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Building Related Life Cycle Assessment (LCA) Software Tools: a State of the Art Review

unter der Leitung von

Univ.Prof. Dipl.-Ing. Dr.techn. Ardeshir Mahdavi
E 259-3 Abteilung für Bauphysik und Bauökologie
Institut für Architekturwissenschaften

eingereicht an der

Technischen Universität Wien
Fakultät für Architektur und Raumplanung

von

Vasiliki Diakoumakou
Matrikelnr.: 1328410
Fleischmanngasse 3/10, 1040 Wien

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ABSTRACT

Along with international efforts to evaluate, reduce and limit negative impact on the environment as wells as detrimental effects on human health, architectural and construction industries started to put more their emphasis on sustainability. As a consequence Life Cycle Assessment (LCA) software tools have been developed to help design and construction professionals to evaluate and document the environmental impact of the life cycle of a building.

This thesis aims to present a state of the art review on currently available building-related LCA software tools. A range of representative software tools are thoroughly assessed with respect to usability. By this case study -based upon selected tools-, the work process of these software tools will be presented and how they guide and support the decision-making in design and architectural workflow.

.

Keywords:
Life Cycle Assessment, LCA software tools, building related software tools

KURZFASSUNG

Laufende internationale Bestrebungen negative Umwelteinflüsse und Auswirkungen auf die Gesundheit zu bewerten, reduzieren und zu begrenzen haben dazu geführt dass auch Architektur und Bauindustrie einen immer wichtigeren Schwerpunkt auf Nachhaltigkeit legen. Um Architekten und Bauingenieure bei der Bewertung und Dokumentation der Umweltbelastungen währen des Lebenszyklus eines Gebäudes zu unterstützen, wurden in Folge dieses Prozesses Computer-Programme zur Lebenszyklusanalyse entwickelt.

Diese Arbeit präsentiert einen Überblick über den Stand der verfügbaren Lebenszyklusanalyse-programme für den Baubereich. Die Gebrauchstauglichkeit einer Auswahl repräsentativer Arbeitshilfen aus verschiedenen Segmenten wird detailliert bewertet. In einer Fallstudie wird der Schwerpunkt der Betrachtung auf den Arbeitsprozess selbst und die Unterstützung bei der Entscheidungsfindung im Ablauf der architektonischen Entwurfsphase gelegt.

Stichworte:
Ökobilanz, Lebenszyklusanalyse-programme, Programme für Architekten und Bauingenieure

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1 INTRODUCTION

1.1 Overview

During the last decades, the phenomenon of extensively augmented environmental emissions and pollution rates has been a concern to many Non-Governmental-Organisations (NGO's), governments and industries. Life Cycle Assessment (LCA) is currently the most commonly used technique for evaluating environmental effects caused by harmful materials, processes or misuse, throughout the life of a specific product (Reiter 2010). LCA is used by industries, governments, scientists and environmental associations and it is proved to be really helpful in the decision-making process for building environmental strategies, adopting legal regulations as well as selecting sustainable materials (Reiter 2010).

LCA software tools have been rapidly developed to help design and construction professionals to evaluate the environmental impact of the life cycle of a building. "*LCA is being promoted as a tool for analysing the environmental impact of buildings and making decisions to reduce these impacts*" (Bayer et al. 2010). The LCA process and the associated calculations and data handling, especially in the steps of inventory analysis (LCI) and impact assessment (LCIA) can be translated into software routines and database links. As a result, one could observe that a market for LCA software tools has been evolved to facilitate the LCA process.

The energy supply crisis and the issue of global climate change led the international industrial community to adopt more ecological approaches in resource management and take initiatives for the protection of the environment. For environmental management several methods and processes, including LCA, are applied.

In the early 90's, the International Organization for Standardization (ISO) defined the process of LCA and by 1997 the ISO 14040 standard for Life Cycle Assessment – principles and framework - was completed. In 2006 ISO 14044 - Life cycle assessment, requirements and guidelines – was published. Architects and building professionals use LCA methodologies in order to understand, evaluate and measure the use of energy as well as the environmental effects associated with different steps of a building's life cycle, such as product manufacture, construction, operation, and demolition (Bayer et al. 2010).

1.2 Motivation

Architects face new challenges in the building design process, as well as a growing demand not only for energy efficient buildings but also for sustainable constructions. The goal is actually to design constructions with reduced environmental impact while respecting the requirements for a detailed documentation of the building design process.

In order to achieve all these, loads of methods and tools have been developed to quantify and compare ecological parameters. LCA is one of these tools and there is a great variety of LCA software available. They range from easy to use to more complex ones; those designed for specific applications; those who target at different user groups.

Previous research and reviews on LCA software tools have been primarily done in Europe and the United States of America (Bayer et al. 2010). These publications evaluated the effort and the efficiency in computational design (Mahdavi et al. 2004), general requirements for LCA software tools (ISO 14040 2006, ISO 14044 2006, Beigl et al. 2004) and gave an overview of various LCA software tools (Herrmann et al. 2014). However, some of the listed software tools which have been updated in terms of functionality receded and were slowly disappeared from the market.

The aim of this thesis is to give an up-to-date overview on currently available LCA software tools for the building sector, to present characteristic segmentation parameters and to mark development trends. Furthermore, this thesis aims to evaluate the usability of selected software segments and tools and to demonstrate by a case study how the user is guided by these tools towards sustainable solutions and ecological building designs.

1.3 Life Cycle Assessment

As a consequence of international efforts to evaluate, limit and reduce negative impact on the environment and health, a series of new standards was developed. In 1996, the ISO 14000, which is related to environmental management, was drafted.

The main forces for the continuous development of environment assessments can be described by the following examples:

- Legal regulations on "life cycle accountability" (EPA 1997) put greater ecological responsibility on manufacturers and designers.
- Businesses participating in ecologically responsible programs emphasize their ecological awareness more and more on their marketing campaigns.
- There is a tendency of raising consumers' environmental awareness and

sensibilisation and making focus on the development of further governmental policies..

One of the described processes and instruments for ecological analysis is Life Cycle Assessment. According to International Standard ISO 14040 (2006), LCA is a "*compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle*". It is a process for the evaluation of environmental impacts caused by a product or by a process on the whole. The environmental impact is assessed by material quantity and incorporated energy which permits the comparison and the optimization of design options that can eliminate negative environmental effects.

Life cycle stages

Every product or process goes through various steps or stages. Each stage is associated with a set of activities. For general products, the life cycle stages of a product are the extraction of raw materials, the manufacturing, the distribution and transport, the usage and the end of life (see Figure 1-1).

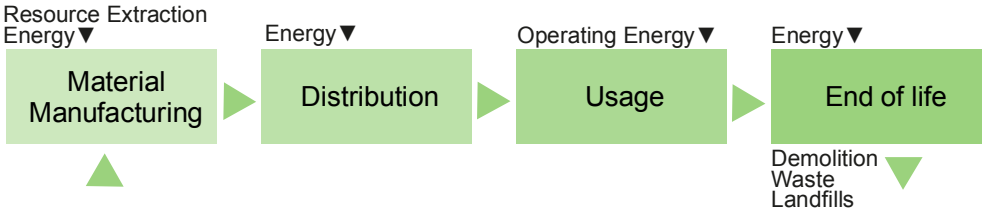


Figure 1-1 - LCA cycle

Phases of the LCA process

LCA is a process which enables the systematic analysis of complex product systems (Wimmer et al. 2004). According to ISO 14040 (2006) the Life Cycle assessment consists of four phases (Figure 1-2):

- **Definition of goal and scope:**

  This phase identifies, defines and specifies the objectives and purpose of the LCA, the product to be analyzed, the system limits and boundaries of the specific assessment and any necessary assumptions. Questions addressed are "what is the purpose of the study?", "what is it included or excluded from the assessment?", "what are the limits of the system?" and "what data is required for the analysis?"

- **Inventory analysis (LCI):**

  Identification and quantification of ecological impacts caused by the object of the assessment. An inventory of energy and raw material input as well as for

emissions and waste output is established either for the life span of a product or for specific stages of its life cycle. Typical procedures include dealing with material, energy quantities and emissions. Their effect is translated into environmental impact factors and indicators in order to compare different project setups.

- **Impact assessment (LCIA):**

  Analysis and evaluation of environmental impacts based on the results of the inventory analysis (LCI). The steps of the LCIA are:

  - Selection and definition
  - Classification of LCI results
  - Characterization of categories
  - Normalization

  The identified and quantified impact factors are grouped and may be weighted according to their importance and their impact on human health or other ecological impacts and risks.

- **Interpretation of results:**

  In this step the assessed impacts and results of the previous steps undergo an analysis and evaluation with respect to the goals that have been set. Potential reduction of product impacts is reviewed as an effort of reducing or limiting the effects of the assessed system on the environment (e.g. reducing energy or material input) is been made. Final conclusions, limitations and recommendations are established and may be the basis for a constant repetition of the process.

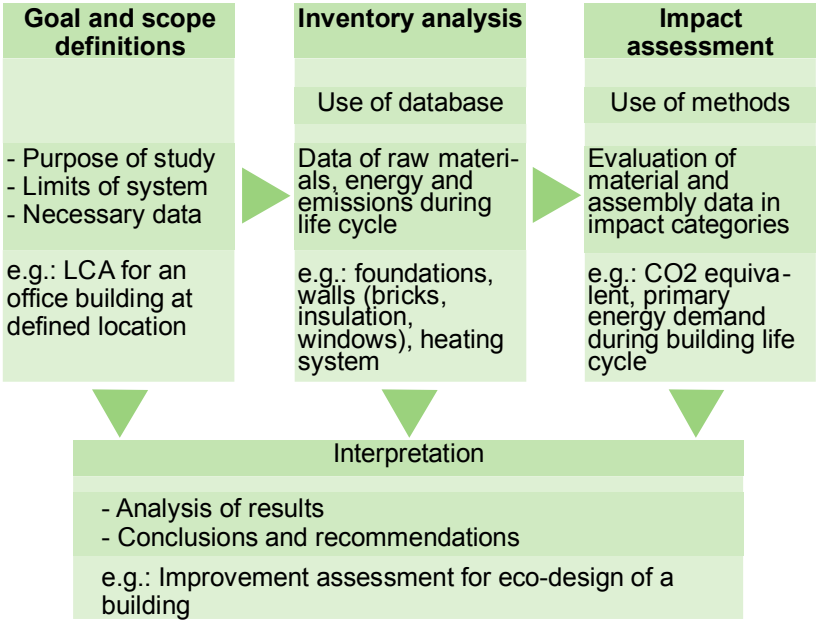


Figure 1-2 - LCA phases (ENSLIC Building 2007)

Process-based LCA Methods

The complete LCA process analyses the environmental impacts associated with all stages of a product's life from cradle to grave. In the goal and scope definition however, the process can be limited or focused on specific elements of the life cycle. Typical definitions are (see Figure 1-3):

- Cradle-to-Grave: this is a full LCA method taking into consideration the extraction of resources, the manufacture of the products, throughout the usage phase up to the final disposal.
- Cradle-to-Cradle: this is a specific type of LCA method where the final disposal of the product is a recycling process. In this case the product is recycled into a new product or it is reused.
- Gate-to-Gate: this is a partial LCA method that takes into account only one part of the process, e.g. the impact of a product from the manufacture site “gate” to construction site “gate”.
- Cradle-to-Gate: this is a partial LCA method that takes into account the impact of a product from the manufacture of raw materials to the fabrication (factory) “gate” or to the construction site “gate”

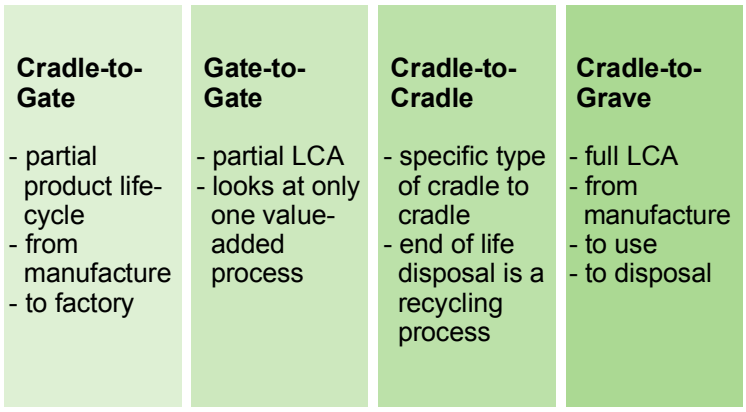


Figure 1-3 - LCA process stage limits (Bayer C. et al. 2010)

Impact categories

The production and the usage of a product consume raw materials and energy and produces emissions and waste. The amalgam of these emissions and waste has a negative effect on the environment (air pollution, water pollution, earth pollution, human health problems, and loss of natural resources). LCA quantifies the used resources and environmental emissions, and evaluates their impact on the environment throughout its life cycle.

The ENSILC project (ENSLIC Building 2007) describes five environmental impact categories with the related impact indicators used in the building sector (see Table 1-1)

Table 1-1 - Impact categories

Impact categories	
Resources • Abiotic resources depletion • Cumulative energy demand (total and non- renewable part) • Water consumption • Energy to extract minerals and fossil fuels • Land use • Resource factor **Air pollution** • Global warming potential • Ozone depletion potential • Acidification potential • Photochemical oxidant formation (summer smog) • Winter smog • Odors	**Water pollution** • Aquatic Eco-toxicity • Eutrophication potential **Soil pollution and waste** • Soil waste • Radioactive waste • Terrestrial eco-toxicity **Health, biodiversity and damages** • Human toxicity • Heavy metals • Carcinogenesis • Ionizing radiation • Disability Adjusted Life Years • Biotic resources depletion • Potential disappeared fraction

According to W. Wimmer et al. (2004) the most common environmental impact categories examined by an LCA study are:

- **Global warming:**

  refers to the increase of atmospheric temperature, caused by the greenhouse gases like CO_2, CH_4 and N_2O. The effect causes climate change on our planet leading to extreme weather conditions, melting polar caps and flooding of low lands and islands. The measurement unit is grams equivalent of CO_2 per functional unit of the product ($grCO_2$ eq/kg) (Wimmer et al. 2004).

- **Ozone depletion:**

  is the decrease of the stratospheric ozone layer of the planet which is caused by chlorinated compounds like CFC-11 (Freon). The reduction of the ozone layer allows short wave radiation to pass through the atmosphere and cause damages to flora and fauna as well as provoke health problems to human beings, such as skin cancer and eye cataracts (Lippiatt 2002). The measurement unit is grams of CFC-11 per functional unit of the product (gr CFC-11 eq/kg).

- **Acidification:**

  is the increase of hydrogen ion concentration in water caused by the acidifying gases like NO_X , SO_X and NH_4 ammonium. They reach the ecosystem through dissolution in rain (acid rain) or in wet depositions. Acidification affects trees, soil, buildings, animals, and humans. The measurement unit is grams of hydrogen ions equivalent per functional unit of the product (gr H+ eq/kg) (Wimmer et al. 2004, Lippiatt 2002))

- **Eutrophication:**

  refers to the increase of chemical nutrients in soil or water, such as nitrogen and phosphorous, causing undesirable shifts in the number of species in ecosystems and a reduction in ecological diversity. In water, for exemple, it is observed the seaweed invasion, which can lead to a lack of oxygen and consequently the decease of aquatic life. The measurement unit for marine water is grams of nitrogen equivalent per functional unit of the product (gr N+ eq/kg) and the measurement unit for inland water is grams equivalent of phosphorous per functional unit of the product (gr PO4+ eq/kg) (OECD 2005).

- **Abiotic resources depletion:**

  is the use of non-renewable resources like crude oil, natural gas, coal and bauxite. The shortage of natural resources will lead the human society to different lifestyles, with the forthcoming need of relying on substitutes for resources to sustain human society (Wimmer et al. 2004). Measurement unit is mega-joules (MJ) of fossil-based energy per functional unit of the product (MJ/kg).

- **Photochemical oxidant formation:**

  refers to the increase of air emissions caused by industry and transportation which are trapped at ground level, where they react with sunlight and produce photochemical smog. The smog can cause breathing problems to humans and growth disturbances to plants. The measurement unit is grams equivalent of ethylene C_2H_4 per functional unit of the product (gr C_2H_4 eq/kg).

1.4 Building related LCA

The LCA for buildings follows the basic definition of the main steps of this process and the methods as indicated above. In some cases, more specific ones, regarding building materials, products and constructions, there can be seen slight differences on the assessment description.

Building products

Buildings are typically built or assembled in several production steps, in each and every one of which having an impact on the environment. As a consequence, software tools are designed for specific building products. Figure 1-4 shows the system of building products and their degree of complexity.

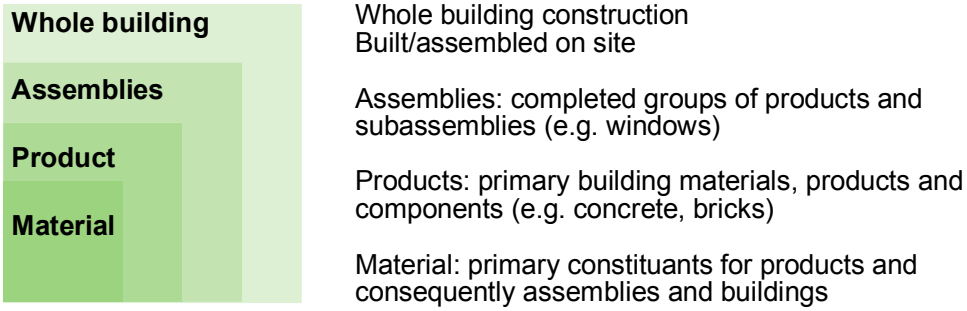


Figure 1-4 - Building products

Life cycle stages

Following the characteristics of building products, the typical LCA stages for buildings are the manufacture of the primary products (e.g. concrete), the production of sub-assemblies and assemblies (e.g. windows), the building construction, the use and maintenance phase, and the demolition and the end of life. For some products, the materials return into a new life cycle via a recycling process.

