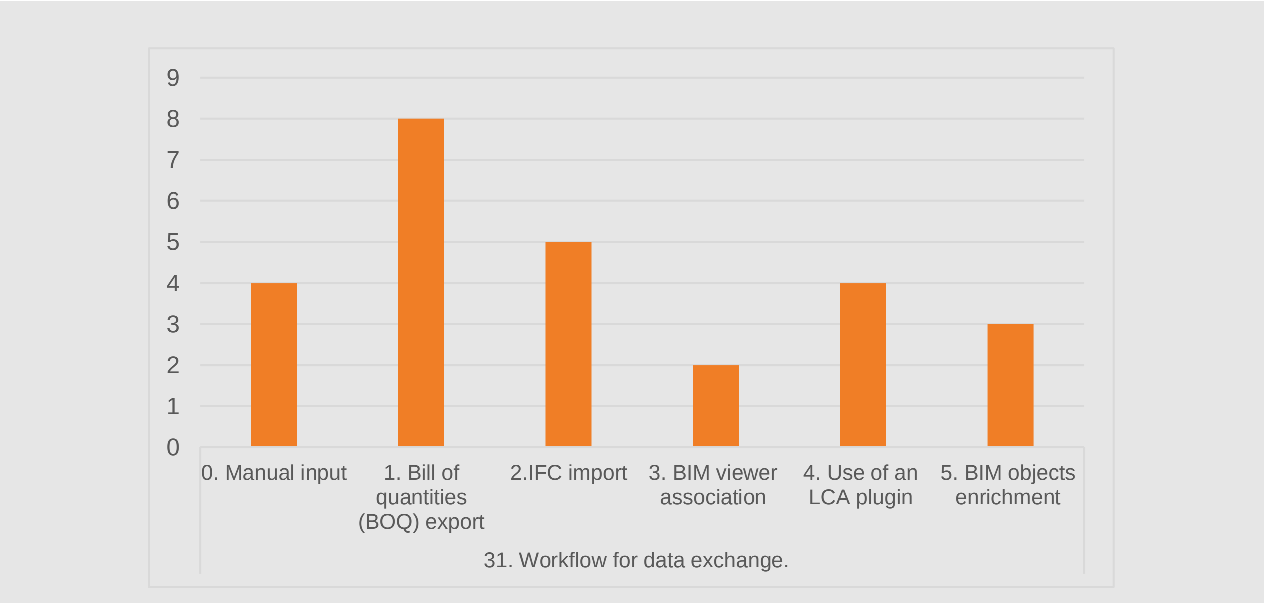


Figure 35: Survey outcomes. Question 31 on workflow for data exchange.

Standards Compliance

The majority of the products comply with the ISO 14040 – ISO 14044, EN 15804 and EN 15978 (in the European context).

PH Ribbon is designed to follow RICS in the UK as close as possible, however it is not an official calculation. Consequently, the document generated as tool-output is based on RICS. FCBS CARBON follows also RICS for a Whole Life Carbon Assessment. ISO 14025: 2010 is included in the ZEB Tool. SIA 2032, Lenoz, SIA 2040 can be included in tools such as Enerweb and Lesosai (valid in the Swiss context) (**Figure 36**).

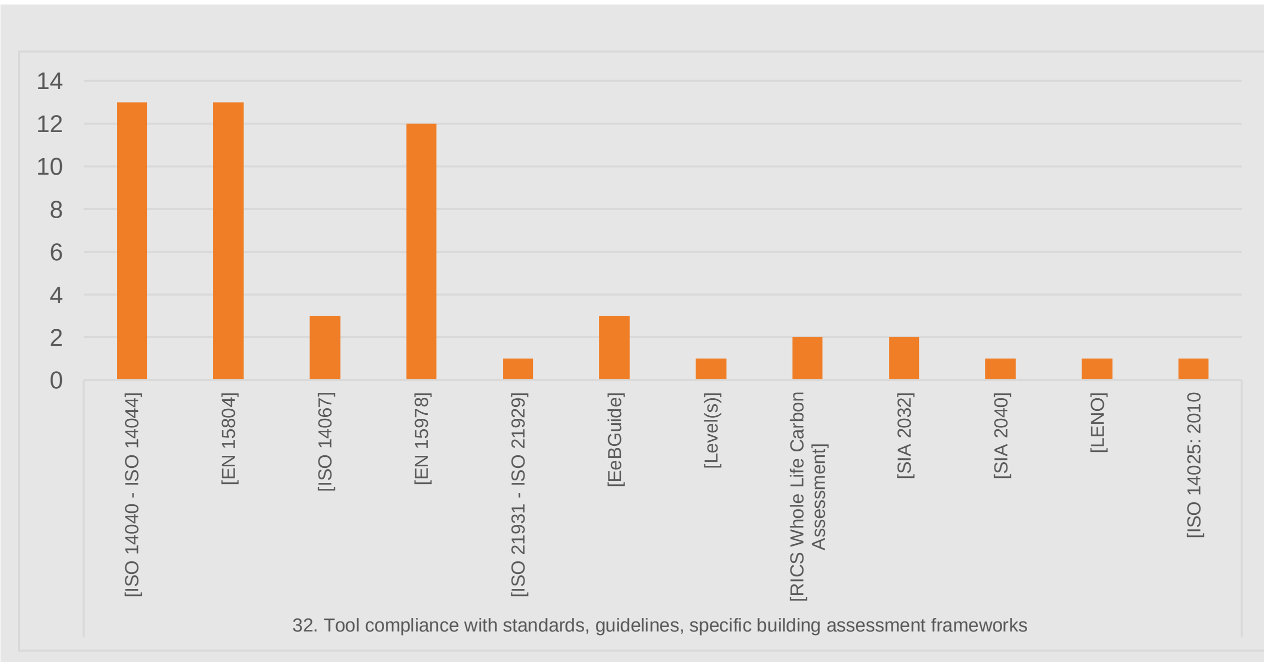


Figure 36: Survey outcomes. Question 32 on standard compliance.

