A Comparative Overview of Tools for Environmental Assessment of Materials, Components and Buildings

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ABSTRACT **Tools for the assessment of environmental performance of materials, components, and buildings are found in the form of software programs and databases. This chapter deals with the identification and analysis of assessment tools on an international level. The work is structured in four parts. The first part provides background information and introduces the topic. In the second, the categories that determine the character of software products are introduced and described. Accordingly, 26 software products are identified and listed, and ten of these are analysed in more detail. The third part of the work focuses on databases for the environmental assessment of materials, components, and buildings. Similarly to the software comparison, the categories of database features are firstly derived. Out of 21 identified and listed databases, six are subsequently analysed in more detail. The conclusions outline the life cycle assessment potentials and limitations in the architectural planning process.**

The aim of this chapter is to provide the knowledge necessary for understanding the scope of tools for ecological evaluation. Derived categories can be used to characterise any software or database product. Furthermore, the work demonstrates that presented software programs and databases can be used to assess the environmental impact of construction alternatives. Thus, the work builds the relevant facts that apply to the choice of appropriate programs and suitable databases, helps the integration of ecological aspects in the architectural planning process, and, by doing so, assists in reducing the impact of the built environment on the natural environment.

KEYWORDS environmental assessment, software, databases, characterisation, comparison

1 Introduction

Environmental assessment in the building context began after the oil crisis, when calculations of the amount of energy needed for building operation became more common. Within the last three decades, the number of green building certificates grew and with it the awareness of different life cycle phases. The production phase of building fabrics and the end-of-life scenario of a building were included in sustainability assessments and received increasing attention. Today, different methods for environmental impact quantification are available, and the life cycle assessment (LCA) represents the most common and the best regulated method in the building context (Klöpffer & Grahl, 2009).

LCA is used to assess different environmental impacts of products, processes, or services called functional units. The method compiles input and output flows and summarises resources and emissions associated with a specific functional unit. Databases and software programs are used mainly in the second phase of the LCA – the life cycle inventory, in which input and output flows are calculated. The resources and emissions are grouped with a characterisation model in the life cycle impact assessment (LCIA). According to this, the environmental impact is displayed using different indicators.

Software programs support the calculation on material, component, and building levels, as large amounts of data are involved. The first LCA flows (in the 1960s) were calculated for the depletion of resources and the generation of energy. (Guinée et al., 2011; Jensen et al., 1998) Meanwhile, a broad variety of data on building materials became available. Product related information is provided by the Environmental Product Declaration (EPD) according to the ISO standard 14025 (DIN, 2011). The variety of databases and software programs allows suitable application according to the planning phase.

For calculation on component and building levels, LCA material flows are connected to the building mass. In the first step of the LCA, that is the definition of goal and scope, the data required for creation of the life cycle inventory (LCI), as well as the materials' origin, i.e. the sources from which they are obtained, are determined. The data are collected according to the processes and are to be considered during the LCI.

2 Development of Software and Databases for Environmental Assessment

In the framework of sustainable construction and, more specifically, the growing application of LCA in the building context, impact assessment started with manual calculation and spreadsheet programs that can be considered as the first tools.

The first software product used to assess environmental impact in the building context was made in 1985 by expanding the database of a spreadsheet program of the Swiss Federal Laboratories for Materials Science and Technology EMPA, which specifically dealt with life cycle assessment (Spreng, 1995). As a result, developed LCA software products, such as Simapro, PIUSoecos and the Boustead Model, were project-specific and limited to a company's in-house use (Müller-Beilschmidt, 1996).

Against the background of the political objectives to reduce environmental impact, and the growing complexity in production processes, large amounts of data were produced, increasing the need for LCA-specific software to handle the extensive calculations (Lüdemann & Feig, 2014).

A large number of software programs for specific applications have been developed in the last 30 years. In addition to the building context, computer programs focused on the city map e.g. the NEST (Yepez-Salmon, 2011), road construction e.g. the ROAD-RES tool (Birgisdóttir, 2005), and many other industrial areas. The European Platform on Life Cycle Assessment was developed by the European Commission's Joint Research Centre (n.d.) to provide an overview of both databases and LCA software programs.

LCA software programs can be divided into 3 levels (Fig. 2.1):

- Level 1 - material,
- Level 2 - component, and
- Level 3 - building.