Figure 1-5 shows the LC stages according to AIA (Bayer et al. 2010):

- Material manufacture takes into account the extraction of raw materials, the transportation, the production of the building products, the packaging and their distribution.
- Construction refers to elements like site work, the amount of energy used and all the activities related to the construction.
- Use and maintenance covers the operating energy, the water use and a potential renovation

- In the end of life one takes into account the necessary energy for demolition, the waste itself and the transportation to the landfills or to the places where recycling is proceeded.

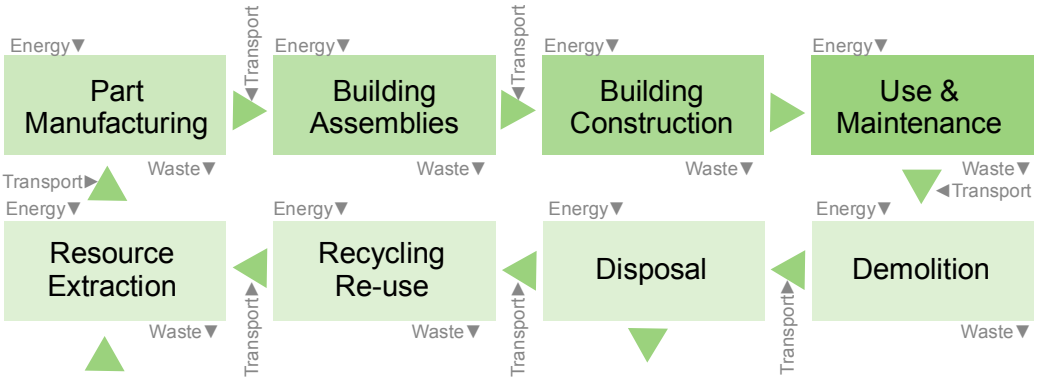


Figure 1-5 - LCA cycle for buildings

Embodied energy and operating energy

During the life cycle stages of a building, all the processes require energy. The total energy used for the products during the extraction, processing, manufacture and transportation of building products to the building site, as well as its final demolition and disposal is subsumed under the term "embodied energy".

The total energy required for heating, cooling, lighting and other appliances of the building during the use phase of the life cycle is defined as "operating energy".

According to Ramesha T. et al. (2010), 80-90% of the totally consumed energy in the life cycle is used for the operation of standard type buildings (operating energy). The embodied energy accounts for only 10-20% of the total energy.

With the development of regulation requirements, which have a focus on buildings with better energy performance, part of the operating energy for the use period of the building is declining. As consequence, the impact of the embodied energy of the building construction becomes more significant (Mumma 1995) and can reach 45% of the total energy consumed in low energy buildings (Thormark 2001) with a life cycle span of 50 years.

On the other hand, increased recycling potential leads to reduction of embodied energy values for new products.

1.5 LCA tools

Software tools provide assistance and support through the LCA, do the calculations for the inventory analysis and support the decision-making processes by providing clear information, which can be used for the interpretation of the results.
According to CMHC (2004), Annex 31-"Types of tools", there are two categories of tools: a) the interactive software for the decision making framework and b) the passive tools for the environmental framework (see Figure 1-6).

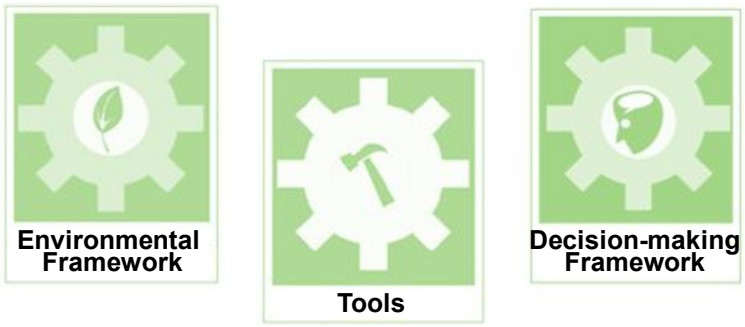


Figure 1-6 - LCA tools (CMHC 2004)

Interactive software - for the decision-making framework:

- LCA tools for buildings, due to the complexity of the LCA process and of buildings, are usually based on computer programs linked to databases, and
- Energy and ventilation modeling and simulation software, which are used to optimize the energy performance in the operating phase of a building. Yet, they do not provide information about the environmental impacts. In some cases, they interact or are linked with LCA tools.

Passive tools - for the environmental framework:

- Environmental assessment frameworks and rating systems
- Environmental guidelines or checklists for design and management of buildings
- Environmental Product Declarations (EPD), catalogues, reference information and certifications and
- Labels.

1.6 Software tools for building related LCA

With respect to the categories of building products (see above) the building related software tools are developed for specific classes of building products (see Figure 1-7):

- **Building products:**

  Building products refer to building materials and products which are typically used along with finished assemblies (e.g. windows) or in the on-site construction process of the building

- **Whole buildings:**

  Whole buildings refer to the completed building product (e.g. residential building), such as materials, products (e.g. concrete, bricks) and subassemblies (e.g. windows) used for the building construction

- **Building assemblies:**

  Building assemblies are intermediate building products, made from materials and "products" (e.g. plastic, glass, sealing for windows) or from other sub-assemblies.

  For this group of intermediate building products there are no specific software tools; it is the tools for building products or the tools for whole buildings that are normally used.

- **Databases**

  Databases are important elements of software tools. They do not represent a software tool by itself, but they provide instead the necessary data for the inventory analysis and the impact assessment.

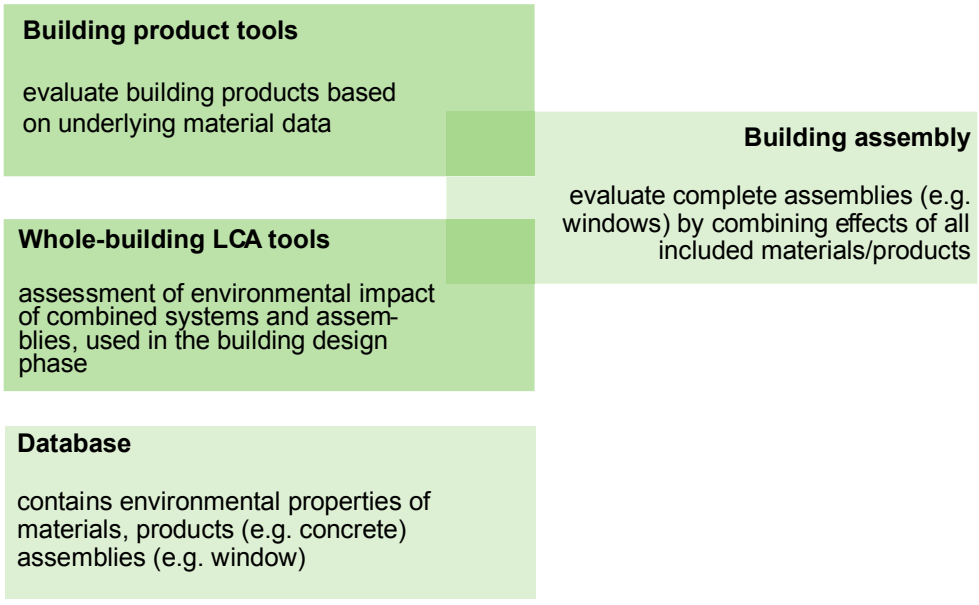


Figure 1-7 - Building related software tools

2 METHODOLOGY

2.1 Overview

The LCA process and its required calculations and data handling, especially in the steps of inventory analysis (LCI) and impact assessment (LCIA), can be relatively easily translated into software routines and database links. As a consequence, a market for LCA software tools is evolved with the establishment of the LCA process. The market is strongly influenced by national standards and in the beginning of its development it was relying on the scientific community and university projects rather than on development projects initiated by established software companies. The development of a dynamic market leads to a high rate of new upcoming products as well as to the fact that many products are discontinued.

This project presents a snapshot of the current market and the developments in the field of building-related LCA software tools. These tools will be reviewed in three steps. The current market is analysed, the usability of representative tool samples is evaluated and a subset of these tools is applied on a realistic refurbishment project.

The respective chapters cover (see Figure 2-1):

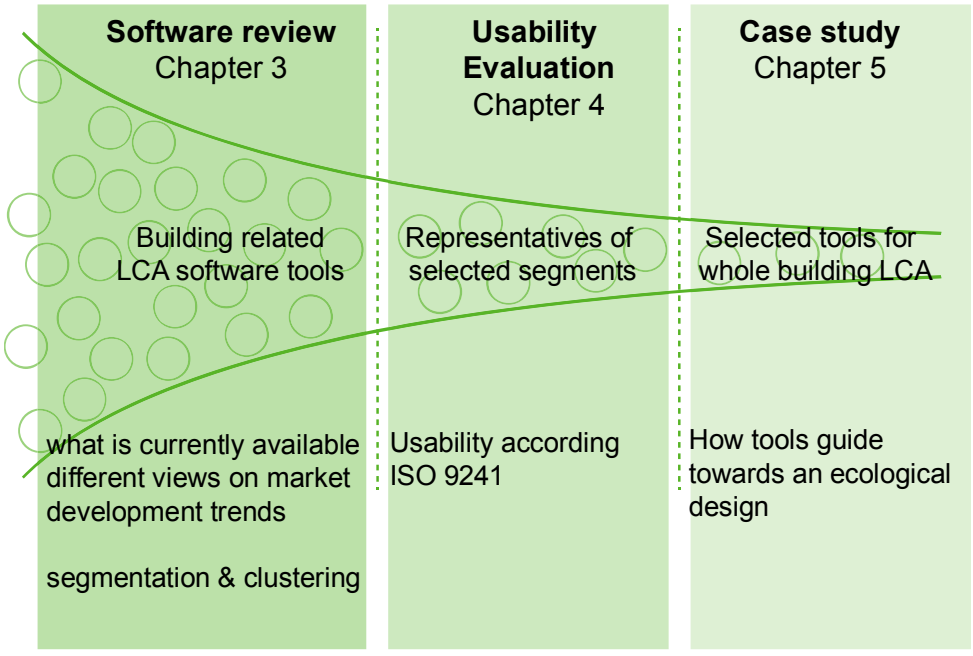


Figure 2-1 - Methodology

- **Software review**

  shows the results of the market research with respect to regional aspect and software application levels. In addition, the development of building related LCA software tools over time and development trends are presented. Finally current tools are clustered according to their applications, their types and the tool level.

- **Usability evaluation**

  Based on the above LCA software clustering, representative tools per category are selected and they are evaluated for their "usability" according to software quality standards. A set of criteria is defined for this evaluation and the selected software is tested on a simple sample project. As the evaluation merely compares representatives of previously defined segments only, it does not represent a ranking of these tools.

- **Case study**

  For the segment of tools for the LCA of whole buildings, the above selected software tools, are tested on a more realistic project. The sample case is a refurbishing project for a residential building. The application of the tools and how the user is guided to an ecologically sustaining solution is extensively described.

2.2 Hypothesis

Trends and the simulated applications in form of a sample project, highlight that the capability of integration into an architect’s workflow is the central point for the selection and usage of the LCA software tools.

Due to differences in national standards and regional building regulations and requirements, and last but not least to different languages the market of LCA tools can be still considered very fragmented.

The software tools can make the complex LCA process easily accessible and can guide architects towards an optimal ecological and sustainable design. Trends towards a higher degree of integration into a building related software framework are necessary for the usability and the avoidance of multiple work processes in the design phase.

2.3 Scope

This project is focused on building related LCA software tools and especially for the architectural and design workflow (design phase). "Building related" in the sense of an LCA done for whole building constructions, for assemblies and for products, materials and energy forming the basic inputs for the building (see Figure 2-2).

The LCA process evaluates the environmental impact of a product for process steps (e.g. cradle to grave) and refer to defined boundaries (e.g. physical boundary). Material flow analysis (MFA) evaluates material, energy balances and impacts for a wider boundary set, e.g. for industrial sectors, regions, nations or eco-systems (see Figure 2-2). As this review refers to LCA tools, MFA tools (e.g. STAN tool) are not included.

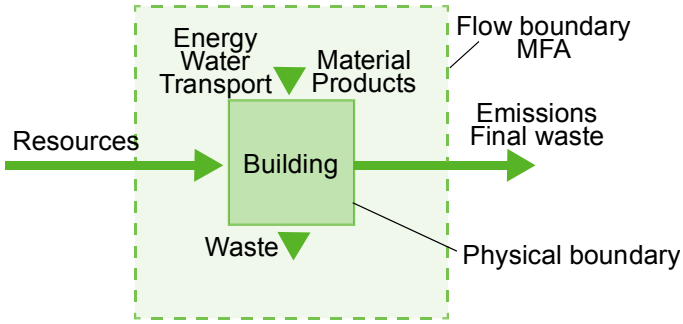


Figure 2-2 - Scope boundaries

Databases are an important element for the function of these tools. However, apart from integrated databases in the building related LCA software packages, the databases typically handle a wide range of products and are usually not limited to building products. These databases, nonetheless, are not part of this review.

Passive tools for the environmental framework which are supporting other LCA processes as e.g. LCA rating and certifications are also not part of this review.

3 SOFTWARE REVIEW

3.1 Objectives, tasks and scope

The process of Life Cycle Analysis (LCA) is a rapidly developing sector with ongoing changes on national and international level. Along with this development of standards and their application in the building world, software assisted LCA and engineering tools, undergo big developments and changes.

This thesis is to provide an updated survey of such LCA software tools, and here particularly for workflows in the building sector. See Figure 3-1 for an overview of the steps in this chapter.

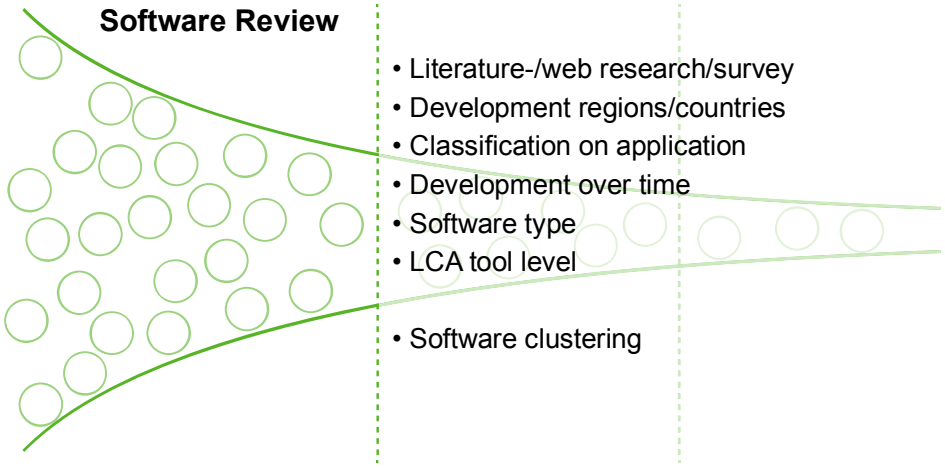


Figure 3-1 - Software review

In the first section a review and a research on European and International LCA software tools is presented. The objective of the review is to create a comprehensive and up-to-dated list related to building LCA Software Tools from worldwide sources, notably from Europe and North America. Sources for the up-to-date information of the review can be considered to be the following: published technical literature, the World Wide Web, previous European projects and product information provided by the developers of LCA software tools.

In addition, this review puts emphasis on aspects of LCA software as:

- Which regions have been more active in the development of such tools?
- The development history of these tools over time
- Trends in the development of building related LCA software tools
- Clustering of the LCA tools regarding various parameters, such as application, tool level and software type.

3.1.1 Literature background

Since 1996 and along with the ISO 14040/44 Standards development, building-related LCA software tools started to appear. Amongst the reviewed technical literature and previous European projects are the following:

- Evaluation of Life Cycle Assessment Tools (Menke et al. 1996)
- Energy-Related Environmental Impact of Buildings Annex 31.(International Energy Agency 2004)
- LCA / LCI Software Tools (Krata 2005)
- ENSLIC BUILDING (2007 and 2009)
- AIA Guide to Building Life Cycle Assessment in Practice. (Bayer et al. 2010)
- Life Cycle Assessment Software, Tools and Databases, (Levin 2010)
- Life Cycle Assessment for Energy Efficiency in Buildings (ENERBUILCA 2011)
- EeBGuide: Operational guidance for Life Cycle Assessment studies of the Energy Efficient Buildings Initiative (project) (The Fraunhofer Institute 2012)
- EeBGuide Guidance Document_PartB Buildings (The Fraunhofer Institute 2015)

In addition to technical literature, data was selected from previous European and International projects as LoRe-LCA (Tritthart et al. 2010), PRESCO (Peuportier et al. 2005), articles and books.

3.1.2 Survey content

The survey covers the last twenty years, when the first software tools were appeared in technical literature.

Some software tools have been discontinued and some tools, especially from the oldest list (Menke et al. 1996), were aiming at other LCA sectors.

A condensed list of currently available building-related LCA software tools, including the respective data bases, was established.

Furthermore, a web research added the information missing on these tools. However, some of these web pages were not informative. In these cases, the author tried to establish direct contact by mail; nevertheless, for the majority of these cases there was no response.