3.3 Synthesis and critical assessment of survey results

The conducted survey served as an instrument to have an overview of tools for buildings LCA. Even if in the market are more tools now available and to still to be potentially investigated, the survey let arise common points and issues.

For the recognition of harmonized and still opened issues, the results were collected the answers counted. Each question has been associated to a specific issue (see Appendix) and the latter has been classified by considering the following criteria:

- Questions which presented at least one answer with counting from more than 75% of participant. “None” – answer is not entailed → **Harmonized issues**. There is an agreement/alignment on such issue
- Questions which presented all answers with counting between 25% and 75% of participants → issues considered **relevant but handled in different way** by tool developers
- Questions in which counting was less than 25% and “none answer” presented higher counting→ open issues. There is an **improvement potential**

Here in Table 1 the results of the critical assessment are provided.

Table 1: Critical assessment. Recognition of harmonized and open issues.

		Harmonized	Handled differently	Open issue
Usability	2. Use case	X		
	3. Intended users?	X		
	4. Level of LCA knowledge		X	
	5 LCA Tool category		X	
	6. Lifecycle stages	X		
	7. Design phase(s)	X		
	8. Direct submission to certification authorities		X	
	9. Support options	X		
	10 country specification	X		

Functionality	11 Language	X		
	12 Tool Entries		X	
	13 Databases		X	
	14 System level	X		
	15. Templates or default values		X	
	16. Predefined building schemes		X	
	17. Parameters used calculation.		X	
	18 Data source modification			X
	19 Predefined building schemes		X	
	20 Visualization		X	
	21 Indicators	X		
	22 Results aggregation	X		
	23 Real Time feedback		X	
	24 Optimization algorithms			X
	25 Tool features		X	
Reliability	26 Error propagation			X
	27 Results deviation			X
	28 Data quality		X	
	29 Quality assessment mechanisms			X
Interoperability	30 Tool interoperability		X	
	31 Workflow for data exchange		X	
Compliance	32 Compliance	X		

The survey reported a harmonized status of the available tools with regard on usability and overall applied LCA methodology.

All tools target similar intended applications, i.e., Building and building parts assessment, comparison, environmental certification and improvement of building environmental performance with an aware choice of products. Intended user are similar as well: tools aim to planners, sustainability consultants and authority. In terms of LCA knowledge, pure calculations tools require a more advanced expertise level, in comparison with complex tools, which, in the other hand, try to support more the user during the building lifecycle modelling.

The variety of languages, the country specification and the several available submissions for environmental certifications demonstrated that building LCA tools target mostly a national audience.

The survey showed furthermore that there is a consensus on applying cradle-to-grave analyses, with few variations for tools that do not consider transport and construction process and the whole building maintenance and renovation activities. There are tools that use building energy simulation, and therefore focus on the building operation. The environmental indicators are derived by core indicators-set according to the EN 15804.

In terms of tools functionality, the survey showed a higher variety in terms of requested inputs, provided templates, visualisation possibilities, results aggregation and tool features. Tool maturity level and the technical/informatics advancements dictate the implementation of more sophisticated features, such as LCA data source modification, real-time feedbacks and optimisation algorithms.

A similar issue can be found in the category “Interoperability/Portability”. Most of the investigated tools show a high interest in data import and export from digital models but prefer working with Bill of Quantities and Spreadsheet. A tools’ coupling is not yet applicable and a limited number of tools achieve higher levels of automation. In this respect, there are also differences in terms of technical advancement and BIM/LCA integration strategies.

3.4 A methodology for tools identification

With the collected answers, it is possible to establish a procedure to identify tool, which can satisfy specific designers' or user needs.

The procedure here suggested consists in systematic pyramidal selection, which starts from the bottom, with a first identification, to the top, where there is a more personalized filtering. Requests belonging to the lower part have higher priority for the tool identification process, but however can provide a lower selection level. Requests on the higher part can select the proper tool with higher level of personalisation. Such requests are related to the survey outcomes that shown more discrepancies.

Five main levels are identified (see **Figure 37**) and a generic example is presented in the following tables.

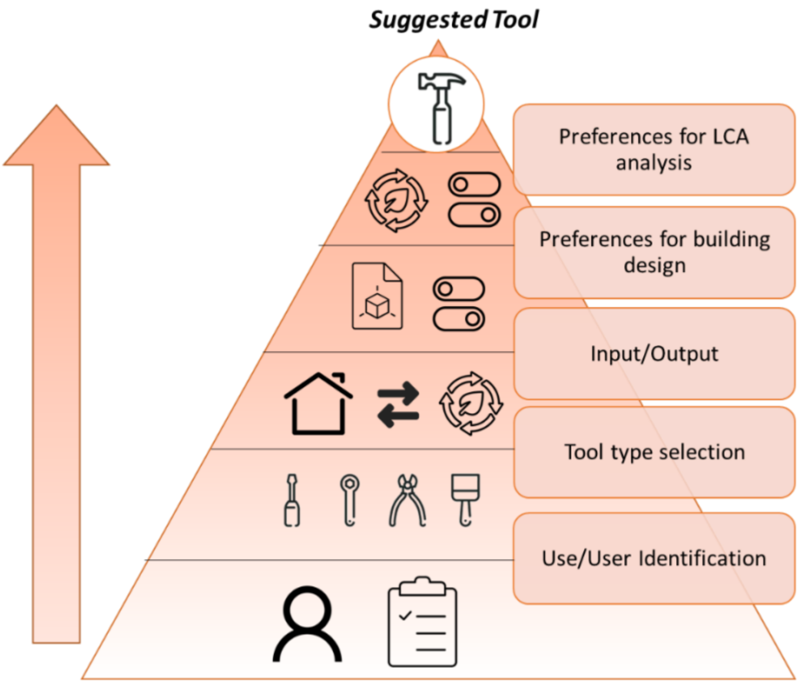


Figure 37: Methodology for Tool identification depending on user's needs.

a) **Use/User Identification**: the application(s) and the intended user(s) need to be targeted and indicated. The country of application is declared. This will automatically select tools with country-specific databases. Furthermore, a preference on languages can be provided (**Table 2**).
b) **Tool type selection**: the potential user selects the tool type, pure calculation or complex tools for the building assessment (**Table 3**).