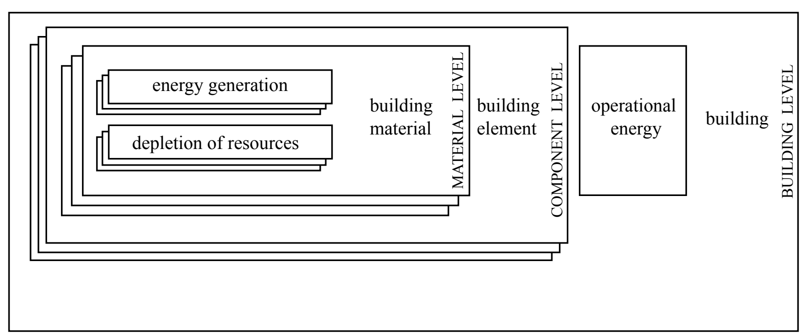

FIG. 2.1 Levels describing the scope of LCA software and databases

LCA on the material level calculates the energy and emissions related to the depletion of resources, the generation of energy, and the steps of production. The results are indicators per material, which can be used to compare different products. Computer programs like GaBi (DE), SimaPro (NL), Umberto (DE), and OpenLCA (DE) are suitable for this purpose and will be introduced later in this text (Sections 3 and 4).

The second level accumulates different materials for a building element. Different planning solutions within a product can be compared against each other. Bauteileditor (DE) represents an example of a product suitable for this purpose.

On the building level, LCA software products can contain two categories of energy; the effort to provide indoor air comfort and electricity is summed up as the operational energy for which (primary) energy and emissions can be calculated with LCA. The second category refers to the building substance and includes all building materials and components that form structure, building envelope, and all interior elements.

LCA software programs can be confused with the tools used for green building certificates. A LCA tool can be a *part* of a green building certificate but does not cover all aspects of it. According to the three pillars of sustainability, economic and social aspects also need to be evaluated for this purpose.

3 Software Programs for Environmental Assessment

For an architect or a planner, computer aided design (CAD) software products serve to provide documents that communicate the design/planning concept. The use of tools for specific application depends on the size of a project. As small projects with repetitive elements (components) are more easily presented, the level of complexity is sufficiently covered by the two-dimensional drawings. In this case, the LCA can be done with an external spreadsheet. For complex building design representations, three-dimensional modelling is more suitable and different types of information (for example, the costs) can be referred to the building volume. Ideally, the LCA is integrated in the design, construction, and detailing phases, and is developed in tandem with the project, by using ongoing internal calculations.

LCA software programs are used to calculate the environmental impact of products and services. LCA data can be applied at different stages of the architectural planning process. In the design phase, for example, LCA can be included as an optimisation parameter. Here, LCA software can be used to determine the optimal characteristics of a building, i.e. to compare different design alternatives, for example in terms of the energy needed for building operation and the energy used to produce the building's materials. In the later stages, LCA data can help to compare finalised products.

Early software products used to determine environmental impact encompassed LCA data for a single product. Today, most products compile LCA for a building volume or mass, but not all of them are able to perform the assessment in the proper sense. According to Fig.2.1, software products that conduct strict life cycle assessments work on the material level.

3.1 Software Characterisation

To characterise and compare different software programs for environmental assessment, eight categories have been identified and introduced in this work: 1) origin, 2) data source, 3) required user's knowledge, 4) accessibility, 5) entry format, 6) level, 7) default settings, and 8) life cycle phases. Characterisation aims to provide the understanding of general calculation concepts employed in software development.

Origin

NAME (COUNTRY)	PUBLISHER/DEVELOPER	WEBSOURCE
360 optimi (FI) (released in 2015)	Bionova Ltd	www.oneclicklca.com/sustainability-metrics-software
Athena (CA) (released in 2002)	Athena Institute International	www.athenasmi.org/our-software-data/impact-estimator
BeCost (FI)	VTT Technical Research Centre	www.virtual.vtt.fi/virtual/proj6/environ/ohjelmat_e.html
Building for Environmental & Economic Sustainability, BEES (US) (released in 1997)	NIST – National Institute of Standards and Technology	www.nist.gov/services-resources/software/bees
Caala (DE) (released in 2016)	Bauhaus University Weimar	www.caala.de/en
Eco Balance Assessment Tool, ECO-BAT 4.0 (CH)	Laboratory of solar energetics and building physics (LESBAT) of the HES-SO of Yverdon-Les-Bains (HEIG-VD)	www.eco-bat.ch
EcoEffect (SE)	Royal Institute of Technology (KTH)	www.ecoeffect.se
Economic Software, ECO-Soft (AT)	ECO-Soft GmbH	www.eco-soft.at/web
e-DEA (FR, DE)	EVEA and GreenDelta	www.edea-software.com
Environmental Improvement Made Easy, EIME (BE, FR)	Bureau Veritas CODDE	www.bureauveritas.com/home/about-us/our-business/cps/our-services/information-services-tools/eime
Economic Input-Output Life Cycle Assessment, EIO-LCA (US)	Green Design Institute at Carnegie Mellon University	www.eiolca.net
eLCA (DE) (released in 2013)	BBSR- BundesinstitutfürBau-, Stadt- und Raumforschung	www.bauteileditor.de
Elodie (FR)	CSTB- Centre Scientifique et Technique du Bâtiment	www.elodie-cstb.fr
Envest (UK)	BRE sustainable consulting	http://envest2.bre.co.uk/detailsLCA.jsp
Ganzheitliche Bilanzierung, GaBi (DE) (released in 1991)	PE International	www.gabi-software.com
Legep (DE) (released in 2005)	Holger König	https://legep.de
Lesosai (CH)	Solar Energy and Building Physics Laboratory (LESO-PB) of Ecole polytechniquefédérale de Lausanne (EPFL)	www.lesosai.com/de
NovaEQUER (FR)	IZUBA énergies	www.izuba.fr/logiciel/equer
OneClick LCA (FR)	Bionova Ltd	www.oneclicklca.com/green-building-software
OpenLCA (DE)	GreenDelta	www.openlca.org
REGIS (CH)	Sinum	www.sinum.com/index.php?id=30
Sustainable Buildings Specifier, SBS Building Sustainability (DE)	Fraunhofer IBP, PE International	www.sbs-onlinetool.com
Simapro (NL) (released in 1990)	PRé Sustainability	https://simapro.com
Tally (US) (released in 2008)	KT Innovations, Thinkstep and Autodesk	www.choosetally.com
Team (FR)	PwC Ecobilan Experts	https://ecobilan.pwc.fr/en/boite-a-outils/team.html
Umberto NXL (DE) (released in 1994)	Ifu Hamburg	www.ifu.com/en/umberto