The information was collected in a survey table providing information on the following parameters:

- Software name
- Developing company
- Web link/contact
- Country

- Language (tool)
- Licensing cost
- Database used
- Covered stages of the LCA process
- Presentation of results
- Target group – architects, specialists, stakeholders
- Impact categories Software type - stand-alone, web-based, plug-in
- Tool type – product, whole building, database
- Tool level – advanced, intermediate, basic
- Standards classification

The gathered information allows a segmentation of these building related LCA software tools, based on AIA (Bayer et al. 2010), with respect to the following criteria:

- Regions/countries - Europe ,North America, Pacific
- Software type - stand-alone, web-based, plug-in
- Development over time
- LCA tool (skill) level - basic, intermediate, advanced
- Application level – whole building, building products
- License fees

3.2 Survey results

3.2.1 Overview

From all previous reports and projects, 44 software tools -including databases- were identified. The table with all 29 software tools, discontinued and current ones, apart from the databases, is shown in Table 3-2.

From the 29 identified software, 23 of them, are currently available in the market and are presented in Table 3-1. The remaining tools have been either discontinued or maybe their progress remains doubtful.

It is worth mentioning that in the first lists (Menke et al. 1996, International Energy Agency 2004) the reports are also referred to LCA software tools for general product LCA, including a wide range of different sectors, e.g. packaging, agriculture or food production. Such tools were excluded from the review.

Table 3-1 - LCA Software tools

	Software	Developer	
	ArchiPHYSIK	A NULL-Development GmbH	DE
	Athena Impact Estimator for Buildings	Athena Sustainable Materials Institute	CA
	BEES	National Institute of Standards and Technology - NIST	US
	CAP'EM Compass	CAP'EM	FR
	CMLCA	Leiden University	NL
	COCON-Excel	Eosphère SARL	FR
	COCON-BIM	Eosphère SARL	FR
	Eco2Soft	IBO - the Austrian Institute for Healthy and Ecological Building	AT
	ECODESIGN+	ECODESIGN Company GmbH	AT
	Eco-Sai	E4tech Software SA	CH
	Eco-Sai Revit Plug-in	E4tech Software SA	CH
	e-LICCO	Cycleco	FR
	ELODIE	CSTB	FR
	eToolLCD	eTool	AU
	eve-BIM ELODIE	CSTB	FR
	GaBi	Thinkstep	DE
	LeGep®-LCA	WEKA	DE
	novaEQUER	IZUBA energies	FR
	openLCA	GreenDelta GmbH	DE
	SimaPro	PRé Sustainability	NL
	Tally®	KT Innovations, Thinkstep and Autodesk®	US
	TEAM™	PwC Ecobilan Experts	FR
	Umberto NXT LCA	Ifu Hamburg	DE

Table 3-2 - LCA Software tools 2

Tool	Developer	Country/ Region	Active	Link	Application level	Software type
Archiphysik	A NULL-Development GmbH	DE/EU	2009 - 2016	http://www.archiphysik.at/	whole building	stand alone
ATHENA	Athena Sustainable Materials Institute	CA/NA	2004 - 2016	http://www.athenasmi.org/	whole building	stand alone
ATHENA Ecocalculator	Athena Sustainable Materials Institute	CA/	2009 - 2015	http://www.athenasmi.org/	whole building	stand alone
BEES	National Institute of Standards and Technology - NIST	US/NA	2004 - 2016	http://ws680.nist.gov/Bees	buildg product	web-based
CAP'EM Compass	CAP'EM	FR/EU	2015 - 2016	http://www.capemcompass.eu/	buildg product	web-based
CMLCA	Leiden University	NL/EU	2005 - 2016	www.cmlca.eu/	buildg product	stand alone
Cocon-BIM	Eosphère SARL	FR/EU	2015 - 2016	http://www.cocon-bim.fr/Tarifs-du-logiciel-Cocon-BIM.html	whole building	plug-in
Cocon-Excel	Eosphère SARL	FR/EU	2015 - 2016	http://www.eosphere.fr/COCON-comparaison-solutions-constructives-confort.html	whole building	stand alone
Eco Quantum	IVAM UvA BV	NL/	2004 - 2012	www.ivam.uva.nl	buildg product	stand alone
ECO2SOFT	IBO - the Austrian Institute for Healthy and Ecological Building	AT/EU	2009 - 2016	http://www.ibo.at/de/ecosoft.htm	whole building	web-based
ECO-BAT	HEIG-VD, Laboratoire d'énergétique solaire et de physique du bâtiment	CH/	2012 - 2015	http://www.eco-bat.ch	whole building	stand alone
ECODESIGN+	ECODESIGN Company GmbH	AT/EU	2004 - 2016	http://ecodesignplus.com	buildg product	web-based
ECO-IT	PRé Consultants	NL/	2009 - 2010	www.pre.nl	buildg product	stand alone
ECO-SAI	E4tech Software SA	CH/EU	2015 - 2016	http://www.eco-sai.ch/en/index_en.html	whole building	stand alone
Eco-Sai Revit Plugin	E4tech Software SA	CH/EU	2015 - 2016	http://www.eco-sai.ch/en/Eco-Sai-revit_en.html	whole building	plug-in
e-Licco	Cycleco	FR/EU	2015 - 2016	https://e-licco.cycleco.eu/	whole building	web-based
ELODIE	CSTB	FR/EU	2009 - 2016	http://www.elodie-cstb.fr/	whole building	web-based
equer	IZUBA energies	FR/	2004 - 2012	http://www.izuba.fr/logiciel/novaequer	whole building	stand alone
eToolLCD	eTool	AU/Pacific	2015 - 2016	http://etoolglobal.com/	whole building	web-based
eve-BIM ELODIE	CSTB	FR/EU	2015 - 2016	https://boutique.cstb.fr/Product/elodie	whole building	plug-in
GaBi	Thinkstep	DE/EU	1996 - 2016	http://www.gabi-software.com/	buildg product	stand alone
KCL ECO	VTT Technical Research Centre of Finland	FI/	1996 - 2009	www.vtt.fi/files/research/ism/manufacturingsystems/kcl_eco_v5_poster.pdf	buildg product	stand alone
LEGEP	WEKA	DE/EU	2009 - 2016	http://legep.de/	whole building	stand alone
novaEQUER	IZUBA energies	FR/EU	2012 - 2016	http://www.izuba.fr/logiciel/novaequer	whole building	stand alone
openLCA	GreenDelta GmbH	DE/EU	2010 - 2016	http://www.openlca.org	buildg product	stand alone
SimaPro	PRé Sustainability	NL/EU	1996 - 2016	https://simapro.com	buildg product	stand alone
Tally®	KT Innovations, Thinkstep and Autodesk	US/NA	2015 - 2016	www.choosetally.com	whole building	plug-in
TEAM™	PwC Ecobilan Experts	FR/EU	1996 - 2016	http://ecobilan.pwc.fr/boite-a-outils/team.html	buildg product	stand alone
Umberto	Ifu Hamburg	DE/EU	2005 - 2016	http://www.ifu.com/en/products/umberto	buildg product	stand alone

3.2.2 Software tools

The following paragraphs give a short introduction to the current building related LCA software tools for the segments covering LCA for building products and LCA for whole buildings (see chapter 3.2.7). A structured listing of features can be found in Appendix A-1.

Athena Impact Estimator for Buildings

Athena Impact Estimator for Buildings is a software tool for the evaluation of whole buildings that allows assessing the environmental impact of a building or an assembly. Athena Impact Estimator is applicable for new construction, renovations and building extensions in North American building types. It can model over 1,200 structural and envelope assembly combinations (Athena 2016) and it provides a cradle-to-grave life cycle inventory profile for whole buildings or assemblies. Operating energy cannot be calculated with this tool; however, it can be entered but it has to be calculated in another energy simulation tool.

The results show the environmental impact of used materials and operating energy, taking into account all the life cycle stages. It also facilitate a comparison among multiple design options as well as among operating and embodied energy. The results are provided in tables or graphs and can be exported in the form of Excel or pdf file, whereas a bill of material (BOM) can be imported from a CAD program in the form of a csv-file.

The tool uses Athena- and USLCI Database and the unit system can be selected as SI or Imperial. The software is for free but the user has to register in in order to download the program and the updates.

ArchiPHYSIK

ArchiPHYSIK is developed by A NULL-Development GmbH in Austria. It is a software for energy performance certification and for the environmental performance evaluation according to OI3 guidelines. It is applicable for the area of Austria, Germany and Switzerland and for new buildings or renovations. ArchiPHYSIK performs simplified but at the same time detailed calculations for energy certificates given to single-zone and multi-zone residential-, non-residential- and other types of buildings. It can import data from CAD programs, like ArchiCAD and SketchUp, via respective add-ons. It has an extensive list of materials, not only from IBO database but from other manufactures, too. The results are given in a numerical form containing all input and output data together with the certification and then they can

be printed as a pdf file. The dialogue language is in German. There are both educational and commercial licenses.

BEES Online

BEES Online is a web-based tool for selecting cost-effective, environmentally-friendly building products for projects in North America. It has been developed by the National Institute of Standards and Technology Engineering Laboratory (NIST), and Applied Economics Office (BEES 2011). There are three different weighting factors between environmental and cost performance which allow the user apply an appropriate weighting.

With the software tool one can compare the building products for their environmental and economic performance. The results are presented in graphs and tables and can be printed as pdf file but they cannot be saved. It uses the BEES 4.0 and US LCI Database and the unit system is both SI and Imperial.

CAP'EM COMPASS

CAP'EM COMPASS is a web-based software tool that enables the user to compare building products with respect to their environmental performance. It is based on Life Cycle Analysis results from the CAP'EM project (CAP'EM 2010).

The software tool allows the user to filter products, based on the user's country or project's site location, and to add the "delivery to site" impacts to the "to factory gate" impacts. The results are numerically or graphically presented for all/selected impacts of products, side by side for a better overview and understanding. A comparison of selected materials can also be performed, included commonly used materials in building construction, such as cement, concrete, steel and timber. The materials developed within the scope of the CAP'EM project are derived from ecoinvent v2.2 database (the Swiss Centre for Life Cycle Inventories 2010, CAP'EM 2010). Typical energy consumption mixes have been established for the five countries involved in the project (France, Germany, United Kingdom, Belgium, and Netherlands).

CMLCA

CMLCA is a stand-alone software tool developed by the Institute of Environmental Sciences of Leiden University in Netherlands. The focus of the program is on advanced computational aspects of life cycle inventory calculations. It calculates the life cycle assessment (LCA), the social life cycle assessment (SLCA), the life cycle sustainability assessment (LCSA) and the life cycle costing (LCC). The results are presented both in bar charts and in numerical form. As it was developed for the needs of the university, the target group is basically students and scientists. It is compatible with the framework and terminology of ISO 14040. The license is free but

it has no help desk, no graphical interface and the data must be downloaded or be bought. The dialogue language is English and it is only available for windows (CMLCA 2012).

COCON-BIM

COCON-BIM is a plug-in software tool developed by the Eosphere SARL in France. It is an LCA tool for whole buildings, for studies of the environmental quality of buildings and materials through the interpretation of BIM models. It is a new software that is expected to be available in the market soon. It is the “follower” of the previous Excel COCON and it has technological developments relating to the digital model through access to the BIM files (IFC) and 3D navigation. It gives the results for all environmental impacts of the life cycle stages including transportation, site work, materials and technical equipment. It uses databases from different countries, like INIES, PEP Ecopasseport from France, the German ÖKOBAU, and the Swiss Kbob and Ecoinvent. It is compatible with the framework and terminology of ISO 14040, EPD (Environmental Product Declarations) according to EN 15804 and other standards for thermal and environmental performance of a building. COCON-BIM allows creating different scenarios of the same building, or comparing solutions, such as new construction and renovation. The results refer to thermal performance or environmental performance. They are presented in a graphical and numerical form and can be exported as graphs or CSV format in Excel (tables). The dialogue language is French. There are three license versions and they cost 700€ /y for one simple user, 1700€ /y for three users, and an educational version for 700 € /y for fifteen users

COCON

COCON is a stand-alone Excel program for LCA, developed by Eosphere SARL in France. It is a software estimating the Environmental Building Quality. It helps to develop efficient construction solutions for thermal and environmental perspective not only for new buildings but also for their renovation. It uses databases from different countries, like INIES, PEP Ecopasseport from France, the German ÖKOBAU, and the Swiss Kbob and Ecoinvent. It is compatible with the framework and terminology of ISO 14040, EPD (Environmental Product Declarations) according to EN 15804 and other standards for thermal and environmental performance of a building. The results may also concern the thermal performance or environmental performance and are presented in Excel graph or table form.

ECODESIGN+

ECODESIGN+ is a web-based software tool for products developed by the ECODESIGN Company GmbH in Austria. ECODESIGN+ allows the calculation of the carbon footprint of products, during their manufacture, transportation, use and end of life based on ISO 14040, 14044 standards.

The results are provided both in graphical and numerical and are updated automatically upon data entry. This tool uses the Ecoinvent database.

The tool allows comparing different scenarios and in combination with the ECODESIGN PILOT assistant, supports product improvement according to the EPD. There are two different license versions and a free demo. The demo version can be used for 72h and has a basic functionality and limited database. The basic version is for one user and it has full functionality and database, and costs 500 €/year. The custom version is multi user license, it has extended functionality and database and CAD files, spreadsheets and information from Databases can be imported. Also it provides an in-house server service and on-site training (ECODESIGN+ 2016).

Eco-Sai

The former USai and Eco-bat software tools have been merged to facilitate the work of professionals in the building sector. The new combined product is now developed by the E4tech Software SA., resulting in a software tool allowing to analyze thermal aspect as U-values and thermal inertia as well as to perform life cycle assessment of a construction (homogeneous and inhomogeneous).

Eco-Sai can calculate the environmental impact of materials according to ISO 14040 standard and allows to calculate the transport impact from the manufacturing plant to the construction site and the impact of HVAC systems. It also provides data to support the decision making process in building renovation projects. In addition, it is connected to the product databases of several major building materials suppliers through thematerialsdb.org system. The results are presented in graphical and numerical form and a comparison of two projects can be done. It has different license versions with different fees: from a basic version to an USai module for building physics, to the ECO module for life cycle assessment. The dialogue language is in English, French, German and Italian. The basic version is free and the fee for the version with Eco module for LCA is 280€.

Eco-Sai Revit Plug-in

Eco-Sai Revit Plug-in is a plug-in version of Eco-Sai tool which is compatible with the CAD Autodesk® Revit® software. It has the same features as Eco-Sai and it is compatible with Lesosai, a thermal performance software. Lesosai is following the SIA180, EN ISO 6946 and EN ISO 13786 standards and allows calculating the operating energy demand.

The Eco-Sai plug-in is relating to the materialsdb.org database. LCA evaluation results are presented in graphical and numerical form. The dialogue language is English, French, German and Italian. The fee for the license is 280€.

Eco2Soft

Eco2Soft is a web-based tool for the ecological assessment of buildings.

It is developed by IBO, the Austrian Institute for Healthy and Ecological Building and uses the IBO Database. The user can organize his projects in files and directories. Each created directory may contain buildings and other directories. It calculates all life cycle stages of a building including the HVAC equipment. It also can take into account the impact of operating energy; however, the heating energy demand cannot be estimated and has to be imported from other sources. It analyses the U-value and the OI3 (GWP, PENRT, AP) indicators. All building elements of the Baubook component calculator can be imported, including the examples of the IBO passive house catalogue. The tool offers two dialogue languages, English and German.

The results are numerical (at least for the educational version) and can be exported in a pdf file. A 2D and 3D presentation of the layers of the building element with all the used materials and values is also shown. The educational version is for free but the user has to register. The full version costs 100€/year.

e-Licco

e-Licco is a web-based software tool developed by Cycleco in France. The user can compare the results from different building scenarios on various impact categories. It is applicable for different types of buildings, like residential-, office- and academic buildings.

The results are provided for all LCA stages and for the application level of whole buildings, taking into account the building envelope construction, HVAC equipment, energy consumption, occupancy, demolition, waste transportation and waste treatment. It uses its own database which does not provide a range variety of materials but rather covers basic construction products. The results are shown in graphical and numerical form with different levels of detail (component, ratios, LCA

categories), chart type, impact category. The dialogue language is French. There is a free demo version upon registration, and the commercial version (SOCIETES) which costs 1230€/year.

ELODIE

ELODIE is web-based software developed by CSTB in France. It is a tool for LCA of whole buildings. For the calculations to be done, all life cycle stages are taken into account, including energy demand, occupancy, impact of the construction site, waste and the transport. It uses the French EPD (Environmental Product Declarations) of building products (called in French „FDES“) and technical equipment (called in French „PEP“) as well as generic data.(The Fraunhofer Institute 2012). To calculate the construction products impact, ELODIE uses EPD provided by manufacturers and made available through the INIES database. The results are presented in a graphical and numerical form, so that specific indicators or different options be compared. The results can be exported to Excel or shared with other design teams. The dialogue language is French and English.

ELODIE - Eve-BIM ELODIE

Eve-BIM ELODIE using the IFC standards is a link to a Building Information Model (BIM) for environmental performance. It has the same features with ELODIE and it is developed to be compatible with BIM, reducing the time for entering data (eve-BIM ELODIE 2016).

eToolLCD™

eToolLCD is a web-based software tool for life cycle assessment for whole buildings (LCA) and design. It is developed by eTool in Australia. AusLCI and Ecoinvent are utilised as databases.

The reports are compliant with international standards EN 15978 and ISO 14044. It is applicable for small houses, multi-residential or other buildings. The process is also related with rating schemes as Green Star, UK Rating Schemes and other international schemes like LEED.