Table 2: Field 1 - Use and User Identification.

Request	Example
User Type	Designer
User preferred Tool Language(s)	English
Use case	Improvement of environmental performance
Country specification for use case	Yes
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 3: Field 2 - Tool identification.

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

With this first selection (see Tables -2-3), it is possible to narrow the tool search, but, according to the survey outcomes, this may lead still to different tools. The identification process can therefore continue.

c) **Input/Output**: the lifecycle stages to be investigated, the system levels and, if still necessary, the underlying LCA database are specified. Furthermore, the potential user can declare the environmental indicator under investigation, the preferred template and the data format for results (Table 4).

Table 4: Field 3 - User preferences for tool Input/output.

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

This further selection can now provide a restricted number of tools. A further level of personalization can be enabled through two last preferences.

d) **Tool features and user's preferences for building design**: this field aim to recognise specific designers' and users' needs, such as provision of results during the early design stages, optimisation algorithms, interoperability with digital planning or tool coupling possibilities (Table 5).

e) **Tool feature and user's preferences for LCA analysis**: preferences about, deviation analyses and quality assessment mechanisms are asked (Table 6).

Table 5: Field 4 - Input and output preferences for building design.

Request	Example
BIM Coupling: Workflow for data exchanges	5 BIM object enrichment
Results provision during design early stages	Yes
Suggested Tool	Pleiades Lesosai

Table 6: Field 5 - Input and output preferences for LCA analyses.

Request	Example
LCA Deviation analysis	Yes
Quality assessment mechanisms for LCA	No
Suggested Tool	PLEIADES

Through the last filtering, based on the survey outcomes, a unique a proper tool has been selected.

3.5 Discussion and outlook on building LCA tools: General and Ideal case

The survey on building LCA tools outlined features and aspects for which a harmonization has been mostly reached. However, certain issues are still challenging. While previous investigations focused mostly on the general usability and functionalities, this report and the related survey included additional aspects, such as optimisation algorithms, data exchange, related to informatics advancement.

According to the survey, LCA tools in a general case (**Figure 38**), as pure calculation tools do not include benchmarks, or, as complex tools, include them. They are capable to support the design process, but not the early stages. They are applied for building and building parts assessment, comparison, environmental certification and improvement of building environmental performance, but do not integrate benchmarks. Intended users are planners, sustainability consultants and authority with at least basic knowledge. Country specification, which is mostly occurring, and dictates languages, underlying databases and the submission for environmental certifications. LCA analysis are carried out cradle-to-grave and under consideration of core environmental indicators.

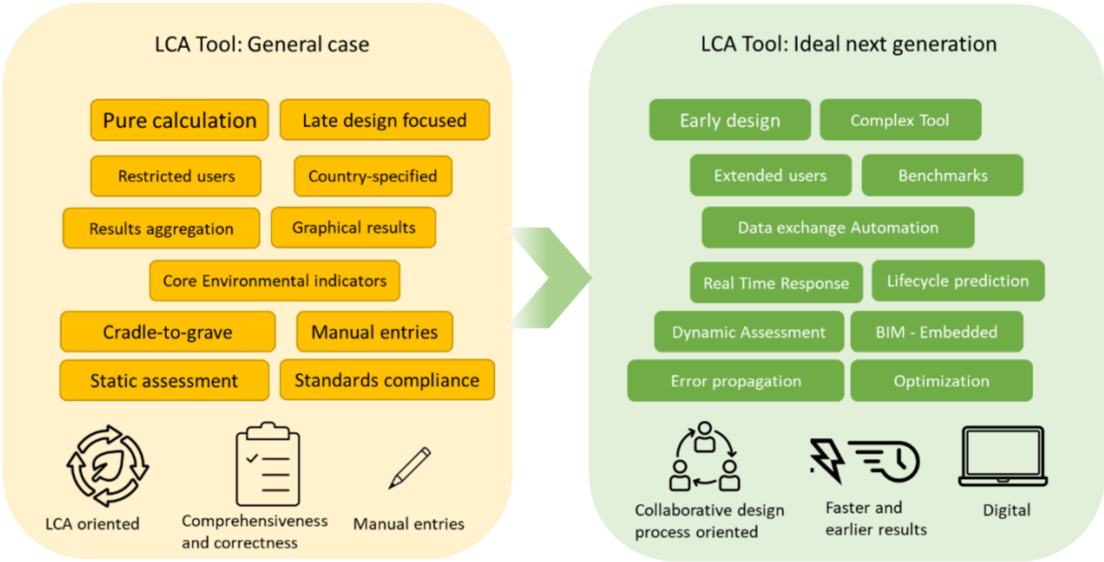


Figure 38: LCA Tool. General and ideal-next generation tools

Input data are often manual. A data exchange is possible: however, users are requested to provide some entries manually, and this may lead to re-entering or errors. Tool outputs are while provided in form of report, 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/or pie donuts are the most frequent visualization possibilities.

Advancements in tools entails the implementation of functions for earlier and faster evaluation of the environmental profile. These requirements are in line with the increasing collaborative design and digitalization in the building sector.

In this sense, the next generation of tools or currently "ideal" tools should support more the early decision making. The intended users should include all stakeholders involved in the building planning, even those who may not have knowledge in the field of LCA, in order 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. Databases need to be extended with statistical records, in order to allow for benchmarks derivation and predictive lifecycle modelling. 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 real time feedback mechanisms and workflows with higher level of automation, e.g., plug-in or IFC object enrichment and import/export. High efforts need to be addressed to BIM portability, which increases collaborations between different fields.