TABLE 3.1 An overview of software programs for environmental assessment

Today, a broad variety of LCA software programs are available. Some software solutions were developed for a specific assessment purpose, while several others were also upgraded with an assessment function. The national background and the context of the development of the software (e.g. for business or research purpose) provide the initial picture regarding its scope and accessibility. The year of release can be an indication to measure how up-to-date or complete a program is. New programs that operate in beta-phase can be included in the optimisation process, while incorporating the latest research results. Programs that have been available for some time might have gone through optimisation and adaption to current research results (by means of updates and new version releases). The criteria aimed at describing the software program origin include *the name of a program, the country in which a program was developed, the year of release, the name of a publisher/developer*, and *the web source*.

Table 3.1 presents the overview of 26 software programs for environmental assessment that have been developed on international scale. The selection was made on the basis of online research and information from LCA experts. The detailed comparison of 10 software programs (marked in Table 3.1) was done according to the categories described below, and the results are presented in Table 3.2 and Fig. 3.1.

Data Source

Each software program for environmental assessment uses databases. The relation between software programs and databases can be described as both active and passive. A software program uses the information stored in databases and calculates the results. In a database, the data relating to a particular product or service are collected. Data source refers to either a single piece of data or the database used. While some software programs are open to different data sources, other are limited to default databases. Databases are described in more detail in Section 4 of this chapter.

Required User's Knowledge

Software programs work on different knowledge levels. The precise determination of boundary conditions allow the utilisation of software by users with limited experience. Users access a program under adjusted framework conditions. Generally, software programs developed for research institutes or consulting firms require a higher level of expertise than the programs designed for planners and decision-makers. The main levels used to describe a user's knowledge of LCA methodology are *expert*, *basic knowledge,* and *no prior knowledge*.

Accessibility

Software programs can be distinguished as those with *free access*, *conditional access*, and *paid access*. Some developers offer free access for educational purposes and paid access for professional use. Some of the software programs collect data in exchange for free use.

Entry Format

According to the input format, software programs can be divided into *based on spreadsheet* or *geometric-based* programs.

Spreadsheet-based programs offer a broad variety in relation to default settings. Some are almost blank, and therefore offer individual assessment, which requires an elaborate process, while others provide default settings and consequently obtain faster results. The input information about a material is based on mass or volume, and the boundary conditions are preset. A program associates building mass or volume with databases and the calculation is carried out automatically.

Geometric programs use 3D information to derive material volume and then connect to databases. LCA information for a building or a building element can be provided via the export of a spreadsheet.

Level
Software products can be conceived at different levels. According to Fig. 2.1, a distinction is made between *material*, *component,* and *building* levels.

Default Settings
In some programs, defaults settings are introduced to simplify and speed up the execution of the LCA. The adaptability of default settings is variable. While some products enable the user to input default settings, others predefine them without the possibility of participation or intervention on the user's part.

Relevant approaches to default settings include:

- Lifecycle phases. This approach is applied when life cycle phases cannot be evaluated separately or when only the production phase can be considered;
- Life cycle duration. The time span describing usage duration varies and thus affects the results significantly. The typical default value (often 50 years) needs to be in line with the aim of the assessment;
- Data basis. Some software products have different options for databases. In general, a suitable product would reflect its national context.