The results are provided both in graphical and numerical form and show the environmental and economic performance of the building. There are five different license versions based on the user target group and it is free of charge in the “open use” version till 400 AUD/month for “specialists".

GaBi

GaBi is a generic LCA software tool that models every element of an industrial product or process. It is one of the leading expert systems for detailed assessment of the environmental impact, the amount of energy used and the cost of all used materials and processes of a product (GaBi 2015). It is developed by the PE Product Engineering GmbH which has now changed its name to Thinkstep. The software uses different databases like Gabi Database, Ecoinvent, US LCI and others, as selected by the customer.

The results are very detailed for all life cycle stages and for all environmental indicators. The input language is English and it can be used at an international level thanks to the elaborate database. For instance, in February 2016, a new database for India region was released.

It provides different versions, including an educational version. The fees depend on the license. A free trial of 30 days is also available.

LeGep®

LeGep® is a stand-alone software tool, developed by WEKA in Germany. The tool supports users in the design, construction phase and for the evaluation of new or existing buildings. All information is structured along all life cycle phases (construction, maintenance, operation, cleaning, refurbishment and demolition). The LeGep® database contains the description of all the elements of a building (based on DIN 276); their life cycle costs (LCC) based on DIN 18960 and calculation rules of the German DGNB and BNB Sustainability Certification. The results are provided in numerical and graphical form. The preset documentation allows the presentation of materials and energy flows of the building (LeGep®-LCA 2015).

The buildings can be specified either by using pre-assembled elements or by defining elements from single building products. The user can also define specific compositions by exchanging layers or element particularities. The advantage of the top down approach is its completeness: if an element is not explicitly changed or eliminated it will remain in the calculation. The fees of the elements are taken from the SIRADOS database. The life cycle Inventories database is based on the German Ökobau.dat and Ecoinvent as used for the German DGNB and BNB Sustainability Certification.

novaEQUER

novaEQUER is a new version of the former EQUER product. It is developed by IZUBA energies and it is linked to COMFIE, the calculation engine STD PLEIADES

and it is commercially distributed since May 2015. It is a life-cycle assessment software (LCA) for buildings or neighborhood. (novaEQUER 2015).
It calculates twelve environmental indicators for the construction, use, renovation and demolition phase, based on the standard XP P01-020-3 end of ISO 14040.
The results are shown in graphs or as a table, set up to compare data with French or European reference. The tool also provides a graphical comparison of projects to visualize the importance of the respective environmental impacts and as compared to a design variation or a reference project. The results can be displayed as radar or histogram graph, for the total life cycle or for a particular step (novaEQUER 2015). The dialogue language is French. It uses the Ecoinvent Database with a fee of 360€. Although the fee of the software is 700€, it has to be taken into account that with the extra required software package mentioned above the fee reaches 2100€.

OpenLCA

OpenLCA is a free web-based LCA software for products, developed by the GreenDelta GmbH in Germany. It is an open source software, i.e. its source code is available for free and it can be modified by anyone. It is applicable for LCA, LCC and EPDs. It is connected with many databases like OpenLCA Nexus, Ecoinvent, GaBi databases, ProBas+, where they can be imported. Some of the database access is for free and for others, like Ecoinvent, presuppose that the user have to pay a fee (openLCA 2014). Additionally, the user can import the impact method s/he wants to use. The results are presented in form of tables, graphs, and Sankey diagrams. The dialogue language is English.

SimaPro

SimaPro is a professional stand-alone LCA software for product design, developed by PRé Sustainability in the Netherlands. It allows comparing and analyzing complex products and processes. The user can model and analyze complex life cycles in a systematic and transparent way, following the ISO 14040 series recommendation. The software can be used for a variety of applications, such as sustainability reporting, carbon foot print, product design, generating environmental product declarations and determining key performance indicators (SimaPro 2016). As it is applicable in many industry sectors, it provides a variety of programs as add-ons for specific analysis.
SimaPro has a multi-user setting which permits several people to work on the same project simultaneously. It uses various databases, like Ecoinvent, US LCI Database, and different methods. There are different licenses, including an educational version. The fees depend on the license and a free trial for 30 days is available.

Tally®

The Tally® application, a plug-in package, allows architects and engineers working in Revit® software to quantify the environmental impact of building designs, and to make analysis on whole buildings as well as to comparative analysis of design options.

It is developed by KT Innovations, Thinkstep and Autodesk®. The dialogue language is English. The tool uses the Tally database which is based on the Gabi database. The tool does not take the impact of HVAC or other electrical equipment into consideration (Tally® 2014). While working on the design in a Revit® model, the user can define relationships between BIM elements and construction materials with the Tally database. This allows direct LCA without leaving the Revit® software environment, thus nicely integrating into the workflow (Tally® 2014).

The results are provided in graphs and numerical tables.

A license is required and it costs $1,200 USD. There is a 30-day trial version and once activating the trial version the user can download the full version via the download page or Autodesk® Exchange.

TEAM™

TEAM is a stand-alone software tool developed by the PwC Ecobilan Experts in France. It is a professional tool for evaluating the life cycle of environmental and economic performance of products. It uses the DEAM, ELCD database and the user can import the Ecoinvent database which makes it applicable at an international level. The user can export the complete set of results or part of a project to text-based files for easy exchangeability. The entire LCA project, from the modelling to the calculation of environmental impacts and running of simulations, can be exported to a single exe file for further use. The advantage is that there is no need for any installation and the results can be simply used from a USB stick (TEAM™ 2016). A multiuser license and an online demo version are available.

Umberto

Umberto is a stand-alone software tool for products, developed by Ifu Hamburg in Germany. It calculates and analyzes the material and energy flow. The Umberto NXT LCA version performs Life Cycle Assessment and uses Ecoinvent and Gabi LCI databases. It provides graphic models of the product LCA, analyzes all environmental impacts and allows the combination of impact indicators. The results are presented in the form of tables, graphs, and Sankey diagrams. In addition, it helps the user to optimize costs, materials, and LCAs. Data can be imported or

exported in Excel. The dialogue language is English and German. There are four license versions of Umberto and a demo web version (Umberto NXT LCA 2016).

3.2.3 Development by region

The results as to which regions, continents or countries are more “active” in developing LCA software tools are shown in Figure 3-2 and Figure 3-3.

Figure 3-2 shows that Europe leads the development of building related LCA software tools. Undoubtedly, North America is also working on developing LCA software tools. The last few years, Australia, Japan and China have also started to develop such tools.

Figure 3-3 shows the development region for the 29 current and discontinued LCA software tools, excluding databases. In Europe 24 tools were developed, with France being the leading country having 9 software tools out of 24, followed by Germany with 5, Netherlands with 4 and the others countries with 6.

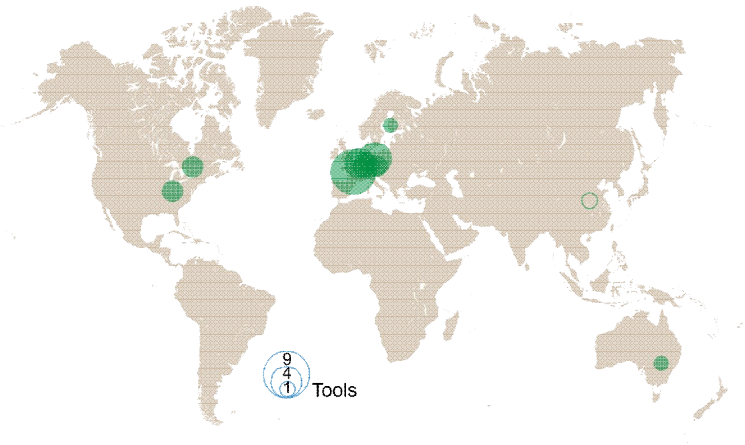


Figure 3-2 - Development map

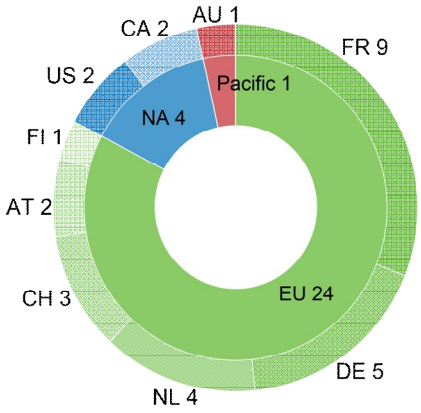


Figure 3-3 - Development Region

3.2.4 Development over time

Figure 3-4 shows the quantitative development of building related LCA software tools throughout the years. The basis is the established total list of 29 tools and the related time of availability, according to the literature review.

Since 2003, there was a significant development for LCA software with new entries in the market. However, this number has successively declined as it can be seen by the diagram. One possible explanation might be the fact that numerous software developments were done in university programs and projects and thus served the needs of the research center of institutes (Menke et al. 1996). Some of them were available to a limited market and for some of them further attempt for development regressed.

Following the results of direct communication between author and developers, some of them, like BeCost, withdrew from the market, because the latter have not updated the database for many years and thus it was out of date. Athena eco Calculator was also found to be out of date and Athena I.E. was instead promoted (Athena 2014). Some other software developers have been cooperated, like ecobat with Eco-Sai, or they have changed the company and/or product name, e.g. the software Equer is now promoted under novaEquer and the developer company like PE INTERNATIONAL is now marketing under the name of Thinkstep.

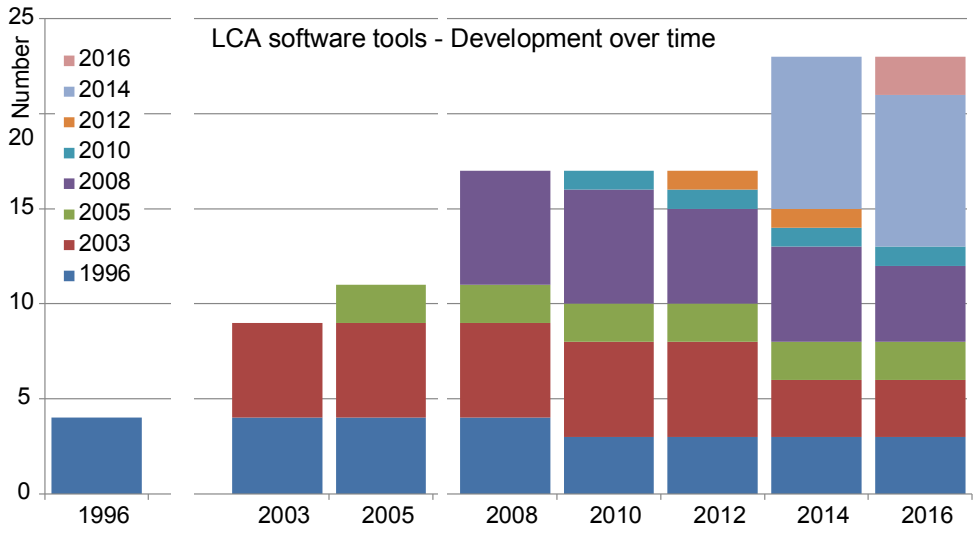


Figure 3-4 - Development over time

3.2.5 Software type

The LCA software tools can be segmented according to the software application type in stand-alone applications, web-based applications and plug-in tool modules.

- The stand-alone application (a desktop application) is running on a single computer like desktop computers or on laptops. They do not need an internet access in order to run the program, but they still might need internet connection to access bigger databases. Project data is stored on the local computer. These tools usually require expensive licenses. Software tools of this category are Athena IE, SimaPro, GaBi, LeGep®-LCA, novaEQUER, TEAM™, Umberto and Eco-Sai.
- Web-based applications are running on a server, accessed through the web. Most of the times the user has to register. Simple services are for free, while more complex services, especially in connection with access to bigger databases, different fees (e.g. yearly fee) are imposed. In web-based applications, project data is saved at the service provider, a sometimes unwanted business model. Software tools of this category are ECODESIGN+,

ECO-SOFT, BEES, ELODIE, openLCA, eTooLCD, CAP'EM Compass.

- Plug-in software modules are applications running within another software package. In the building related sector and architects workflows such software are for example CAD and Building Information Modeling (BIM) like Revit® and eve-BIM. As these tools are directly linked with the host software, data availability and transfers (e.g. dimensions and bill of materials) are provided and they therefore give a better integration in the workflow. LCA Software tools offered as plug-ins are tools Tally®, Eco-Sai Revit plug-in or eve-BIM ELODIE.

Figures 3-5 and 3-6 show the trend in building related LCA software tools with respect to the software application type. With the advantage of easy access and licensing models, web-based applications are gaining market share against the stand-alone systems.

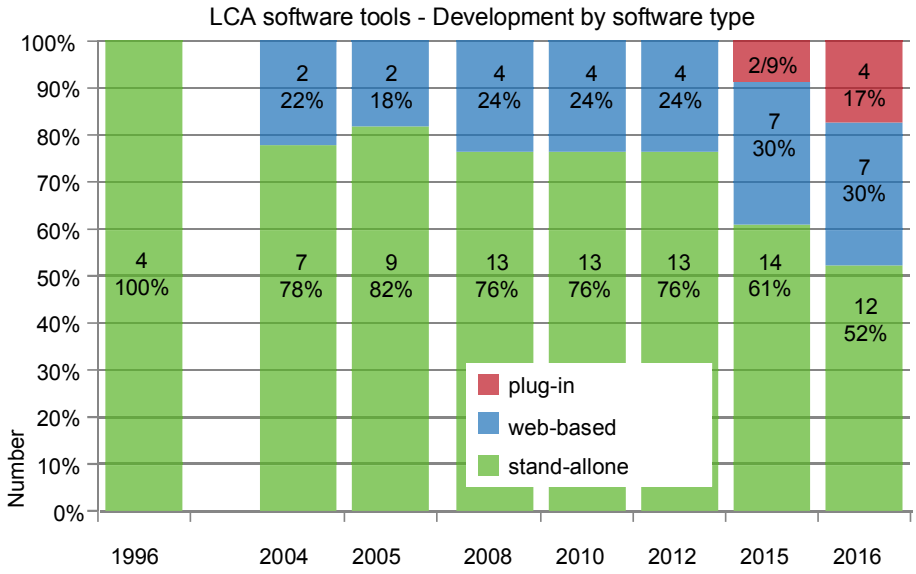


Figure 3-5 - Development by software type

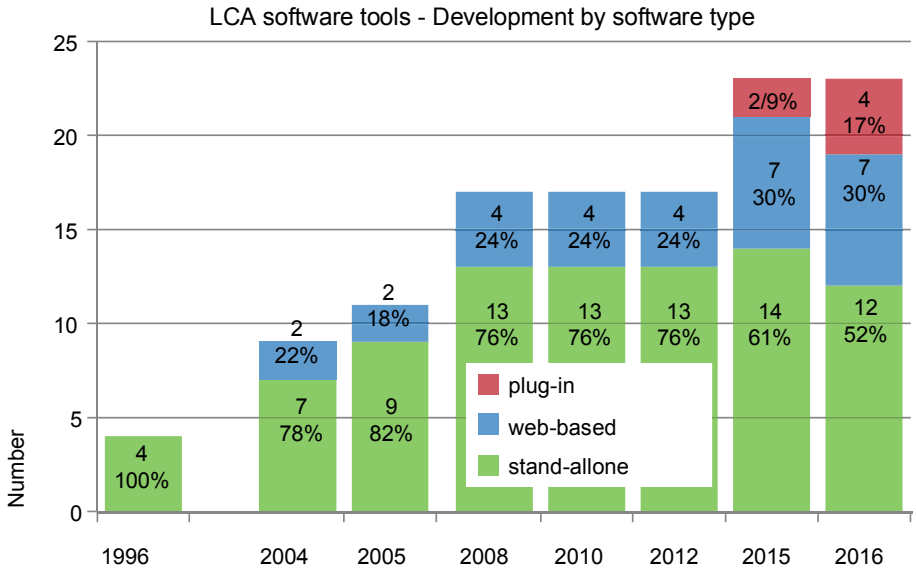


Figure 3-6 - Development by software type

Plug-in modules for software usually used by architects offices (e.g. CAD, BIM), however, integrate better into the work-flow than stand-alone systems. That is why the impact of plug-in tools is growing.

In 1996 there were only stand-alone LCA software tools whereas now they are down to 52% and the majority of them are in the segment of general product life cycle assessment (SimaPro, GaBi). This is a segment where the integration into a designer's workflow is not necessary.

Recently, plug-in software tools are entering the market. The requirements for sustainable design and the development of Building Information Modeling (BIM) in the last years make it more interesting for software developers to find a solution for the architect's workflow: how to make a complex Life Cycle Assessment study easier. The plug-in LCA software tools integrate with CAD and BIM software in order to make the architect's workflow easier and help them in the decision making process at an early design stage, attaining an environmental performance without the necessity to become an LCA specialist.

3.2.6 Classification by LCA tool level

For LCA users it is convenient to make use of an software tool in an appropriate level of the application or user. As in ENSLIC project (ENSLIC Building 2007) and in ENERBUILCA (ENERBUILCA 2011) the software can be split in a rough way into three levels of software complexity: the basic level, the intermediate level and the advanced level (ENSLIC Building 2007).

- The basic LCA software tools like simple Excel tools or BEES are considered for simpler LCA studies and require little experience. In a basic tool the inputs and outputs are simplified, analyzing one or few life cycle stages or impact categories.
- Intermediate software tools like Athena IE, novaEQUER, Eco2Soft, Tally®, are considered more suitable for architects and engineers as some basic LCA calculations and assumptions are provided or proposed by the tool. Some specific applications have been developed to facilitate LCA use in the building sector. The provided databases are locked and cannot be edited by the user. (Bayer et al. 2010) They can be used only for building products, materials, and processes in a predefined way. Usually the interface is user-friendly and is assists the data input without the need for a structure analysis. In spite of that, some experience and understanding of LCA methodology and the working functions of the software tool is required.