4 Conclusion

Within this background report an overview on designers’ need and tool set is provided.

In particular, the tool set has been prepared with help of a questionnaire, in which 70 participants provided information on LCA tools usability, functionality, reliability, interoperability and conformity. Based on this, a process for tool selection has been established.

The survey represents the core part of this report, which allowed some reflections on a general status quo of currently available building LCA tools as well as ideal next generation tools and upcoming developments. Constraints of the analysis and of the critical assessment are due to the restricted number of participants, which did not cover the whole Building LCA tools market. Despite such a limitation, the survey demonstrated an alignment on tools usability and conformity, but also high variability in terms of tools functionality. Most of the open issues and future potentials entails tools’ results reliability and interconnectivity. Tools’ development focus was on results comprehensiveness and correctness.

All inhere presented issues are belonging to the current requirements and necessary developments in the context of a more integrated and digitalized planning process. Based on designers’ need as well, Ideal LCA tools should be in the future more oriented to the design process. As digitalization in the building sector and life cycle assessment is receiving also more attention, approaches and their respective interfaces need be further developed aiming at a faster and a more robust LCA. The market is still open and new interfaces are fostered. New products will support environmental decisions within building development, by allowing higher level of interoperability with other interfaces, e.g., BIM, geospatial information (GIS) and similar. This makes possible faster and robust statements already in the early design stage under limited information basis and uncertain boundary conditions. This will require a higher and a more effective provision of benchmarks (Björklund, 2002).

It is important to underline that in the construction industry, in comparison with other sectors, the adoption of digital instruments has been slower, and typically only focused on isolated aspects of the building process due to the fragmented nature of the construction sector and a compartmentalised field. National and local governments in this context aim in following years to facilitate the uptake of digital technologies in the construction sector by providing, e.g., e-services or by issuing building permits and keeping the repository of building data.

Tool developments need therefore to follow changes in the design process, which is now requested to become more collaborative. In this regard, tools’ evolution should focus also on direct and support the environmental assessment to all the stakeholders involved. With the establishment of such new approaches, next generation products will aim to frame the building and design process, as a whole, in a holistic way.

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Appendix

I) Survey: comprehensive answers

In the following tables, all outcomes are collected. All comments provided by participants are reported as well.

	2. Use case										3. Intended users?											4. Level of LCA knowledge			5 LCA Tool category		
	Assessment	*Choice*	*Improvement*	*Product comp*	*Projects comp*	*Buildings Comp*	*Marketing*	*[Labeling / Certification]*	*standards]*	*urban designs]*	*Product manufacturer*	*[Building designer*	*[Consultant*	*Auditor*	*[Contractor*	*[Building owner*	*[Financier*	*[Tenant / user*	*[Service provider]*	*[Authority]*	*[Researchers]*	*None*	*Basic*	*Advanced*	*[Pure calculation]*	*[Complex tool*	*With benchmarks*
Pleiades	X	X	X	X	X	X		X		X		X	X	X	X	X		X		X	X		X			X	X
FCBS CARBON		X	X									X	X				X			X		X			X		X
GPR Building	X		X		X			X				X	X							X		X			X		
CAALA	X	X	X		X							X	X	X		X		X				X				X	X
One Click LCA	X		X	X	X			X				X	X											X	X	X	X
SimaPro	X		X	X		X			X			X	X											X	X	X	
PHribbon	X	X	X		X	X						X	X											X		X	X
LCAUS (n.r.)	X	X	X		X	X						X									X		X		X		
BIMEELCA	X	X	X									X	X										X			X	X
The ZEB tool	X	X		X	X							X	X											X	X	X	
TOTEM tool	X		X		X							X											X			X	
Energy Plus; eQuest; Athena Impact + Tally	X	X	X		X							X	X											X		X	
LCAbyg	X		X	X	X	X		X				X	X	X	X								X			X	
Enerweb	X		X		X				X			X			X								X		X		
Lesosai	X	X	X	X	X				X			X	X							X			X		X	X	X
GREG	X	X	X		X			X	X			X	X											X	X		
SBToolCZ, Envimat	X	X	X		X		X	X	X		X	X	X			X	X	X		X			X			X	X
TOTEM	X		X		X							X			X					X		X			X		
GENERIS	X		X	X	X	X		X				X	X	X									X			X	X
LCA_US	X	X		X	X							X												X	X		
Sphera GaBi	X	X	X	X		X		X			X	X	X			X	X			X				X	X		