Life Cycle Phases
Standard EN 15804 (DIN, 2012) defines 16 life cycle phases: A1 – Raw material supply; A2 – Transport (to the manufacturing facility); A3 – Manufacturing; A4 – Transport (to the construction site); A5 – Construction/ installation process; B1 – Use; B2 - Maintenance including transport; B3 – Repair and transport; B4 – Replacement including transport; B6 – Refurbishment including transport; B6 – Operational energy use; B7 – Operational water use; C1 – De-construction demolition; C2 – Transport; C3 – Waste processing; C4 – Disposal; and D – Re-use recovery and recycling potential. Nonetheless, only a few software programs for environmental assessment support differentiation in this detail. For this category, each phase included in software (and available thanks to the linked database) is listed in Table 3.2.

3.2 A Comparative Overview of Software Programs

The first software solutions were used to assess simple products and energy generation processes. The German **Ganzheitliche Bilanzierung** (Holistic Assessment) and the Dutch **Simapro** programs were introduced in the early '90s. Today, GaBi, Simapro and **Umberto** have evolved into expert tools based on very detailed information, and are used mainly to assess products (Environmental Products Declarations). The use by architects (at building level) has been limited due to the extensive processing time. The focus of the German software **Legep**, released in 2005, is on building materials; the entry format is spreadsheet based and oriented according to the design stages. At the same time, **Athena**, established in Canada, is focused on material selection, by using the US units of building materials.

SOFTWARE	DATA SOURCE	REQUIRED USER'S KNOWLEDGE	ACCESS	ENTRY FORMAT	LEVEL	DEFAULT SETTINGS AND ADAPTABILITY	LIFE CYCLE PHASES
Athena (Impact Estimator for buildings)	Athena Database Details	Basic (tutorials)	Free (registration needed)	Spreadsheet	Material; Component	Default setting partly adaptable	A1-A3; A4-A5; B1-B7; C1-C2; C3; C4; D
Bauteileditor eLCA	Ökobau.dat	No prior knowledge	Free (registration needed)	Values entered in default spreadsheet	Component	Default setting not adaptable	A1-A3; C3; C4; D
BEES	Environ. Perform. Score; Econ. Perform. Score	Basic; Expert	Free (no registration)	Spreadsheet	Component	Default setting partly adaptable	A1-A3
Caala	Ökobau.dat	No prior knowledge	Beta Version is free	3D geometrical	Building	Default setting partly adaptable	A1-A3; C3; C4; D
Ganzheitliche Bilanzierung	GaBi Database; Ökobau.dat	Expert (tutorials and manuals)	Conditional access (30 days trial); Paid access (license needed)	Spreadsheet with graphical elements	Material; Component; Add on "Built-it"	No default setting	A1-A3; A4-A5; C3; C4; D
Legep	Ecoinvent; Ökobau.dat	No prior knowl-edge; Basic; Expert	Paid access (license needed)	Spreadsheet	Component; Building	Default setting adaptable; Default setting partly adaptable	A1-A3; C3; C4; D
Umberto	GaBi Database; Ecoinvent	Expert (no tutorials or manuals)	Limited access (14 days free trial); Paid access (license needed)	Spreadsheet	Material; Component	Default setting adaptable	A1-A3; C3; C4; D
Simapro	Various	Basic; Expert	Conditional access; Paid access (license needed)	Values are en-tered in default spreadsheet	Component; Building	Default setting adaptable	A1-A3; C3; C4; D
Tally	-	-	Conditional access	3D Geometrical	Building	Default setting partly adaptable	A1-A3; C3; C4; D
360 optimi	Various, for example Ökobau. dat, EPD	No prior knowledge	Free access (registration part access); Conditional access	3D Geometrical	Building	Default setting partly adaptable	A1-A3; C3; C4; D

TABLE 3.2 Comparison of a selection of software products for environmental assessment in the building context

At the beginning of the millennium, the building sector showed a growing interest in LCA data and the spreadsheet program structure was brought closer to architects. For example, GaBi developed the "Built-it" interface that organises building elements according to the DIN 276 (DIN, 2017) with iterative optimisation steps. To increase the number of users, the **Open LCA** program provided free access and included a broad variety of databases. The spreadsheet entry format was illustrated with graphical elements, but framework conditions (for example durability of elements, time span, reference unit) needed to be set by the user. Complex details supported the LCA as a niche application used by experts. The growing number of green building certificates motivated the use of LCA and defined the framework conditions and benchmarks.