- Advanced software tools like GaBi, SimaPro, Umberto, usually are intended for LCA practitioners, researchers or other LCA experts. They demand much higher experience and methodology understanding in order to use the tools and for the interpretation of the results. On the other hand the user has more freedom to define certain assumptions by structuring the analysis and the frameworks. Usually more than one databases are and datasets can be edited or replaced by the user.(ENSLIC Building 2007)

As shown in Figure 3-7 69% of the tools can be classified as tools with intermediate complexity. Some tools help architects in their work by providing, apart from the impact calculations, support in the form of material and assembly assumptions (e.g. adding nails for the fixing of insulation) or adding a percentage of used material quantity, accounting for material waste during the building construction process (Athena 2016).

3.2.7 Classification by level of application

In AIA (Bayer et al. 2010) LCA Software tools are classified based on the analyzed building systems. Figure 3-8 refers to LCA software tools for the four identified levels of applications (Bayer et al. 2010):

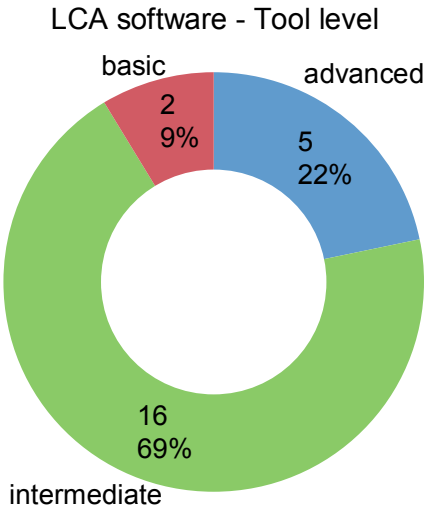


Figure 3-7 - Tool level

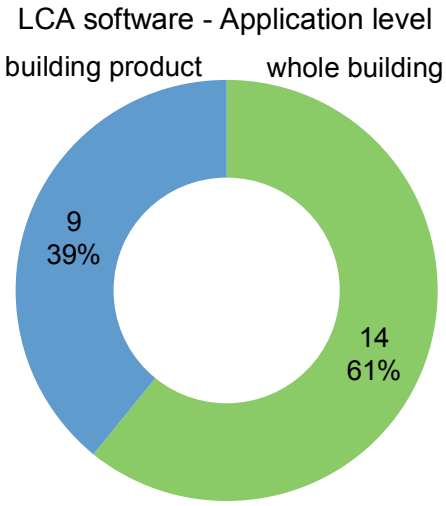


Figure 3-8 - Application level

- **Building products evaluation**

  “Products are the smallest elements in a building and LCA software that evaluate and compare building products giving precious information about them, especially for those that they are similar in their composition as in their function in the building and based on the underlying material data” (ENSLIC Building 2007). Software tools in this category are e.g. GaBi, SimaPro, and Umberto.

- **Building assembly evaluation**

  “A building assembly is a group of interdependent building components that make up a system within a building”. (ENSLIC Building 2007) for example, a wall is made up of several elements, a window is made up of several products and materials. Building assembly tools evaluate complete assemblies by combining the impacts of all included materials and products.

- **Software evaluation tools for the whole-building**

  These tools assess the environmental impact of the total building construction, bringing together all assemblies and subsystems. These tools compare different design options for a building and are helpful during the initial design. (Bayer et al. 2010). Such tools are Athena IE, LeGep®-LCA, novaEQUER, Eco2Soft, ELODIE.

- **Databases**

  For the architect and the building designer the database is probably the most important part for an LCA analysis. It represents a collection of ecological data for materials, available products and subassemblies. Databases provide all the environmental properties of the materials, products (e.g. concrete) and assemblies (e.g. window).

Some LCA software tools have developed and are using their own database like Athena IE, CMLCA. Others use one specific database like ELODIE, Eco2soft, and others provide access to different databases like SimaPro, GaBi. Depending on the database, some are locked and others are accessible in order the user to modify his data or expand it to his needs. International databases like Ecoinvent are locked and there is a fee for accessing the data.

3.2.8 License and fee

The license fee of the LCA software tools varies from free of charge to very expensive. The price of the license depends on:

- The used or provided database: the more detailed database the more expensive is the license fee. Some software tools sell the database access separately (openLCA) and others provide data from their own database (Athena IE)
- Complexity of the software functionality: software like SimaPro, GaBi, which have more complex data structures and are very analytical the license fee can be more than 10.000 €
- The target group: the fee is different if the license is for individual user, for companies, students or academic versions.
- The type of license fee: there are license models representing a rental type where the fee is indicated for the period of a year, a model that is also used for the fees for database access. There are also full licenses as typically for stand-alone tools.
- The tool version: for professional use, company licenses, trial versions with usually limited features and for a limited time or versions for academic or educational use.
- The service support: some license models include support from the developer for a defined period.
- The software application type: stand-alone software tools are provided for a high license fee, there are different license models. These tools are usually offered in demo versions or trial versions of 30 days.
- Web-based tools, on the other hand, are free or they have a relatively low annual low fee if it is for commercial use like Eco2soft or ECODESIGN+. With web-based applications the user has to register and to create an account.
  Plug-in modules can only be used in the respective software environment (e.g. CAD). Usually these programs are professional tools, the license fee for the LCA tool has to be paid separately

3.2.9 Combined Clustering by software type, tool type and level

To provide a clustered overview and as basis for the selection of LCA software tool representatives for the next chapters the available tools were split to segments based on a set of selection criteria.

Table 3-3 and Figures 3-9 and 3-10 show the result of this combined the clustering of the software tools according to the:

- application level - whole building and building products,
- software type - stand-alone, web-based or plug-in, and
- tool level - basic, intermediate and advanced

Table 3-3 - Software segmentation

Software application	**Software type** Stand-allone	Web-based	Plug-in
Whole building	• Athena IE • ArchiPHYSIK • Cocon-Excel • EcoSai • Legep-LCA • NovaEquer	• Eco2soft • e-LICCO • Elodie • eTooLCD	• Cocoon-BIM • EcoSai • eve-BIM Elodie • Tally
Building products	• CMLCA • GABI • SimaPro • Team • Umberto	• BEES • CAP'EM • Ecodesign • OpenLCA	

Tool level
Basic
Intermediate
Advanced

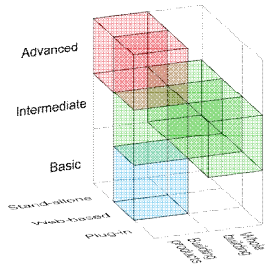


Figure 3-9 - Segmentation overview

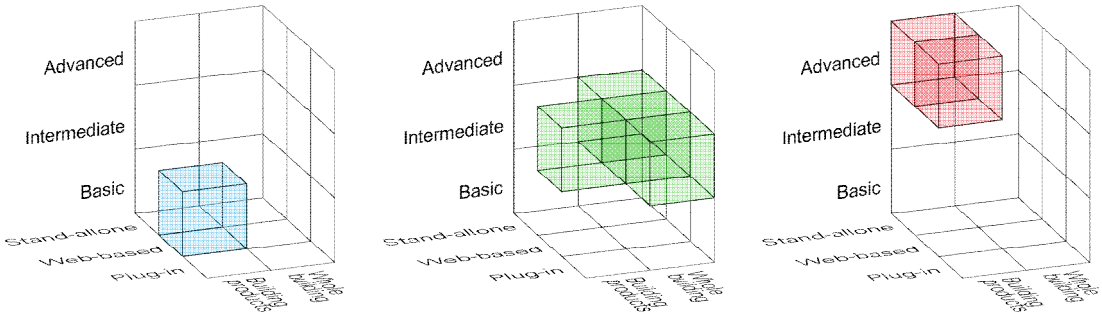


Figure 3-10 - Software segmentation

For the segmentation on the application level the previously stated segment of building assemblies (e.g. windows) was excluded. As indicated in Figure 1-7 this application area can be covered either by the tools for building products section or by

the tools for whole buildings. There are no specific tools for the segment of building assemblies.

The result for LCA tools for building materials are represented in stand-alone segment in the advanced tool level only. This is due to the complex data and processes involved. For web-based type they span from advanced down to basic level. The basic level is a numerical and graphical comparison of two or more predefined materials only. Most software tools fall into the intermediate tool level category. This is also the tool level of the plug-in software tools.

There are no representatives for building products in the plug-in segment, as these products are not directly involved in a CAD building design workflow, these tools are not offered as plug-ins.

3.3 Summary

In the course of this review for building related LCA software tools, especially for the design and specification phase, currently available and described LCA software tools have been located as well as databases linking into these tools.

With regard to the activities in the different regions, Europe remains the leader in the development of such LCA tools. However, in other regions tools also are available taking the regional requirements into account.

The trends show that the market change is slightly slowing down as some long-term and established players strengthen their position and some bigger software developers and market developments (e.g. BIM) are getting established.

In that course also new software application types are offered. Web-based application give relatively easy access to the LCA topics and plug-in applications establish the LCA process as step within the design workflow (e.g. CAD, BIM).

A clustering with respect to a set of selection criteria - the software application level, the software type and the tool level - was established and serves as basis for the selection of representative software tools for the evaluation of usability (see chapter 4) and the case studies (see chapter 5).

4 USABILITY EVALUATION

4.1 Objectives, tasks and scope

In this section building related LCA software tools, representing different tool clusters, will be evaluated in view of the term "usability" according to international standards for ergonomics of human-computer interaction and the evaluation of software quality.

For the evaluation of the usability a measurement scheme is developed, specifically focusing on the requirements for building related user target groups, as architects and designers. Using the selected software tools on a simple example building model, the derived parameters are evaluated in an empirical analysis. The evaluation is based on personal use of these tools, on reports in current literature and published support material for these.

The results of the selected software tools and the represented clusters are analysed and compared. Figure 4-1 shows an overview of the steps followed in this chapter.

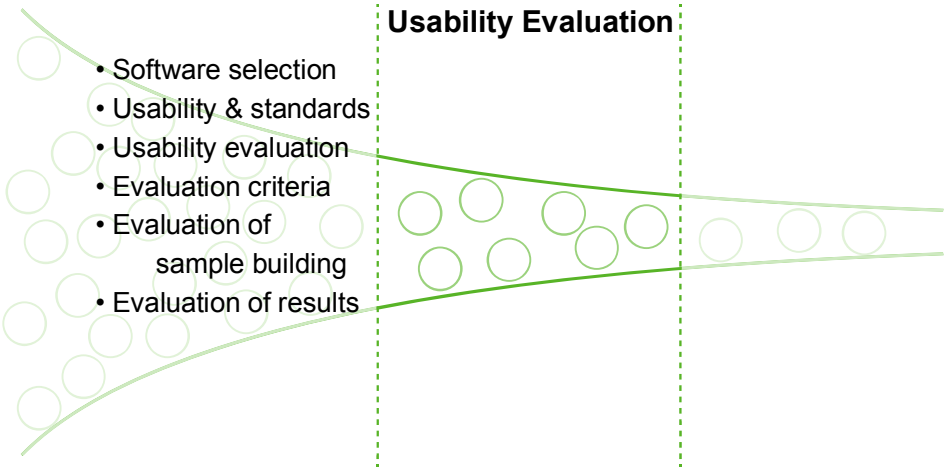


Figure 4-1 - Usability evaluation

With the focus on specific segments of LCA software tools and on building related user target groups, as architects and designers and their workflows, the present chapter intends to cover the following questions:

- Are LCA software tools suitable for the architects and building designers workflow?
- What is the estimated learning curve or how fast the users can achieve results?
- Can complex LCA process be made easily accessible?
- How the user is satisfied in a particular context of use?
- Is there support, training material and are language versions provided?

4.2 Selection of representative tools

As derived in the previous chapter, the LCA software tools have been clustered by three parameters:

a) clustering by application:

- Software tools for building **products** to establish product related information on ecological impact factors
- Software tools for **whole-building** LCA to compare different design options for a building in the design phase

The databases as a service tool with important impact for the LCA analysis, providing environmental properties of the materials, products and assemblies are not considered for the usability test as they do not run on their own.

b) classification by LCA tool level, clustering the tools into three levels of software complexity:

- **basic** tools with limited functionality
- tools of **intermediate** complexity and
- tools for **advanced** LCA practitioners.

c) clustering by software type, differentiating:

- **stand-alone** systems, running on local computers
- **web-based** applications, providing the LCA assessment results by web-services
- **plug-in tools** as tools working in the context of other software packages

For the investigation regarding the usability of the LCA tools within these clusters representative tool per cluster (see above) are selected. The selected software tools are shown in Figure 4-2:

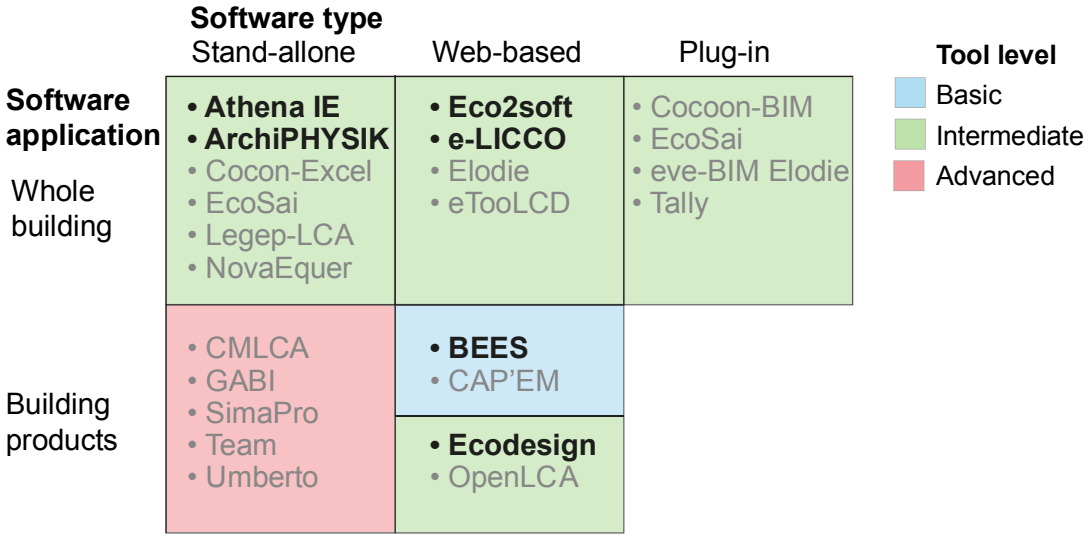


Figure 4-2 - Software selection for usability evaluation

Selected tools for evaluation of whole buildings:

- **Athena IE**

  has been chosen for its LCA capability for the whole building, is widely known in North America, there are tutorials and user manuals that help in self learning. An additional plus is that it is made available for free.

- **ArchiPHYSIK**

  is a stand-alone software tool with whole building LCA capability. It may not be considered as a direct LCA software tool. Nevertheless it provides the OI3 indicators which are Primary Energy Demand (PEI), Global Warming Potential (GWP) and the Acidification Potential (AP). With the calculation capabilities of heating energy demand of a building it provides the necessary input for LCA for the usage period. It includes a local IBO database and is designed for the standards in Germany, Austria and Switzerland.

- **Eco2soft**

  is chosen for representing a web-based software tool for intermediate user level; it is applicable in Austria and uses the IBO database: As result it provides the OI3 indicators.

- **e-LICCO**

  is also in the group of web-based applications but it represents a tool with intermediate functionality.

The tools for evaluation of building products:

- **ECODESIGN+**

  also a representative for the LCA tools for general and building products, has been chosen for representing a web-based software tool. Other than the other softwares it provides the result in CO2 equivalent Carbon footprint.

- **BEES**

  is chosen for representing a web-based software tool and as Athena IE is widely known in North America for application in building products. It not only displays the environmental performance of the products but also the economic performance.

4.3 Usability

Together with the rapid software, international standards were developed to specify requirements and recommendations for human-centred design principles.
Numerous national and international standards relate to "usability" and ergonomics of software tools (Userfocus 2015) like “ISO 13407:1999 Human-centred design processes for interactive systems”, “ISO/TR 6982:2002 Ergonomics of human-system interaction -- Usability methods supporting human-centred design” to name a few.
In spite of existing standards for better human- system interaction and the development of better software tools, the perceived lack of "usability" of software tools is one of the major reasons that in practice architects do not use tools designed to support them in their workflow (Mahdavi et al. 2003, Weytjens et al. 2010, Beigl et al. 2004).

4.3.1 Definition & standards

ISO 9241-11, 1998 (ISO 9241 -11 1998), covering all aspects of usability, also of software and ergonomics of human-computer interaction, usability is “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use”.
With three guidelines for usability of software this standard provides help to structure a usability-evaluation. The three evaluation categories are

- effectivity
- efficiency
- satisfaction

ISO/IEC 9126-1, 2000 (ISO/IEC 9126-1 2000) and its successor ISO/IEC 25010:2011, international standards for the evaluation of software quality, states that usability is “the capability of the software product to be understood, learned, used and is attractive to the user, when used under specified conditions”. Software quality can amongst others be qualified with respect to:

- usability, referring to : understandability, learnability, operability, attractiveness
- functionality and suitability
- efficiency: level of performance and resources used like time behavior, resource utilization, efficiency compliance

IEEE Std. 610.12-1990 (IEEE 1990), a standard glossary of software engineering terminology, defines usability as “The ease with which a user can learn to operate, prepare inputs for, and interpret outputs of a system or component.”