	6. Lifecycle stages							7. Design phase(s)										8. Direct submission to certification authorities															9. Support options					
	A1A3	*A4-A5*	*B1-B5*	*B6*	*Urban system*	*C+D*	*[Other-module D optional]*	*. [0 - Strategic Definition]*	*[1 - Preliminary studies]*	*[2 - Concept design]*	*[3 - Developed design]*	*[4 - Technical design]*	*[5 - Construction*	*[6 - Handover commissioning]*	*[7 - Operation Management]*	*[8 - End of use, Recycling]*	*[Other - All stages]*	*Available*	*[DGNB]*	*[BNB]*	*[DGNB Dk]*	*[French E+C- label]*	*[BREEAMM*	*[SNBS]*	*[GLA]*	*[RICS calculation]*	*[MPG]*	*[Sméo]*	*[Lenoz]*	*[Minergie-ECO]*	*[LEED]*	*[Manual]*	*[Webinar]*	*[Tutorial]*	*[FAQ]*	*[Hotline - Helpdesk]*	*[Trainings]*
Pleiades (+ EQUER)	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X		X				X										X	X	X	X	X	X
FCBS CARBON	X	X	X	X	X	X		X	X	X								X							X	X						X		X			
GPR Building	X	X	X	X		X			X	X	X	X	X			X		X									X					X	X	X	X	X	X
CAALA	X		X	X		X	X	X	X	X	X	X						X	X	X												X	X	X	X		X
One Click LCA	X	X	X	X	X	X		X	X	X	X	X						X														X	X	X	X		X
SimaPro	X	X	X			X		X	X	X	X		X			X																X	X	X			X
PHribbon	X	X	X	X		X				X	X															X						X	X				
LCAUS (not regist)	X	X	X	X		X					X	X	X	X	X	X																					X
BIMEELCA	X	X	X	X		X				X	X	X	X																			X					
The ZEB tool	X	X	X	X	X	X			X	X	X	X				X	X															X					
TOTEM tool	X	X	X	X		X				X	X	X																				X	X	X	X		X
Energy Plus; eQuest; Athena Impact+ Tally	X	X	X	X		X				X	X	X			X																X	X	X	X	X		
LCAbyg	X	X	X	X		X			X	X	X		X		X	X		X			X											X	X	X			X
Enerweb		X							X	X	X							X												X		X			X	X	X
Lesosai	X	X	X	X		X			X	X	X	X						X										X	X	X		X		X	X	X	X
GREG	X			X		X				X	X	X						X												X		X		X			
SBToolCZ, Envimat	X		X	X							X	X	X	X	X			X														X	X	X			X
TOTEM	X	X	X	X		X					X	X	X	X									X									X	X	X	X		X
GENERIS	X		X	X		X				X	X	X		X		X		X	X	X			X									X	X	X	X	X	X
LCA_US	X	X	X	X		X		X	X	X	X	X	X																								X
Sphera GaBi	X	X	X	X		X		X	X	X	X	X	X	X	X	X																X	X	X			X

	12 Production phase.			12 Construction and erection of the building.				12 Operational phase of Buildings.		
	[Energy and mass	services]	[Other]	[Type and quantity of building	transport cost	construction processes	[Other]	[Quantity of energy necessary	[Type of energy	[Other]
Pleiades (+ EQUER)			according to the geometry (possibly BIM), energy calculation etc.				% material surplus and transport distance (not cost)	No	X	the quantities (heating, cooling, hot water, lighting, ventilation...) are calculated by the associated energy simulation tool
FCBS CARBON			Building form only, and selection from pre-curated list of components	X				X	X	
GPR Building	X	X		X	X	X		X	X	Operational energy is evaluated, but is excluded from MPG performance assessment
CAALA			link to CAD model or import of existing building					Yes		calculation done by tool
One Click LCA	X			X	X			X	X	
SimaPro	X			X	X	X				
PHribbon	X			X				X	X	
LCAUS (not regist)	X			X			Distances from factories to site. Mean of Transport.	X	X	
BIMEELCA	X			X				X		
The ZEB tool	X	X	depending on the availability of generic and/ or specific data	X				X		
TOTEM tool										
Energy Plus; eQuest; Athena Impact+ Tally										
LCAbyg			Included in the phase data	X		X				Included in the phase data
Enerweb				X						
Lesosai			Data come from database	X		X			X	energy are calculated
GREG										
SBToolCZ, Envimat	X	X						X	X	
TOTEM			type and quantity of materials	X						the energy demand based on the U-values

GENERIS			Mass of products				X	X
LCA_US	X	X		X	X	X	X	X
Sphera GaBi			Default avaragae	X	X	X	X	X

	12. Urban Systems during the Use phase.				12. Renovation and Maintanance Activities.					12. Building End-of-Life.			
	[Type and quantity of energy]	*other user-dependent energy*	*[Possibly type and volume of person and goods transport to / from location]*	*[Other]*	*[Time interval*	*[Type and mass/energy flows*	*[Time interval (elements substitution, building retrofit and refurbishment)]*	*energy flows for renovation activities]*	*[Other]*	*[Type and volume of demolished including]*	*possible re-usable material /*	*recyclable material / systems]*	*[Other]*
Pleiades (+ EQUER)	X	X	X	water mains leakage, waste sorting system, streets, district heating characteristics, pipes, parks with water needs etc.			X	X	derived from the geometry and life spans	X	X	X	derived from geometry, the input is the type of EoL process
FCBS CARBON	X						X			X			
GPR Building								X	maintenance is included				EOL mostly included
CAALA					X				RSLs integrated	X			calculated by tool
One Click LCA	X	X			X		X			X	X	X	
SimaPro					X	X	X	X		X	X	X	
PHribbon							X			X		X	GIA based, materials assessed at disposal by the proportion of recycling, incineration and landfill.
LCAUS (not regist)						X		X		X	X	X	
BIMEELCA					X		X			X			
The ZEB tool				more in The ZEN tool	X					X			
TOTEM tool													
Energy Plus; eQuest; Athena Impact+ Tally													
LCAbyg					X		X						
Enerweb													

Lesosai	X	X	X	X					by default value
GREG									
SBToolCZ, Envimat									
TOTEM					automatically calculated				automatically calculated
GENERIS	X		X			X			
LCA_US	X	X	X	X		X	X	X	
Sphera GaBi	X		X			X	X	X	

	13. Underlying data basis														14. System levels				
	[Environmental Product	*[Comment]*	*[Ecoinvent]*	*[Comment]*	*[GaBi]*	*[Comment]*	*[Global LCA Data Access (GLAD)]*	*[Comment]*	*[Ökobau.dat]*	*[Comment]*	*[Further generic construction materials databases]*	*[Comment]*	*[Other]*	*Other comment]*	*[Districts]*	*[Building stock]*	*[Building]*	*[Building parts / component]*	*[Material]*
Pleiades (+ EQUER)	X	French EPDs INIES	X	v2.2 will soon be replaced with 3.4											X	X	X	X	X
FCBS CARBON	X										X	ICE database					X	X	X
GPR Building	X		X	v 3.6							X	NMD 3.0 (National Environmental Database)					X	X	X
CAALA	X								X					upload possible	X		X	X	
One Click LCA	X																X	X	X
SimaPro	X		X													X	X	X	X
PHribbon	X	around 300 entries											ICE database and Building Transparency.org.	additional 141 entries from ICE.			X		X
LCAUS (not regist)			X	V2.0												X	X	X	