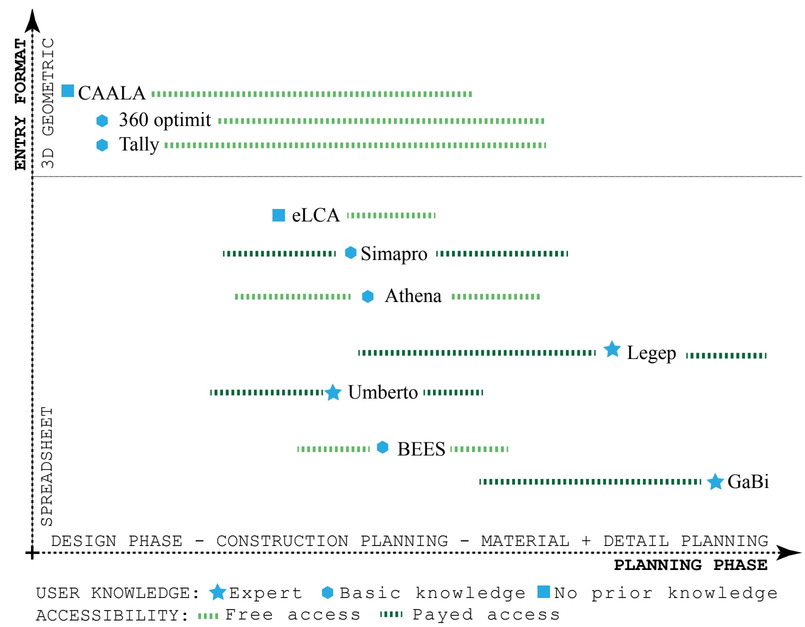

FIG. 3.1 Planning phases, user knowledge, and accessibility of software products

The spreadsheet-based tool Bauteileditior **eLCA** (Building Element Editor) limited the entry mask and provided a large amount of default settings, which allowed for easy calculation at the building element level. eLCA is able to compare planning alternatives to strengthen the application as a basis for decisions, rather than documenting the results. This free tool motivated the integration of LCA for the German context. Against the background of the increasing amount of information linked to building volume, 3D tools that provide reference points between information and building materials are increasingly more common (building information modelling – BIM). This offers the chance to connect ecological data and include it in the early design stage rather than in the phase of construction when the scope of intervention regarding environmental impact reduction is limited. **Tally** and **360 optimi** provide the link between 3D data and different LCA databases. **Caala** connects to Ökobau.dat and includes an optimisation feature, which assesses the ecological impact from the building fabric and relates it to a simplified (operational) energy calculation. In comparison, this computer program, which is currently in the Beta phase, shows the greatest number default settings that are currently non-exchangeable. In this way, design decisions regarding the cubature *and* material choice can be optimised and the LCA methodology can help to reduce the environmental impact of a building. A growing number of add-ons for computer programs like Revit (Autodesk) or Rhinoceros (McNeel) are available.

It can be stated that LCA tools were essentially developed for experts able to model framework conditions. However, built-in default settings simplified the entry format and helped to increase of the number of users.

4 Databases for Environmental Assessment

In the LCA framework, databases serve to store data for a particular flow that can, for example, refer to material resource extraction. Companies can be holders of particular LCA data, expressing the ecological characteristics of a product. Framework conditions are the key to a comparable LCA. In Europe, the comparability is most commonly achieved by compliance with the ISO 14025 that regulates the data as type III certificates (DIN, 2011) – the Environmental Product Declaration (EPD). This includes certain framework conditions for each material group and a third-party review. In the last three decades, the number of LCAs in the built environment increased and the collection of data was developed to make it easily accessible to planners and decision makers. All of the data from one base set are expected to have the same framework conditions, as a prerequisite for fair comparison. In addition to collections of particular LCA data by companies, a number of databases with generic data sets are available. These include average values of industrial data. The associations, such as World Steel, which represents more than 160 steel producers, collect the data and share them as average industrial or generic data.

Databases include LCA information on material or component levels, which are used to compare different alternatives or to calculate the environmental impact of components or buildings in order to meet a benchmark. Most software products allow all types of databases to be imported. Most of the databases provide an export in spreadsheet format. While single data can be opened with common tools like a web browser, PDF reader, or Excel, the database (the multitude of data) requires software products.

4.1 Databases Characterisation

To characterise and compare databases for environmental assessment in the building context, seven categories have been identified and introduced in this work: 1) origin, 2) validity, 3) data source, 4) accessibility, 5) reference unit, 6) referent level, and 7) geographical reference.

Origin

Most databases were initiated by the experts who conducted the LCA at the product level for companies. At some point, literature information and the data obtained by experts formed a collection that was of interest for others. The relevance of the origin and background for database formation can be illustrated on the following example:

Depletion of resources for the production of electricity is reflected in all flows that are relevant in the building industry, as they all include the electricity. The ratio of non-renewable to renewable sources varies among the countries and so do the emissions related to a product. Additionally, the transport distances from one production site to another vary between countries (Khasreen, Banfill, & Menzies, 2009). Transferability is limited and the country for which the LCA data was calculated is important in judging its scope.