Nielson (Nielsen 2012) defines that “Usability is a quality attribute that assesses how easy user interfaces are to use" and that usability is defined by “five main usability characteristics”.

- Learnability: the users should be able to accomplish easily basic tasks for the first time they encounter the design.
- Efficiency: Once the system design has be learned, the users can perform tasks efficiently,
- Memorability: When users return to the design after a period of not using it, how easily can they re-establish proficiency,
- Errors: How many errors do users make, how severe are these errors, and how easily can they recover from these errors,
- Satisfaction: subjective user contentment when the design is used.

4.3.2 Usability test

The usability test is performed as an empirical software evaluation. The object of study are the selected LCA software tools. These tools as used by architects and engineers in the context of architects and building designers workflow. The data collection is done by a personal assessment of the author. The evaluation follows the criteria catalogue and evaluation scheme as described below.
The evaluation parameters for the test are based on the definitions of ISO 9241-11 regarding the usability terms as effectiveness, efficiency and satisfaction.

Criteria

In accordance with ISO 9241-11 definitions an evaluation check-list was established. In addition to the core terms as effectiveness, efficiency and satisfaction other parameters aiming at learnability (Nielsen 2012) and other usability terms according to ISO/IEC 9126-1 have been added. Additional focus was put on language versions, support, training material and manuals.
The developed evaluation checklist is shown in Table 4-1.

Table 4-1 - Evaluation checklist

Usability Evaluation		1	2	3	4	5	
Effectiveness							
Implementation sample building	no						full
Construction	predefined						open
Material selection	limited						wide
Quantity of help function calls	often						never
Efficiency							
Required time for first trial task	>10h						<1h
Time necessary for corrections	>2h						<0.1h
Cost	expensive						free
Satisfaction							
GUI/intuitive functionality	no						clear
Learnability	hard						easy
Data input	detailed						short
Quality of output presentation	confusing						organized
Visualization	numeric						graphical
Language versions	one						>5
Support	none						full
Satisfaction with help/support	disappointed						satisfied
Training material	none						available

The evaluation parameters and the definition and evaluation method are shown in Table 4.2. The parameters are classified in a scale from 1 to 5, 1 being the least and 5 the most favourable result (Cetin 2010).

Table 4-2 - Evaluation parameters

Usability evaluation	
Parameter	Description
Effectiveness	
Implementation of sample building	Is the software suitable to implement the sample buildings geometrical and material data.
Construction	Describes whether an element construction can be designed freely or whether there is a limited number of predefined elements and designs.
Material selection	Indication of extent of materials provided by the database. It is evaluated from limited availability or small set of predefined materials (e.g. by categories as "insulation") to a wide range of materials and products to select from.
Quantity of help function calls	Number of help function calls for completion of first trial task
Efficiency	
Required time for first trial task	The time that the author needed to accomplish the first trial task (in hours).
Time necessary for corrections	The time that the author needed to correct mistakes of the input data to get to the sample building. Application of changes in case of no errors.
Fee	License fee from expensive to free or functional demo version
Satisfaction	
GUI/intuitive functionality	Evaluation of degree of self-explanatory graphical user interface and the presentation of data and results
Learnability	The time required to get familiar with the software and to reach a level to perform the trial task. This includes time for tutorials, reading manuals, etc..
Language versions	The language versions the software is offering. The evaluation is based on valuing language support as a positive feature, especially in context with used materials.
Data input	Simple and intuitive data input. The depth and degree of required data and availability of default data inputs. The more complex the software the more detailed input data is needed (and more time to handle it).
Quality of output presentation	The general quality the results are presented and supporting the work flow by clearly directing to necessary steps. The evaluation refers to the output data being confusing or detailed and well organized.
Visualization	The way the output data is presented. The evaluation 1 refers to a strictly numerical presentation whereas 5 indicates that the results are presented also in form of graphical charts.
Support	The support is an important aspect for the usability of software. It allows the user to solve technical or methodological problems. It varies from simple help functions to FAQ's to forums and live chat function and to support via telephone or email contact with the tool developer.
Satisfaction with help/support	Evaluation based on author's subjective experience based on personal use of the provided support functions as help function, detailed FAQ's and response time on help requests.
Training material	Grades the availability and quality of various kinds of training materials for the software tools, as manuals, tutorials, examples of case studies, webinars, etc. to help you master the functionality of the tools.

The final results, showing the evaluation of the selected software tools for their respective cluster are shown in Table 4-5.

4.3.3 Evaluation sample building

To run and address the usability of the selected LCA software tools a simplified but typical architect and building designer's task, in form of a sample building model has been designed in SketchUp (Figure 4-3). The main dimensions are shown in Table 4-3.

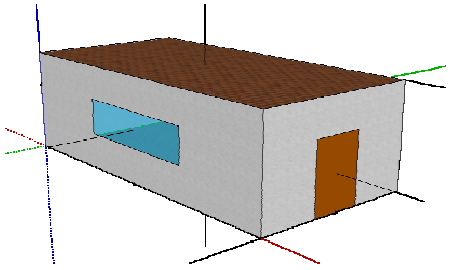


Figure 4-3 - Sample building

Table 4-3 - Sample building

Building element	Dimensions l*w (m)	Area (m2)
North Wall	10*3	30
South wall	10*3	26
West wall	5*3	15
East wall	5*3	12
Floor to ground	10*5	50
Flat roof	10*5	50
Window	4*1	4
Door	1.5*2	3

The assumed life expectancy is 50 years. The annual operating energy is taken from the heating energy results in ArchiPHYSIK and is applied to the other software tools where required.

Table 4-4 shows the assumed bill of materials (BOM) of the building construction of the sample building, with their layers ordered from outside to inside. The materials are selected for the usability evaluation of the software tools only and not to obtain any specific building performance. For the LCA analysis only the building envelope is taken into consideration.

Table 4-4 - BOM sample building

BOM - Sample Building		
Building element	Material (layer)	Width (m)
External wall	Silicate plaster	0.012
	EPS-F (insulation)	0.160
	Normal concrete with reinforcement 1% (2300kg/m2)	0.200
	Filler- gypsum filler	0.012
Floor to ground	Fillings made of sand, gravel, grit	0.150
	Building paper	0.003
	Normal concrete Normal concrete with reinforcement 1% (2300kg/m2)	0.150
	XPS-G	0.200
	Polyethylene (79kg/m3)	0.001
	Cement	0.050
	Solid parquet	0.010
Flat roof	Fillings made of sand, gravel, grit	0.050
	Polymer bitumen sealing sheeting	0.003
	XPS-G	0.150
	Polyethylene (PE) vapor brake	0.005
	Reinforced concrete 100kg/m3 reinforcing steel	0.150
	Normal plastering mortar GP lime cement	0.015
Window	Double-glazed heat-protection glass, Argon,	0.024
	Plastic-aluminium frame	0.118
Door	Double-glazed heat-protection glass, Argon,	0.024
	Wood / aluminum frame spruce	0.120

4.3.4 Evaluation results

Table 4-5 shows the results of the usability evaluation for the selected software tools.

Table 4-5 - Usability evaluation results

Usability Evaluation		1	2	3	4	5	
Effectiveness							
Implementation sample building	no						full
Construction	predefined						open
Material selection	limited						wide
Quantity of help function calls	often						never
Efficiency							
Required time for first trial task	>10h						<1h
Time necessary for corrections	>2h						<0.1h
Cost	expensive						free
Satisfaction							
GUI/intuitive functionality	no						clear
Learnability	hard						easy
Data input	detailed						short
Quality of output presentation	confusing						organized
Visualization	numeric						graphical
Language versions	one						>5
Support	none						full
Satisfaction with help/support	disappointed						satisfied
Training material	none						available

Description by software

Athena IE

Athena IE for buildings is a user friendly software tool. The learning time, needed in this test to learn the program to run the sample building project was 8,5h including watching tutorials, reading manuals and navigate the program. The input language is English.

The material database is limited and specifically oriented to North America. Therefore many assumptions (used materials, construction details) had to be done for the sample building. On the other hand, the program runs some background calculations concerning the construction details and needed products (e.g. cast in place concrete assembly). The materials, the construction of the buildings, input data as the energy grid and the transportation of the products are calculated according to the American and Canadian standards and values. Although Athena IE is taking the impact of the annual energy consumption for heating, cooling and domestic hot water (DHW), the user has to provide the energy requirement as an input which makes it necessary to use another energy simulation tool.

A BOM can be imported into the program. File formats currently supported include Comma Delimited Text (CSV), Tab Delimited Text, Other Delimited Text, and Excel. XML is not yet supported.

The help function at each window provides guidelines of how to apply inputs and how to select the different options in the respective dialog window.

Although in the beginning it may take time to collect the available information and guidelines, they are helpful to understand and learn the program and they offer good support. Questions that had been asked from the author via email were immediately answered. In addition, the provided FAQ support answered the questions and problems that the author was confronted.

The report is provided in form of graphs and tables. The type of reports are available for all life cycle stages, the assembly group embodied effects, the operating and embodied energy.

Although the absolute value and summary measures by LCA stages have been discontinued, the results can be exported to Excel. Obviously, this demands more effort and does not give an immediate visualisation of the results.

A comparison among projects or different versions of a building element (e.g. a wall with different materials), can be done. In addition, it is possible to generate rating system reports. "*The Impact Estimator for Buildings is an approved software tool for the Green Globes and LEED building rating systems, and Rating System Reports*

are available to provide the report tables that are required as submissions to those programs. The tables and graphs show the summary measures that are required by each system for comparison between reference and proposed building designs".(Athena 2016)

A negative aspect is the fact that it takes more than 20 minutes to start the program and to open a project.

ArchiPHYSIK

ArchiPHYSIK as mentioned above, primarily considered to be an energy performance software. Nevertheless it also provides calculations of OI3 index for housing subsidies and the material balance for the ÖGNI (Österreichische Gesellschaft für Nachhaltige Immobilienwirtschaft) certification. The combination of energy and environmental performance plus the data exchange with CAD programs like ArchiCAD and SketchUp makes it an "architect friendly" software tool.

The learning time was 25h including tutorial hours and navigation around the program. It is time-consuming to establish the model in CAD and to establish the BOM. 2D graphs provide a view of the element layers and values like thickness, U-value, vapour diffusion and ecological index.

The offered language support and the climate data restrict the potential number of users as it makes it applicable only for countries like Germany, Austria, and Switzerland. Tutorials and user manuals are exclusively in German.

Values out of the limits as stipulated by standards or regulation are marked in red, a helpful feature to improve the design. The results are provided in numerical form, graphical results are only available for energy calculations. A full report can be exported as a pdf file.

BEES

This free, online LCA and LCC tool is also user friendly software. Once the user gets familiar with the manual (it is referred as tutorial) can easily navigate round the software. There are manuals and an online help function. Information about the materials of the database are available in the online help function.

The working language is English and the database is applicable for the North American market.

If required, more than two products can be selected and compared for their environmental and/or economic performance. The results are presented in form of graphs and tables with numerical values and they can be printed. As it is not designed for the whole building LCA, extra time is required for comparison of an entire set of building materials as a respective comparison has to be run one by one

and for a complete result of impacts they have to be added up. This tool is useful only for comparison of products.

Eco2soft

Eco2soft is a user friendly software tool for LCA analysis. It does not require much time to learn it and once the used materials are known it is easy to accomplish the sample task.

The provided examples of building elements with construction details and values, like U-values and OI3, are very helpful; not only for inserting the data into the program but also for having an overview of the layers with the materials of the building elements.

Wherever there is an explanation it is marked with green letters (e.g. GWP, explains what GWP is and the units it is measured in). A message guides in case a value is incorrect or an element of the necessary data set is missing.

There are two options for input language, German and English. Eco2soft allows to calculate the environmental impact of the building elements, HVAC, other elements (like stairs, balcony), transportation and disposal. The results for the OI3 indicators are numerical and can be printed. In addition, there is a 2D and 3D graphic display of the building elements which can be helpful especially when there is an error concerning the thickness (d) of element layers.

A problem that the user may encounter is internet connection. If the connection is not good, the program is either slow or not working at all.

The database has some limitations, e.g. it does not contain doors, only as a transparent element. Although there are no tutorials, the given examples with the construction details are very helpful.

ECODESIGN+

ECODESIGN+ is a web-based software tool for building products LCA.

It is easy to learn, use and navigate.

As it is specialized for the LCA of products, also beyond building products, the practitioner has to provide very thorough information, not only on the materials used but also on the manufacture process, distribution and transport, the use and the process at the end of life. ECODESIGN+ is therefore oriented towards product engineers and product designers. The supported LCA stages are from Business to Business (B2B) or from Business to Customer (B2C). The tool can import CAD files, spreadsheets & custom PDM information.

The results are provided in form of graphs and numbers, and they refer to the Product Carbon Footprint (PCF) which in turn refers to the total Greenhouse Gas (GHG) emissions in CO2-equivalents (100a) of the product across its life cycle.
The results are presented according the LCA stages, leading the user to the LCA stages where the materials need to be optimized. In addition, there is a possibility to compare different product models, a helpful feature to guide the user through further improvement strategies.

e-LICCO

e-LICCO is a web-based software tool for the LCA of whole buildings. The application is easy to learn and intuitive to use.
The user is guided through the steps by its GUI. Although it does not have help functions (at least for the demo version), it is easy to use and there is an available terminology guide for each building element.
Manuals are available for downloading but only with registration and payment of 1230 € per year for the licence. The working language is in French but with the help of automated translation of the browser content it can be translated with sufficient results to English or in another language.
As this is the case for all web-based software tools, a good and reliable internet connection is crucial.
The input data is limited because the database is sizeable and is limited to basic constructions of building elements (e.g. external wall, concrete block or brick wall etc.) and basic material selection (isolation: Styrofoam, rock wool, polyurethane).
The final output is presented well organized and with different options of presentation. The results are provided in graphs and tables and refer to all impact indicators, also indicating the elements or materials with the biggest impact. A comparison of two scenarios is also possible. The results can be saved as pdf file.

4.4 Summary

As each building is a unique “product” (Rossi et al. 2011), so each LCA software tool is unique and it is developed to help a specific group of users, like architects, constructors, stakeholders, who are not specialist in LCA or LCC analysis and they do not want to be either. For that reason, most of the software, excluding the general LCA for products like SimaPro and GaBi, are not so complicated, they do not require much experience and they are easy to use. Also, each software tool for calculating the environmental impact indicators uses different methods, databases, codes and standards, depending on the country the building is designed for. The location, the energy grid, weather data (energy demand), and other parameters influence the final results. Consequently, an architect who wants to do an LCA analysis and manage the ecological impact of his projects, prefers to work with a software tool which is applicable in the specific country (a “national”, "regional" or “local” development) where calculations are based on national requirements, standards, EPD and rating systems.

5 CASE STUDIES

5.1 Objectives, tasks and scope

In the third section selected LCA software tools will be used to compare their role in a decision-making process in the design phase of a refurbishment project. (see Figure 5-1)

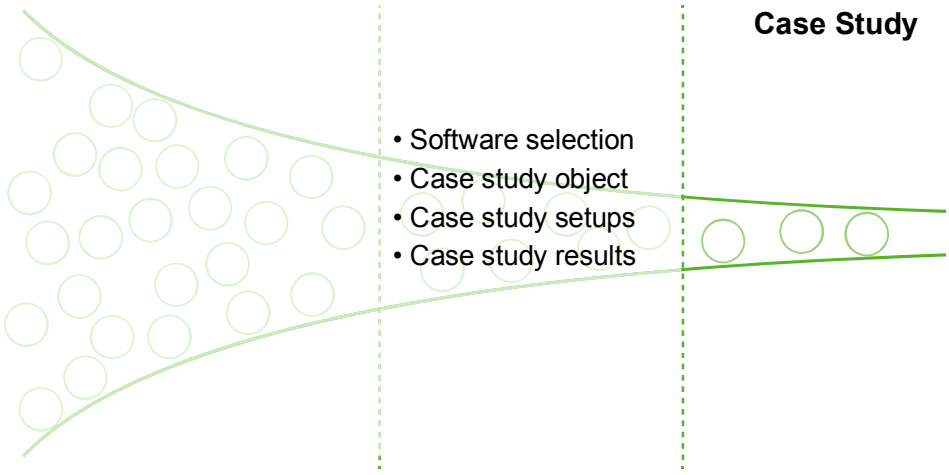


Figure 5-1 - Case Study

For the case study a student residence building in the center of Vienna was selected. In a previous research (Ghiassi et al. 2015) this building was considered being a representative sample for the residential building sector and then, due to its specific use, for the category of hotels. It was built in the beginning of 70s and in view of its design and age it represents a type of building which is a reasonable target for a refurbishment project.

Four software tools, a sub-selection from the previous section, are selected to perform an LCA. With the aid of this evaluation and with different design options this chapter intends to answer the following question: whether these LCA software tools guide architects in their design workflow to select the optimal products and materials and to reach sustainable solutions with respect to environmental performance of the building.

5.2 Selection of tools

Following the clustering of the current building related software tools in chapter 3, and the selection of representative tools per cluster in chapter 4, a set of tools is selected for the case studies.

The software tools selected to perform the LCA study of the refurbishment project are ArchiPHYSIK, Athena, Eco2soft and e-LICCO. These tools are the representative tools for the segment defined by stand-alone and web-based software types and whole building LCA applications.