BIMEELCA	X	European	X	Version 3										X	X
The ZEB tool	X		X			X							X	X	X
TOTEM tool															
Energy Plus; eQuest; Athena Impact+ Tally															
LCAbyg	X	The user can inset EPDs				X	2020						X	X	X
Enerweb										KBOB-List	Official KBOB list of Switzerland		X	X	X
Lesosai	X	Customer data				X	2016	X	kbob list	materialsdb.org	different LCA databases	X	X	X	X
GREG															
SBToolCZ, Envimat	X		X					X	Envimat.cz				X	X	X
TOTEM	X	will be included in the course of 2021	X										X	X	
GENERIS	X					X	2021	X	ESUCO 2011				X	X	X
LCA_US			X	v2.0										X	X
Sphera GaBi	X				X	X								X	X

	15. Templates or default values		16. Predefined building schemes (		17. Parameters used calculation.			
		[Comment]		*[Comment]*	*[Life Cycle Impact Assessment Characterization method]*	*[Conversion factors for quantity calculation]*	*[Algorithmic generation of building quantities]*	*[Not full LCA calculation, Embodied CO2 only - RICS guidance]*
Pleiades (+ EQUER)	X	Materials characteristics (e.g. densities), typical life spans, transport distances, electricity production mix, water mains leakage, occupancy profiles (number of occupants, use of electricity, water consumption...)	X	French E+C- label	X	X		
FCBS CARBON	X	Tool is entirely based on standard components and materials, enabling quick design choices to be made at early stages. Direction and magnitude of decision impact is key at early stages.			No	X	X	Algorthimic generation of building quantities based on basic building parameteres (height, footprint, etc.) Standard component list.

GPR Building	X	Reference buildings of different types	X	Building-type specific technical life time	X	
CAALA	X	All default materials are set based on typical variants (e.g timber, concrete). They can be changed and adapted				X
One Click LCA	X	EPDs	X	BREEAM		X
SimaPro					X	
PHribbon	X	There are templates for the comparison constructions, which can be one of the options shown.				X
LCAUS (not regist)					X	
BIMEELCA	X	From EPDs and Ecoinvent			X	
The ZEB tool					X	X
TOTEM tool						
Energy Plus; eQuest; Athena Impact+ Tally						
LCAbyg	X	Library	X	DGNB DK	X	
Enerweb						X
Lesosai	X	coming from standard SIA2032, label Minergie ECO and Lenoz			X	X
GREG						
SBToolCZ, Envimat			X		X	X
TOTEM	X	standard building elements that can be modified by the user. User can copy elements from the library and modify or delete existing layers				
GENERIS	X		X	DGNB; BNB ; BREEAM International NC 2016		
LCA_US					X	
Sphera GaBi	X	Lots of default values for practically everything	X		X	

	18. Are the LCA data sources modified, selected or complemented prior to their provision to the user?		19. Data output: results presentation							
		[Comment]	*[Spreadsheet Document]*	*Template Report (PDF, DOC, etc.*	*[Extensible Markup Language (XML)]*	*[Dashboard for results visualization]*	*HTML document browser]*	*[In BIM Model directly]*	*[json]*	*[No template presentation upon the assessor]*
Pleiades (+ EQUER)	X	Contextualization of products that are mainly national (e.g. concrete), calculation of some indicators not provided in ecoinvent (e.g. CO_2 including biogenic according to forest management for wood)	X	X	X	X				
FCBS CARBON	X	Standard material EPD data is converted to workable building elements, that are then presented as components for use within the tool.	X	X						
GPR Building				X		X				
CAALA				X		X	X			
One Click LCA			X	X		X				
SimaPro	X	Nationalized.	X							
PHribbon	X	Units in the EPDs vary widely and can be awkward, so they are generally converted to $kgCO_2$ per m3, that allows a crosscheck for consistency too. Sometimes materials are in other units, e.g. per m2 if the thickness is not generally known, e.g. for carpet. Or per m for I-beams and Easi-joists. They can also be per kg or per kWh for ASHPs, these are not generally converted from the EPD.	X							
LCAUS (not regist)				X						
BIMEELCA								X		
The ZEB tool			X	X		X				
TOTEM tool										
Energy Plus; eQuest; Athena Impact+ Tally										
LCAbyg			X	X		X			X	
Enerweb	X	It is possible to modify the data but not the default way to use Enerweb.		X		X				
Lesosai	X	For example: reinforced concrete	X	X	X	X				
GREG										
SBToolCZ, Envimat										X
TOTEM	X	ecoinvent data is combined and modified	X	X						

GENERIS			X		X
LCA_US	X				
Sphera GaBi	X	X		X	

20. Data output: results visualization

	[Pie chart/donut chart]	[Multi-level Pie Chart]	[Sunburst]	[Bar chart]	[Grouped bar chart]	[Stacked bar chart]	[Normalized bar chart]	[Multiple series 3D bar charts]	[Line chart]	[Stacked area chart]	[Sankey/Alluvial Diagram]	[Tree map]	[Heat map]	[Radial chart/spider chart/polar chart]	[Parallel coordinates]	[Pictorial unit chart]	[Scatter plot]	[Cluster]	[3D Scatter plot]	[3D Color code]	[Bubble map]	[Color map]	[Scale]	[Other]
Pleiades (+ EQUER)	X	X		X	X	X	X							X										
FCBS CARBON	X			X					X															
GPR Building	X	X																						
CAALA	X			X	X																		X	
One Click LCA	X			X		X	X																	
SimaPro	X	X		X					X						X									
PHribbon							X						X											
LCAUS (not regist)				X	X	X																		
BIMEELCA																				X				
The ZEB tool				X																				
TOTEM tool																								
Energy Plus; eQuest; Athena Impact+ Tally																								