Table 4.1 presents an overview of 21 databases for environmental assessment developed on an international scale. The selection was made on the basis of online research and other available information. Furthermore, six commonly used databases (highlighted in Table 4.1) were compared in detail, according to the categories described below, and the results are presented in Table 4.2.

NAME (COUNTRY)	PUBLISHER/DEVELOPER	WEBSOURCE
Agribalyse (FR)	French Environment and Energy Management Agency (ADEME)	www.ademe.fr/agribalyse
AusLCI (AU)	ALCAS (Australian Life Cycle Assessment Society)	www.auslci.com.au
DEAM TM Data for Environmental Analsys and Management (UK)	Ecobilane	www.ecobilan.com/uk_deam01_02.php
Ecoinvent (CH) (released in 2003)	Ecoinvent centre	www.ecoinvent.org
ELCD (EU) (released in 2006)	JRC (Joint Research Centre)	http://eplca.jrc.ec.europa.eu/ELCD3/
ESU World Food (EU)	ESU-services Ltd.	http://esu-services.ch/data/fooddata
EuGeos' 15804-IA (UK)	EuGeos	-
Exiobase (NL)	EXIOBASE Consortium	http://exiobase.eu
GaBi (DE) (released in 1991)	Thinkstep	www.gabi-software.com/databases/gabi-databases
Gemis Database (DE)	IINAS (International Institute for Sustainability Analysis and Strategy)	http://iinas.org/database.html
The Inventory of Carbon and Energy, ICE (UK)	University of Bath. Sustainable Energy Research Team	www.bath.ac.uk/mech-eng/research/sert/index.html
IO Database for Denmark 1999 (DK)	Who we are 2.-0 LCA consultants	-
New Energy Externalities Developments for Sustainability, NEEDS (EU) (released in 2009)	The NEEDS Project	www.needs-project.org/needswebdb
Ökobau.dat (DE) (released in 2009)	BMUB (Bundesministeriumfür Umwelt, Naturschutz, Bau und Reaktorsicherheit)	http://oekobaudat.de/datenbank/browser-oekobaudat.html
Pharos Project Database (US)	Healthy Building Network	www.pharosproject.net
ProBas (DE)	Umwelt Bundesamt	www.probas.umweltbundesamt.de/php/index.php
PSILCA (DE)	Green Delta	-
Quartz (US, DE)	The Quartz Project	http://quartzproject.org
U.S. LCI (US)	NREL (National Renewable Energy Laboratory)	www.nrel.gov/lci
USDA (US)	United States Department of Agriculture (USDA)	-
Wecobis (DE)	BMUB	www.wecobis.de/#&slider1=5

TABLE 4.1 An overview of databases for environmental assessment

Validity
LCA data have limited validity. Over time, framework conditions change and influence the results. Therefore, updates are needed to track relevant changes and to adapt the values if necessary. For this reason, the criteria to distinguish different levels of validity are *Regular updates*, *Validity is shown*, and *Validity is not shown*.

Data Source
Data sources can be distinguished as primary or *specific* data and *generic* data. Primary data are determined by the quality of a product, while generic data refer to the average data. When possible, primary data should be preferred over generic data (Prox, 2016). However, to provide a basis for decision-making in the early planning phase where the products have not yet been defined, the use of generic data is appropriate (for example, as an argument for a type of construction). Generic data sets are also suitable for research projects where few to no primary data records are available, as well as for closing the gaps in primary data sets.

Mixing databases should be avoided. Lasvaux, Habert, Peuportier, and Chevalier (2015) compared primary data with French EPD, generic data, and Ecoinvent flows, and noted a significant deviation of up to 100%.

Additionally, generic records differ within different databases (Frischknecht, 2006; Peereboom, Kleijn, Lemkowitz, & Lundie, 1998). In the literature, the LCI of a single product is carried out using different databases, in order to compare the data records. Although the numerical calculations differ greatly, the results are nevertheless comparable with respect to their relations (Takano, Winter, Hughes, & Linkosalmi, 2014).

Accessibility
In relation to accessibility, the databases for environmental assessment can be characterised as those with *Free access*, *Conditional access* and *Paid access*.

Reference unit
Relevant flows in the building context refer to either *mass*, *volume,* or surface *area*. Technically, indicators could also refer to services like one hour electricity with 1000 Watts. However, services are not investigated here, as the complex functions of materials or components do not occur in databases.

Referent level
According to the characterisation of software products, the referent levels are distinguished as *material*, *component,* and *building*.