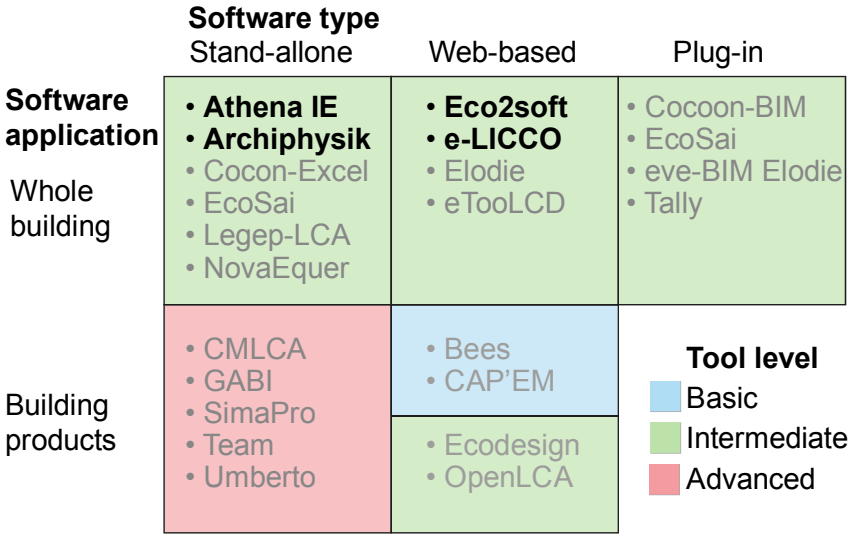


Figure 5-2 - Software selection for case studies

5.3 Case study

5.3.1 Case study object

The case study refers to a student residence building in the center of Vienna. The dimensions of the building have been taken from the building plans as they were submitted for the building permission (see Figure 5-3).

The bill of material (BOM) for the envelope and the areas of components (e.g. walls, windows) has been calculated in a Excel form. The building elements taken into account are representing the building envelope (external walls, ground floor, roof, windows and doors). For reasons of simplicity, intermediate floors, internal walls, staircases, HVAC and electrical equipment are not included. This boundary definition corresponds to the definition of BG0 according to OI3 (IBO 2013) excluding the intermediate floors.

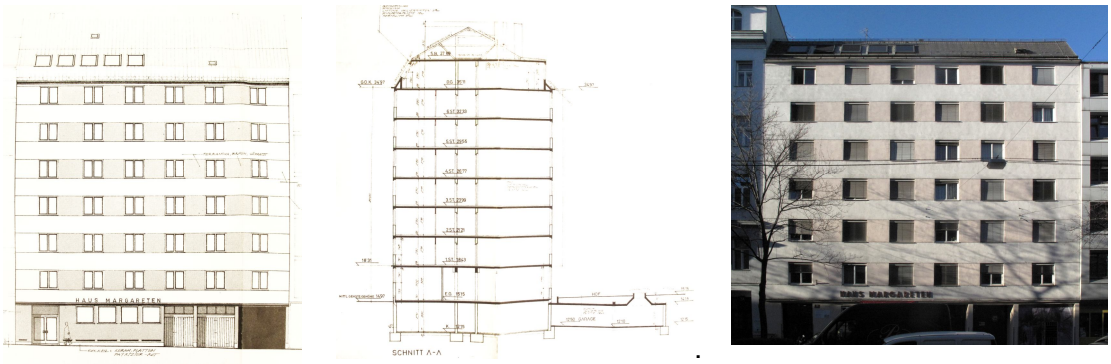


Figure 5-3 - Case study building

5.3.2 Case study setups

Three different setup options will be examined:

- Case A - The base building, in which the materials that are used and already exist, serve as a reference building for the comparison of the environmental performance.
- Case B - The retrofit building, were the basic structure is kept and additional materials for better thermal performance are added, and
- Case C - An ecological retrofit building with ecological materials, in which once again the basic structure is kept in place but in this case the additional materials are selected for their “eco-friendliness”.

5.3.3 Case study results

ArchiPHYSIK

For the base case (case A base building), layered envelope elements are generated in ArchiPHYSIK for materials not defined in the plans the U-values from the OIB RL6 tables (OIB 2015) were applied, according to the period the building was erected and its main use. The ecological impacts in the form of OI3-values have not been taken into account as the building already exists.

For the retrofit case (case B), new construction elements were selected to fulfil the minimum thermal standards of OIB RL6. The envelope construction of the base building remains unchanged but improved by adding new insulation and finishing layers. The main goal of case B was to improve the thermal performance of the building in order to reduce the operational energy demand and consequently the environmental impact.

In the ecological retrofit case (case C), the new materials added for improved thermal performance are selected to enhance the OI3 values as well as to reach the

required U-values. Consequently, new "eco-friendly" materials were applied (e.g. cork, timber).

Fig 5-4 and 5-5 present the layering of the additional materials for an element and the respective values for the OI3 indicators.

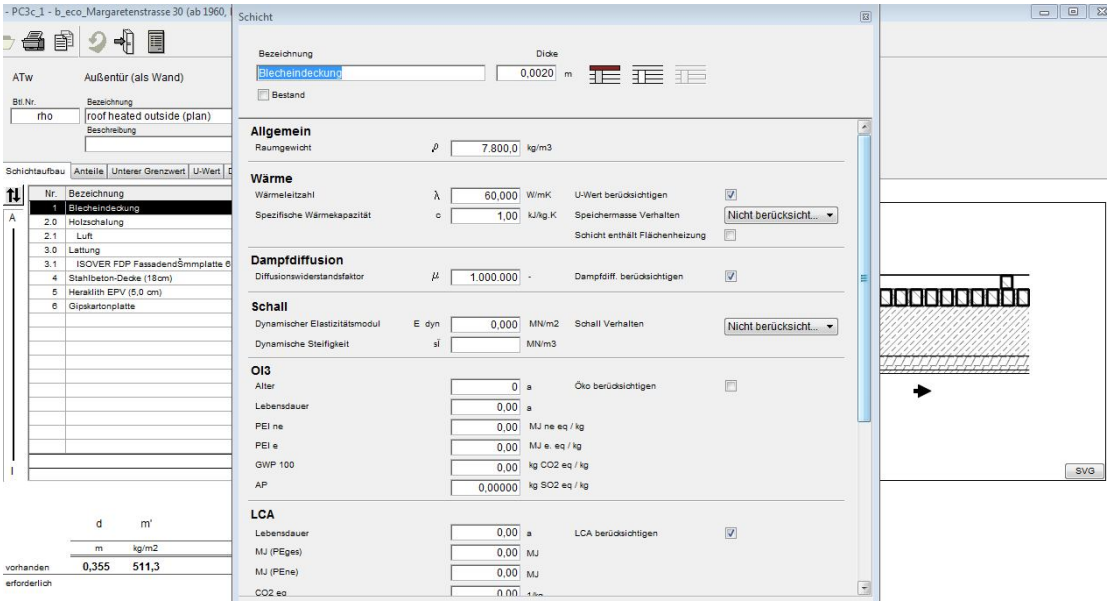


Figure 5-4 - Materials input

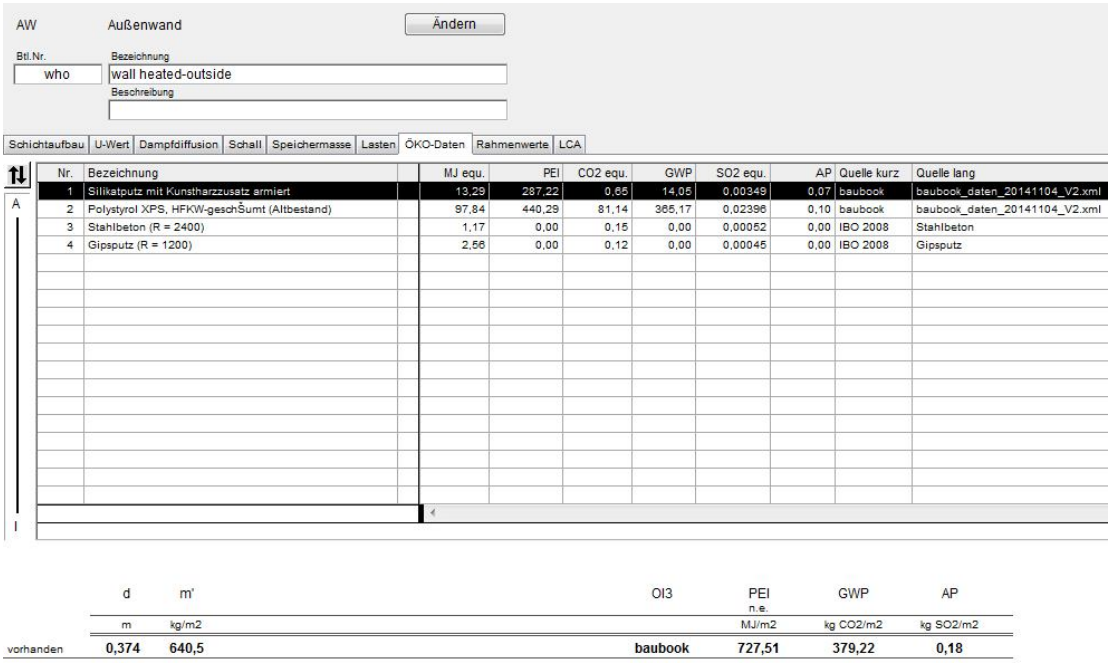


Figure 5-5 - Materials indicators

The calculations in ArchiPHYSIK for thermal energy demand and for energy certificates of the building have given the following results:

- Case A - Base case: Heating demand of 117.29 kWh/m2.a
- Case B - Retrofit case: Heating demand of 50.91 kWh/m2.a
- Case C - Retrofit with eco materials: Heating demand of 41.12 kWh/m2.a

The comparison of the results of three cases shows a decrease in operating energy of 56% in case B and 65% in case C. The classification of the three cases are shown in the following pictures (Figure 5-6)

Base case | Retrofit case | Retrofit w. eco-materials

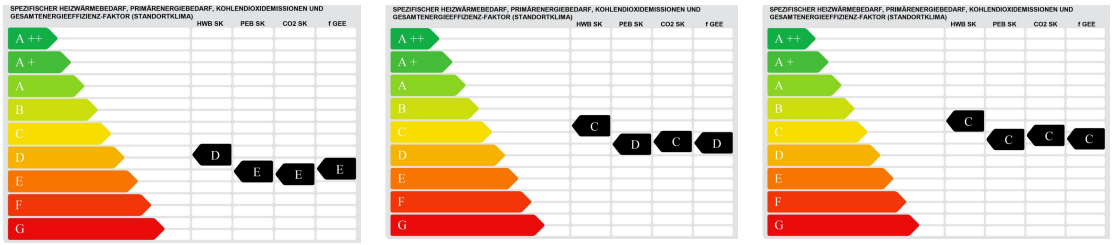


Figure 5-6 - Energy demand

The OI3 indicators as calculated in ArchiPHYSIK are displayed in the Table 5-1. The results show a difference in primary energy demand between case B and case C of only 29.24MJ/m2 while the difference in Global Warming Potential is 117.74 kg/m2.

According to IBO guideline for indicators (IBO 2013) the ΔOI3 is:

$$\Delta OI3=1/3*[1/10(PEI)+1/2(GWP)+100/0.25(AP)]$$

Table 5-1 - Results ArchiPHYSIK

OI3 Indicators	**CASE B**	**CASE C**
PEI (MJ/m2)	576.64	547.4
GWP (kg/m2)	132.72	14.98
AP (kg/m2)	0.15	0.19
ΔOI3=1/3*[1/10(PEI)+1/2(GWP)+100/0.25(AP)]	61.34	46.08

During the selection and design of the layered materials, the indication of the U value of the element guides the designer for reaching the desired result or the minimal thermal performance required by the building standards. What is more, the values of the OI3 indicators, as presented in Fig 5-5, guide the user for selecting a material with low environmental impact.

For a selected life span of 50 years, the amount of saved energy reduces not only the environmental impact of the building but also the operating cost. “Eco-friendly” materials, thus, can help not only to reduce the operating energy demand but also to have a better environmental performance of the building.

Athena Impact Estimator

Athena IE, as mentioned before, is a software tool specifically applicable in North America. This is due to differences in the used materials and therefore in the database and differences in typical way buildings are designed and constructed.

Because of these differences, it is not possible to model an identical envelope construction or to select the same type of materials. For certain assumptions, the software tools require a building location, which is limited to the North American continent. The city of Toronto was selected as location as it refers to the same climate zone as Vienna.

The examined building elements are the same as in the case of ArchiPHYSIK (external wall, fire wall, ground floor, ceiling, roof).

Athena IE does not provide any operating or heating energy calculations. However, if the operating energy did not included, the retrofit and eco-retrofit cases would show worse results because of the environmental impacts of additional insulation materials. Therefore, it is assumed that the operating energy demand is the same as in the ArchiPHYSIK case study.

Figures 5-7 and 5-8 show the comparison of the three cases, (base case, retrofit and eco retrofit) for the operating and embodied energy and for an assumed life span of one year and fifty years.

Figure 5-7 indicates that when the operational energy is low the embodied energy has the biggest impact but in a life span of fifty years the biggest impact is coming from the operating energy.

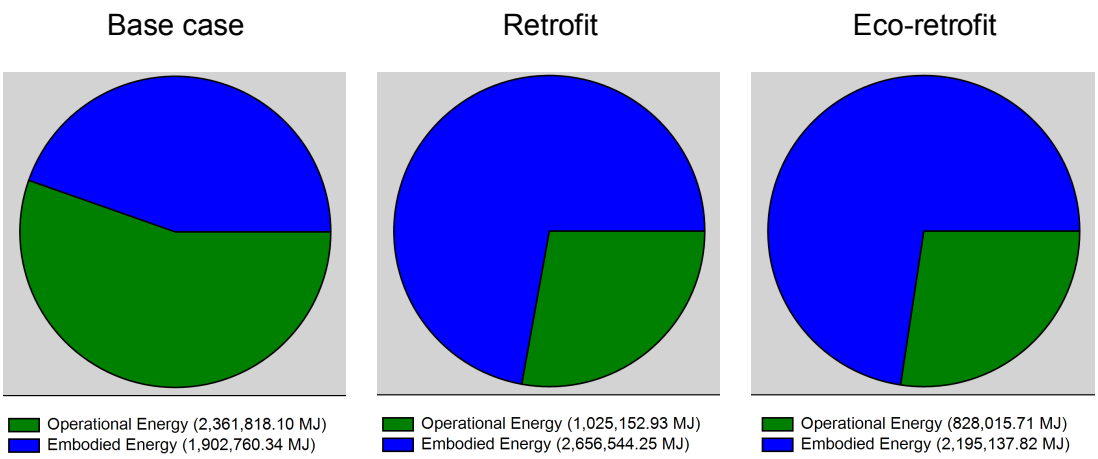


Figure 5-7 - Comparison operational vs. embodied energy for 1 year

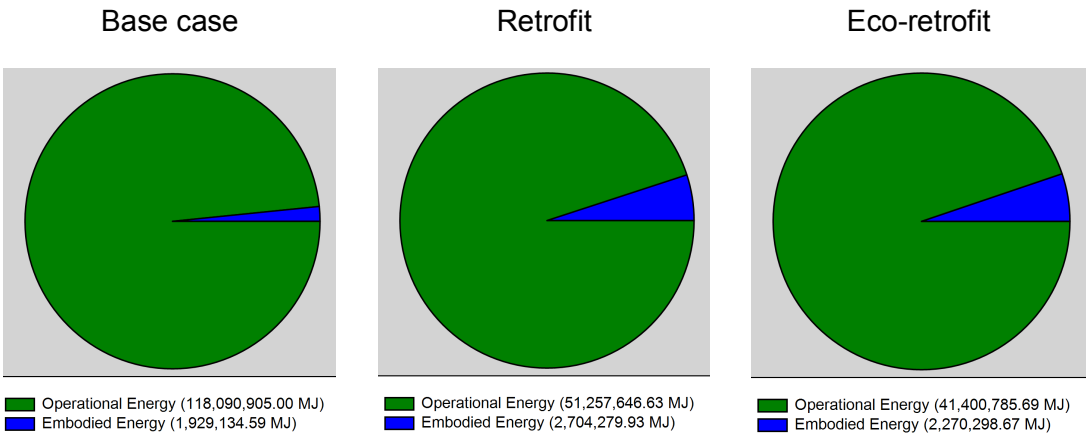


Figure 5-8 - Comparison operational vs. embodied energy for 50 year

Figure 5-9 and 5-10 show that the manufacture of the building products and the operating stage represent the biggest environmental impact.