LCAbyg		X		X	X		X							
Enerweb	X	X												
Lesosai	X	X	X	X		X		X						
GREG														
SBToolCZ, Envimat														result upon the assessor
TOTEM	X													
GENERIS	X	X	X		X									
LCA_US		X								X				
Sphera GaBi	X	X	X	X	X		X	X	X	X	X	X	X	

	21. Indicators for environmental impact assessment.															22. Results aggregation is possible?				23. Real time feedback		24. Optimization algorithms	
	GWP	ODP	AP	EP	POPC	ADPE	ADPF	PERT	PENRT	Share renewable energy	[Water use]	UBP	[Share of secondary materials]	[All core indicators]	[None]	[Element's aggregation]	[Lifecycle stages aggregation]	[Time aggregation]	[Aggregation to a single monetarized value]		[Comment]		[Comment]
Pleiades (+ EQUER)	X		X	X	X	X			X		X			X		X	X				one minute computation time for energy simulation; real time feedback imprecise	X	
FCBS CARBON	X															X	X	X		X	Designed to enable enhanced design, so feedback is key.		Not currently.
GPR Building	X	X	X	X	X	X	X	X	X				X			X	X			X			
CAALA	X	X	X	X	X			X	X							X	X			X			under development, prototype working
One Click LCA	X	X	X	X												X	X						
SimaPro	X	X	X	X	X		X	X	X							X	X						
PHribbon	X															X			X	X	Results update instantly with any change		

LCAUS (not regist)	X	X	X	X	X	X	X	X	X							X					
BIMEELCA	X	X	X	X	X	X	X	X	X						X	X		X			
The ZEB tool	X															X		X	at different stages of design to provide feedback on different material and design choices	X	Dynamo/Revit for dynamic parametric approach.
TOTEM tool																					
Energy Plus; eQuest; Athena Impact+ Tally																					
LCAbyg	X	X	X	X	X	X	X	X	X				X		X	X		X	Comparison of elements		
Enerweb								X	X			X			X			X	Calculation after every change.		
Lesosai	X		X	X	X			X	X			X			X	X				X	
GREG																					
SBToolCZ, Envimat	X	X	X	X	X				X	X	X					X			SBToolCZ is an open method, real-time feedback possible.		
TOTEM	X	X	X	X	X	X	X							X		X	X	X			
GENERIS	X	X	X	X	X	X	X	X	X	X				X	X	X					
LCA_US	X	X	X	X	X			X	X	X						X					
Sphera GaBi	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					

	25. Special features.	26. Does the tool incorporate error propagation?
Pleiades (+ EQUER)		
FCBS CARBON	The tool is designed to provide early estimates of the embodied carbon of building at an early stage, when bills of quantities are not yet available. Instead, it uses a standardised algortihm to provide guidance during design about better or worse material/form choices. Components are based on standard build-ups, modelled using EPD and ICE data. With in 30 minutes, it is expected that a building whole life carbon analysis can be undertaken, and then iterated on to find lower carbon solutions.	
GPR Building		
CAALA	link to CAD/BIM model, import and export of gbXML, simplified LCC calculation, variant comparison	
One Click LCA		

SimaPro		
PHribbon	It integrates with PHPP, the Passivhaus Planning Package. It uses quantities of materials from that and also generates a combined Embodied and Operational graph that uses operational data from the PHPP.	
LCAUS (not regist)		X
BIMEELCA	Developed via Revit API and integrated in that BIM tool.	
The ZEB tool	The ZEB tool can be used on its own to calculate embodied emissions for materials and has an input to link with simulated emissions from operation. Due to it being excel based, it can be used to model different life cycle modules depending on the availability of generic and, or specific data (EPD). Norwegian EPD are collated and linked in the EPD library in the tool and the user can use a drop-down menu to choose different materials (linked to the EPD). The ZEB Tool can be connected to REVIT using Dynamo plugin/	
TOTEM tool		
Energy Plus; eQuest; Athena Impact+ Tally		
LCAbyg		X
Enerweb		
Lesosai		
GREG		
SBToolCZ, Envimat		
TOTEM		
GENERIS	Dynamic entries Comparison of constructions and buildings	
LCA_US		
Sphera GaBI		

	27. Results deviation observed				28. Data quality									29. Is a quality assessment mechanism integrated?
	[None]	*[Sensitivity analysis]*	*[Uncertainties analysis]*	*[Other]*	*[None]*	*[Regional]*	*[Comment]*	*[Verified]*	*[Comment]*	*[Independent]*	*[Comment]*	*[Other]*	*[Other comment]*	*[Comment]*
Pleiades (+ EQUER)		X	X	only for energy calculation		X		X	ecoinvent review process					
FCBS CARBON	X				X									

GPR Building	X			X	For building product available on Dutch market	X				cat 1, 2 and 3	Two categories for verified data: cat1 for producer-specific, cat 2 for sector-specific. Andt cat 3 for generic, unverified data (mostly ecoinvent)	X	optional independent review for GPR certificate
CAALA	X			X	ökobau.dat	X	EPDs					X	simple model checker to check quantities from CAD/BIM model
One Click LCA	X					X	EPDs						
SimaPro		X		X		X						X	
PHribbon	X							X	The quality of the data is assessed according to source. the ICE database less good because less product specific.				
LCAUS (not regist)	X		X										
BIMEELCA	X			X	Only verified generic (Ecoinvent) or site-specific (EPD) datasets are considered.								
The ZEB tool	X					X	Ecoinvent and EPD					X	Database third party verified.
TOTEM tool													
Energy Plus; eQuest; Athena Impact+ Tally													
LCAbyg	X			X	DK			X	Own data				
Enerweb	X					X	KBOB	X	User specified				
Lesosai	X					X	KBOB, Ökobaudat, lenoz	X	KBOB, Ökobaudat, lenoz	user value	Epd	X	Changes showed in report: check materials values
GREG													
SBToolCZ, Envimat	X			X		X		X		.	Data sources are: EPD, Envimat.cz, Ecoinvent		
TOTEM	X		X										
GENERIS	X					X						X	check for information required for LCA or for DGNB and BNB certification submission
LCA_US	X		X										
Sphera GaBi		x		X		X		X				X	Conservation of mass automatically checked per process. Saturation of process input/outputs visual. Computability of

linear equation system automatically checked.