Geographical reference
As mentioned earlier, the geographical reference is relevant in describing the scope of LCA data. It is common practise that countries without sufficient databases for construction materials use foreign data, for example, Danish architects use German data for a project in Denmark.

As this includes uncertainty, a safety margin is added for compensation. This is the best choice, but the safety margin nonetheless weakens the accuracy of results. In any case, the scope of data needs to be specified. The criteria to mark geographical references are distinguished as *national*, *European*, *international,* and *no reference*.

4.2 A Comparative Overview of Databases

The interest in LCA data for building products grew during the 1980s. At that time, Swiss, German, British and Austrian institutes started to collect data from individual products. Values calculated for specific products were mixed with the information from literature (Ecoinvent, n.d.).

DATABASE	VALIDITY	DATA SOURCE	ACCESS	REFERENCE UNIT FORMAT	LEVEL	GEOGRAPHICAL REFERENCE
Ecoinvent	Regular updates (ecoinvent 2/ 3.0, / 3.1/ 3.2/ 3.3, current version 2017); Validity is shown	Generic, specific	Paid access	Volume; Mass	Material; Component	National (Switzerland, Austria, Germany); European
European Life Cycle Database (ELCD)	Validity is shown	Generic, specific	Free access	Volume; Mass	Material; Component	European
Ganzheitliche Bilanzierung GaBi Database	Regular (annual) updates; Validity is shown	Generic, specific	Paid access	Volume; Mass	Material	No reference
Inventory of Carbon & Energy, ICE	Validity not shown	Generic	Free access	Volume; Mass	Material	National (UK); No reference
New Energy Externalities Development for Sustainability NEEDS	Validity not shown	Generic	Free access	Volume; Mass	Material	National (Switzerland, Austria, Germany)
Ökobau.dat	Regular updates; Validity is shown	Generic, specific	Free access	Volume; Mass	Material	National (Switzerland, Austria, Germany)

TABLE 4.2 Comparison of six databases for environmental assessment in the building context

All databases collect input and output flows but they vary with regard to focus and indicators. In the beginning, data sets showed differences in the time span, life cycle phases, energy supply, and other parameters. Comparability became relevant at the beginning of the 21st century and the developers of **GaBi**, **Ecoinvent** and other databases cooperated in order to develop a consistent framework format - the **European Life Cycle Database** (ELCD). Here, not only a format to display LCA results was developed, but, in addition, processes at the European level were provided with free access. At the same time, the free database **US Life Cycle Inventory** was released in the US.

At the beginning of the 2010s decade, databases were assigned a specialised focus, for example agricultural (like **Agri-footprint**), or social (like **PSILCA database**). In the building industry, national databases **Ökobau.dat** and **WECOBIS** (both in Germany), and the **Inventory of Carbon and Energy**, ICE (UK) were released. The Ökobau.

dat that originates from GaBi data was sold to the German government, which later published the free-access dataset with both generic and specific information from EPDs. The **NEEDS** database, released in 2009, included different future scenarios for energy supply (optimistic, realistic, and pessimistic).

A variety of databases are available today (Table 4.1). Giving preference to one of them depends on the national context, as the data refer to the energy generation context and the scope of assessment. While years ago, a choice about software program was defined by the type of databases, OpenLCA now enables a free choice.

5 Conclusions

In order to explore the potential of LCA, it is important not only to carry out the ecological assessment of a building, but also to include the results as support for decision-making during the early stages of the planning process, and thus to choose a solution with the least ecological impact. For this purpose, a wide range of software programs are developed, continually optimised, and adapted to meet the current state of research, user needs, and changing data.

Software products can be used in any national context. It is the database that embodies the regional reference. However, the lack of national LCA databases does not necessarily have to be an obstacle for LCA application. For example, in the US context, no open comprehensive database is available and yet the studies are conducted by researching single assessments. This is controversial with regard to the framework conditions, but it can be a first approach if no other solution is available.

Until recently, LCA tools, for the most part, did not consider the connectivity of materials, which consequently led to a choice of materials that caused ecological problems at the end of the use phase. Currently, some tools are being upgraded in terms of reintroducing the material in the life cycle (e.g., the eLCA).

Nonetheless, an integrated approach to negative environmental impact reduction should, alongside the LCA, include the considerations of operational energy, as well as the utilisation of other natural resources, such as water and free land.

References

Birgisdóttir, H. (2005). *Life cycle assessment model for road construction and use of residues from waste incineration* (Doctoral dissertation). Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.566.8489&rep=rep1&type=pdf

DIN (2011). *DIN EN ISO 14025 Environmental labels and declarations - Type III environmental declarations - Principles and procedures (ISO 14025:2006);* . Berlin: Normenausschuss Grundlagen des Umweltschutzes (NAGUS) im DIN [Standards Committee principles of environmental protection (NAGUS) at DIN].