	30. Interoperability of your tool.												31. Workflow for data exchange.						
	[Excel/Spreadsheet]	*[Comment]*	*[Revit]*	*[Comment]*	*[ArchiCAD]*	*[Comment]*	*[Rhino & Grasshopper]*	*[Comment]*	*[SketchUp]*	*[Comment]*	*[Other custom integration]*	*[Comment]*	*[0. Manual input]*	*[1. Bill of quantities (BOQ) export]*	*[2.IFC import i*	*[3. BIM viewer association*	*[4. Use of an LCA plugin*	*[5. BIM objects enrichment*	*[Other]*
Pleiades (+ EQUER)	X		X	plugin to export or directly use Pleiades in Revit			X	export a gbXML file that can be imported in Pleiades			X	own 2-3D modeler	X		X	X	X	X	possible use of gbXML instead of IFC
FCBS CARBON											X	Manual input of 7 variables. Agnostic of software.	X						
GPR Building																			integrated visualization of building element and completeness
CAALA			X				X		X		X	Open Street Map		X			X		gbxml import
One Click LCA	X		X											X	X		X		
SimaPro	X													X					
PHribbon	X																		quantities come from the PHPP, though additional info is needed for items that are not part of that thermal model
LCAUS (not regist)	X													X					
BIMEELCA	X	Data input	X	Tool developed via Revit API													X		
The ZEB tool	X		X											X	X				
TOTEM tool																			
Energy Plus; eQuest; Athena Impact+ Tally																			
LCAbyg	X		X				X							X					
Enerweb																			

Lesosai	X	X		X		X	X		Bausoft		X	X	X	X
GREG														
SBToolCZ, Envimat	X										X			
TOTEM														
GENERIS	X	X	IFCxml	X	IFCxml		X	IFCxml				X		X
LCA_US	X									X				
Sphera GaBi										X				

32. Tool compliance with standards, guidelines, specific building assessment frameworks

	[ISO 14040 - ISO 14044]	[EN 15804]	[ISO 14067]	[EN 15978]	[ISO 21931 - ISO 21929]	[EeBGuide]	[Level(s)]	[RICS Whole Life Carbon Assessment]	[SIA 2032]	[SIA 2040]	[LENO]	[ISO 14025: 2010
Pleiades (+ EQUER)	X	X		X			X					
FCBS CARBON	X			X				X				
GPR Building		X										
CAALA	X	X		X								
One Click LCA	X			X								
SimaPro	X		X									
PHribbon								X				.
LCAUS (not regist)	X	X	X	X								
BIMEELCA		X		X								
The ZEB tool	X	X		X								X
TOTEM tool												

Energy Plus; eQuest; Athena Impact+ Tally									
LCAbyg		X							
Enerweb		X					X		
Lesosai	X			X			X	X	X
GREG									
SBToolCZ, Envimat	X	X		X	X	X			
TOTEM	X	X		X					
GENERIS	X	X		X		X			
LCA_US	X	X		X					
Sphera GaBi	X	X	X			X			

II) One-pager template draft for an exemplary tool

LCAbyg	Short description of the tool

Usability	***Functionality***	***Reliability***	***Interoperability***	***Compliance***
Intended use	**Data input**	**Error propagation**	**Data exchange**	**Compliance**
Assessment of building and building products/Improvement of environmental performance/Product comparison/Projects comparison/Comparison with reference buildings/Labelling / Certification/	A1-A3 Production phase: Included in the phase dataA4-A5 Construction and erection of the building: Type and quantity of building/construction processes /B6 Operational phase of Buildings: Included in the phase data	error propagation incorporated	Excel - Spreadsheet /Revit /Rhino & Grasshopper /	[EN 15804]/
	B6 Urban Systems during the Use phase: B2-B5 Renovation and Maintenance Activities.: Time interval /Time interval (elements substitution, building retrofit and refurbishment)]/C-D Building End-of-Life. :			
Intended user	**Underlying data basis**	**Results deviation**	**Workflow for data exchange**	
Building designer/Consultants/Auditor/Contractors/	Environmental Product Declarations (EPD) The user can inset EPDs/Ökobau.dat 2020/	None/	1. Bill of quantities (BOQ) export/	
Level of knowledge	**System levels**	**Data quality**		
Beginner X Basic Expert	Building/Building parts / component/Material	Regional DK/Independent Own data/		
Tool type	**Parameters**	**Quality assessment mechanism**		
Complex tool/without benchmarks	Life Cycle Impact Assessment Characterization method/	Not integrated		
Life cycle modules/phases	**LCA data modified?**			
Production/Transport/Construction/Renovation and Maintenance/Building operation/End of Life/	n.a.			
	Data output			
	Spreadsheet Document/Template Report			

	(PDF, DOC, etc.)/Dashboard for results visualization/json/		
Design stages	**Visualisation**		
1 - Preliminary studies/2 - Concept design/3 - Developed design/5 - Construction/ 7 - Operation and management/8 - End of use, recycling	Bar chart/Stacked bar chart/Normalised bar chart/Line chart/		
Certification scheme(s)	**Indicators**		
Direct Submission to certification authorities//DGNB Dk//////////	GWP/ODP/AP/EP/POPC/ADPE/ADPF/PERT/PENRT/ [Share of secondary materials]/		
Support	**Aggregation**		
Manual/Webinar/Tutorial/Trainings	Elements aggregation/Lifecycle stages aggregation/		
Languages	**Real life time feedback**		
Danish/	Real time feedbacks available: Comparison of elements		
Country specification	**Optimisation algorithms**		
Country specified	n.a.		