DIN. (2017). *Building costs* (Vol. 276). Berlin: Beuth.

DIN (2012). *Sustainability of Structures - Environmental Product Declarations Basic Rules for the Product Category Construction Products; EN 15804:2012* (Vol. 15804:2012). Berlin: DIN Deutsches Institut für Normung e. V.[German Institute for Standardization]

Ecoinvent. (n.d.). *History*. Retrieved from http://www.ecoinvent.org/about/history/history.html

Frischknecht, R. (2006). Notions on the Design and Use of an Ideal Regional or Global LCA Database. *The International Journal of Life Cycle Assessment, 11*(1), 40-48. DOI:10.1065/lca2006.04.010

Guinée, J., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R, Ekvall, T., Rydberg, T. (2011). Life Cycle Assessment: Past, Present, and Future. *Environmental Science & Technology, 45*(1), 90-96. DOI: 10.1021/es101316v

Jensen, A. A., Hoffman, L., Møller, B. T., Schmidt, A, (1998). *Life Cycle Assessment - A guide to approaches, experiences and information sources*. Copenhagen, DK: European Environment Agency. Retrieved from https://www.eea.europa.eu/publications/GH-07-97-595-EN-C

Joint Research Centre of the European Commision. (n.d.). *European platform on life cycle assessment*. Retrieved from http://eplca.jrc.ec.europa.eu

Khasreen, M., Banfill, P. F., & Menzies, G. (2009). Life-cycle assessment and the environmental impact of buildings: A review. *Sustainability, 1*(3), 674-701. DOI:10.3390/su1030674

Klöpffer, W., & Grahl, B. (2009). Einleitung. In *Ökobilanz (LCA): Ein Leitfaden für Ausbildung und Beruf* [In LCA: Guidelines Education and Profession] (pp. 1-26). Weinheim, DE: Wiley-VCH Verlag GmbH & Co. KGaA. DOI: 10.1002/9783527627158.ch1

Lasvaux, S., Habert, G., Peuportier, B., & Chevalier, J. (2015). Comparison of generic and product-specific Life Cycle Assessment databases: application to construction materials used in building LCA studies. *The International Journal of Life Cycle Assessment, 20*(11), 1473-1490. DOI:10.1007/s11367-015-0938-z

Lüdemann, L., & Feig, K. (2014). Comparison of software solutions for Life Cycle Assessment (LCA)– a software ergonomic analysis, *Logistics Journal*. DOI: 10.2195/lj_NotRev_luedemann_de_201409_0. Retrieved from https://www.logistics-journal.de/not-reviewed/2014/09/3991/luedemann_2014.pdf

Müller-Beilschmidt, P. (1996). Software zur Unterstützung der Okobilanzierung- ein Überblick [Software to support Life Cycle Assessment-an overview]. In M. Schmidt & A. Häuslein (Eds.), *Ökobilanzierung mit Computerunterstützung* [Computer aided LCA] (pp. 3-10). Berlin: Springer.

Peereboom, E. C., Kleijn, R., Lemkowitz, S., & Lundie, S. (1998). Influence of inventory data sets on life-cycle assessment results: a case study on PVC. *Journal of Industrial Ecology, 2*(3), 109-130. DOI:10.1162/jiec.1998.2.3.109

Prox, M. (2016, April 19). *Erfolgsfaktor für Ökobilanzen (Life Cycle Assessment, LCA): Daten, Daten und nochmals Daten* [Data, data and data again]. Retrieved from https://www.ifu.com/knowtheflow/2016/erfolgsfaktoren-fur-okobilanzen-life-cycle-assessment-lca-daten-daten-und-nochmals-daten/

Spreng, D. (1995). *Graue Energie-Energiebilanzen von Energysytemen* [Embodied Energy- Energy assessment in energy generation systems]. Zürich, CH: Hochschulverlag AG an der ETH Zürich, B.G. Teubner Stuttgart.

Takano, A., Winter, S., Hughes, M., & Linkosalmi, L. (2014). Comparison of life cycle assessment databases: A case study on building assessment. *Building and Environment, 79*(Supplement C), 20-30. https://doi.org/10.1016/j.buildenv.2014.04.025

Yepez-Salmon, G. (2011). *Construction d'un outil d'evaluation environnementale des ecoquartiers: vers une méthode systémique de mise en œuvre de la ville durable* [Construction of an environmental assessment tool for ecoquartiers: towards a systematic approch to implement the sustainable city] (Doctoral Dissertation). Retrieved from http://ori-oai.u-bordeaux1.fr/pdf/2011/YEPEZ_SALMON_GRACE_2011.pdf