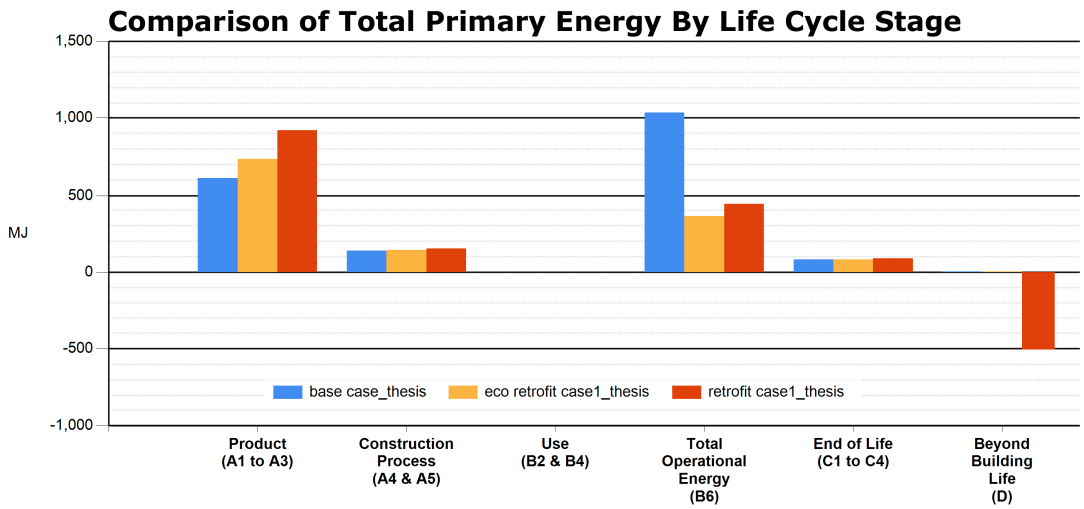


Figure 5-9 - Total primary energy by life cycle stage

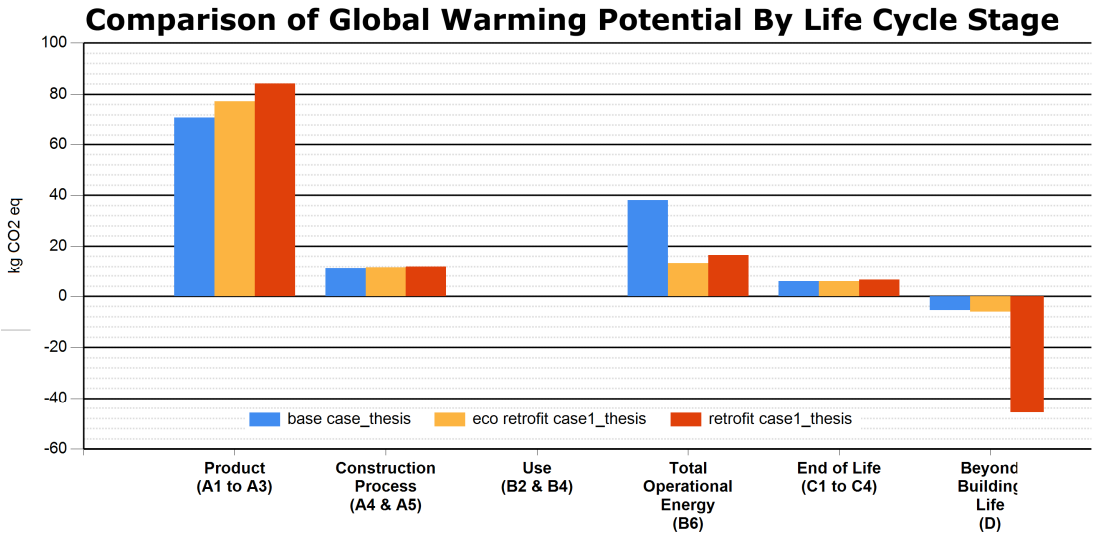


Figure 5-10 - Global warming potential by life cycle stage

It is only the database that has such a limited product range, especially for insulation. There is no value to indicate the environmental performance of the product in order to guide you towards the right selection. Moreover, the results do not indicate which materials of an element have the strongest negative ecological impact and would need primary attention in the design process.

Eco2Soft

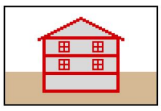
In Eco2Soft, too, the three different cases were evaluated. Exactly like in the previous case, the building envelope was taken into account. Eco2Soft does not calculate energy demand and it also requires the input. Here also the results from ArchiPHYSIK were applied.

As the structures are already in place for the base case, there are no results shown for the OI3 indicators.

Figure 5-11 and 5-12 present the results for the “retrofit” and “eco retrofit” cases. Although the main construction did not change the choice of eco materials like cork or wood for insulation layers, have as a result, a reduction of the environmental impact of the building. The results of the building elements with their environmental performance of used materials are shown in Figure 5-13.

For the selection of materials the database provides some details on materials as e.g where it is applied and whether it is produced from renewable resources. Indicated values for the OI3 indicators support decision-making and guide through the selection process.

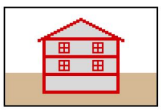
However, when the materials are selected and applied in a building element, there is no indication about the environmental impact of them, only in the total results are provided as presented in Figure 5-13.



solid and transparent building elements

area	building element	ΔOI3 BG2, ref. area	ΔOI3 per m²	PENRT kWh per m² ref. area (OI3)	GWP100 total $kgCO_2equ.$ per m² ref. area (OI3)	AP $kgSO_2equ.$ per m² ref. area (OI3)	EI_{KON} points per m²
950,53 m²	external wall front back	48	134	170,6	46,41	0,1468	0,55
682,20 m²	FIREWALL	17	65	63,8	12,15	0,0526	0,50
67,00 m²	floor heated	1	41	3,8	0,58	0,0036	0,58
648,00 m²	roof	13	54	52,8	7,64	0,0413	0,72
15,99 m²	window	1	85	1,8	0,34	0,0017	
14,79 m²	window	1	104	2,2	0,40	0,0018	
132,30 m²	window	5	100	19,1	3,42	0,0159	
	sum			**314,2**	**70,93**	**0,2637**	**0,61**

Figure 5-11 - Results of retrofit case



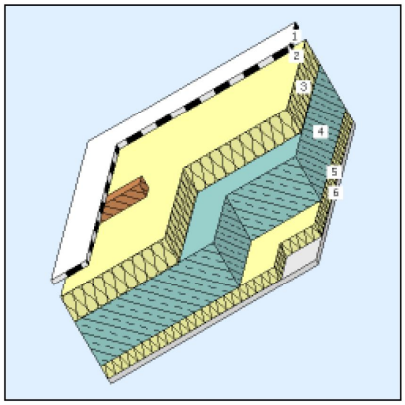
solid and transparent building elements

area	building element	ΔOI3 BG2, ref. area	ΔOI3 per m²	PENRT kWh per m² ref. area (OI3)	GWP100 total $kgCO_2equ.$ per m² ref. area (OI3)	AP $kgSO_2equ.$ per m² ref. area (OI3)	EI_{KON} points per m²
950,53 m²	external wall front back	35	97	137,9	18,43	0,1128	1,09
682,20 m²	FIREWALL	13	50	46,8	7,82	0,0438	0,44
67,00 m²	floor heated	1	41	3,8	0,58	0,0036	0,58
648,00 m²	roof	13	55	54,9	2,87	0,0471	0,72
15,99 m²	window	0	61	1,1	0,13	0,0016	
14,79 m²	window	1	104	2,2	0,40	0,0018	
132,30 m²	window	5	100	19,1	3,42	0,0159	
	sum			**266,0**	**33,64**	**0,2266**	**0,79**

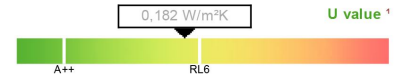
Figure 5-12 - Results of eco-retrofit case

roof

Ceiling, roof, 30°: Flat or pitched roof exposed to outside air – not back-ventilated – heat flow ascending



no.	type	layer	d cm	λ W/mK	R m²K/W	ΔOI3 Pkt/m²
1		Villas Polymerbitumenbahnen Steildach	0,100	0,170	0,006	2
2		*inhomogeneous (parts parallel to the eaves)*	5,000			
		57,5 cm (92%) Air (1 kg/m³)	5,000	0,025	2,000	0
		5 cm (8%) Timber (425 kg/m³) - rough, air-dried	5,000	0,110	0,455	-0
3		ISOVER FASSADENDÄMMPLATTE	10,000	0,033	3,030	11
4		Waterproof concrete with 160 kg/m³ reinforcing stee	18,000	2,500	0,072	34
5		Heraklith-EPV	5,000	0,100	0,500	5
6		Knauf Gipskarton Bauplatte	1,250	0,250	0,050	2
		R_{si} / R_{se} =			0,100 / 0,040	
		R' / R'' (max. relative error: 2,4%) =			5,634 / 5,371	
		building element	**39,350**		**5,502**	**54**



mass	**470,8 kg/m²**	
PENRT	780,964 MJ/m²	**service life:** nein
GWP100 total	31,404 kg CO_2/m²	**type:** Sanierung (2016)
AP	0,170 kg SO_2/m²	
EI_{KON}	0,72 points/m²	

Figure 5-13 - Building element with 3D presentation and products detail

e-LICCO

The three different cases were also run in the e-LICCO tool. However, in e-LICCO only basic construction methods can be applied as the database provides a very limited variety of products to select from.

Additionally, e-LICCO does not calculate any energy demand. The user has to provide the energy demand which has to be calculated in an Energy Simulation Tool (EST) first. Like as for Athena IE and Eco2soft, the operating energy is taken from the calculations in ArchiPHYSIK and entered in e-LICCO.

The comparison results for the three scenarios is presented in Figures 5-14 to 5 17, showing the graphs for the GWP, AP and NRPE indicators and the total energy.

The graphs present the ranking of materials according to their impact, a support which guides the user towards environmentally better solutions.

Furthermore, graphs indicate that not all the materials (elements) have the same impact for all indicators, e.g. Figure 5-16 shows that operating energy (in this case electricity) has a big impact for the NRPE indicator but does not have the same impact magnitude for the GWP indicator (Figure 5-14).

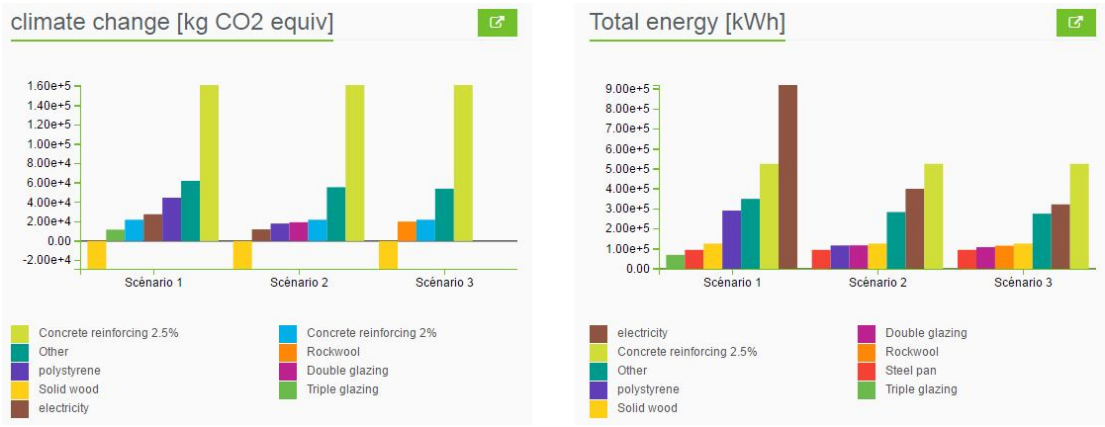


Figure 5-14 - GWP and total energy of the materials with life cycle of 1 year

Figure 5-15 - GWP and total energy of the assemblies with life cycle of 50 years

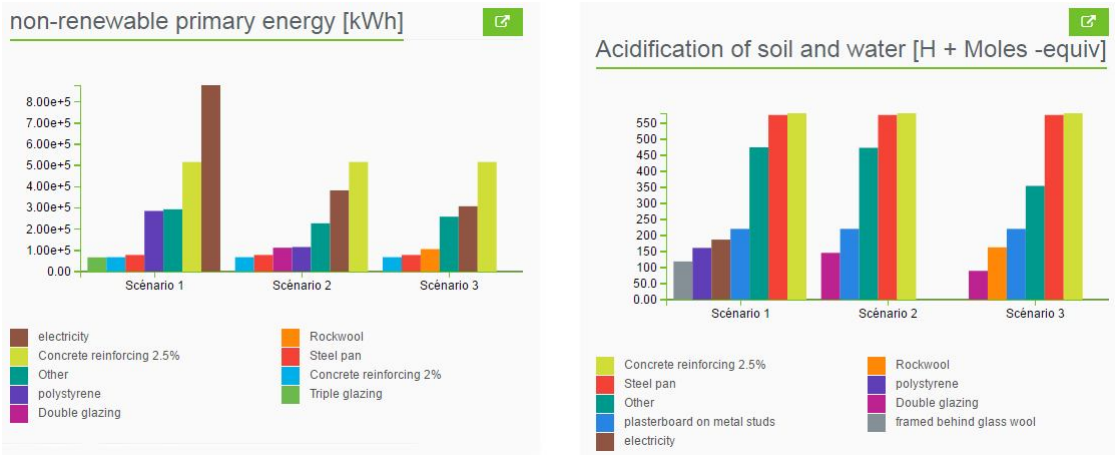


Figure 5-16 - NRPE and AP of materials used with life cycle of 1 year

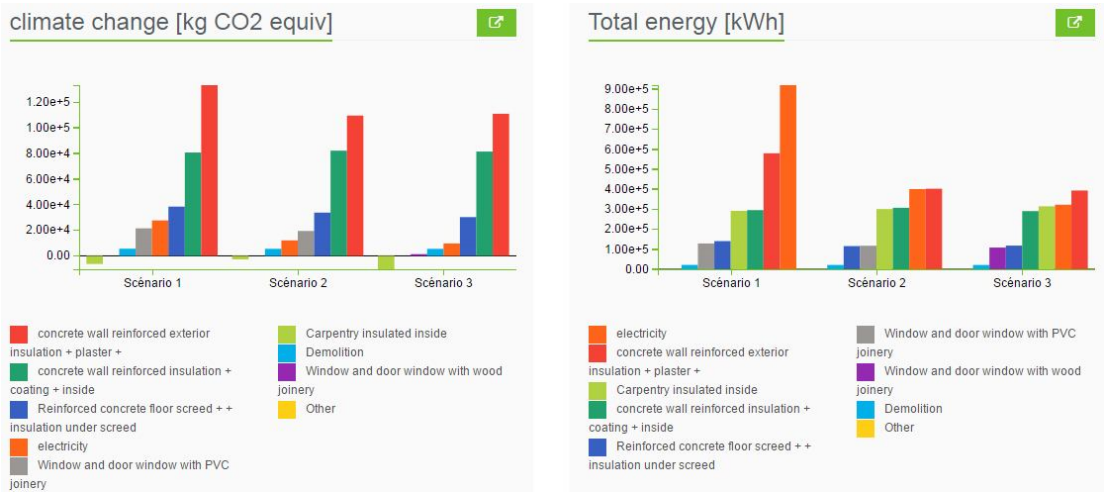


Figure 5-17 - GWP AND total energy of the assemblies with life cycle of 1 year

Figure 5-18 shows that the impact of total energy in a life span of 50 years represents 94.3% of the total ecological impact of the building in the base case scenario and 89,8% in the eco-retrofit case.

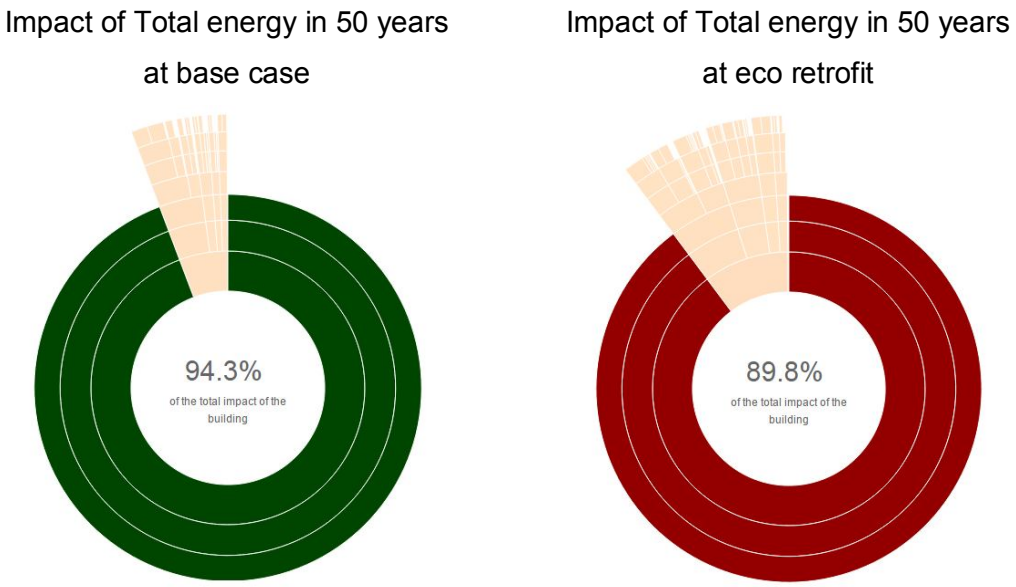


Figure 5-18 - Impact of total energy in 50 years life cycle

The e-LICCO software tool can guide you towards better or optimal selections but the lack of material choices in the database make the decision-process seem more like a rule of thumb.

5.4 Summary

It is expected that LCA software tools can help architects to design sustainable buildings but a lot is yet to be done. More specifically, current tools sometimes have some problems when applied in real workflow situations.

One major problem of some intermediate level tools seems to be the lack of material selection in the provided databases. After that, the fact that the energy consumption has the biggest impact on emissions, especially during the long duration of the "use and maintenance" stage of the building, makes the calculation of energy demand a necessary and basic element for the LCA.

For this reason, although software tools, like ArchiPHYSIK do not present their results in informative diagrams and graphs, they still fit better into the architects workflow and give more precise results and guidance towards better designs.

On the other hand, software tools like e-LICCO give results that can guide architects and designers towards optimal solutions but they do not provide flexibility for the design or selection of materials and they therefore give only rough indications on the way to an optimal solution.

6 CONCLUSION

This thesis presents a review on building-related LCA software and exhibits the development of these tools with respect to the regional focus throughout time. A clustering with respect to a set of selection criteria, such as the software application level, the software type and the tool level, has been established.

With regard to activities in the different regions, Europe remains the leader in the development of such LCA tools. This is also due to the fragmented situation in Europe with many national standards and regional building regulations as well as many languages.

In general, the tools are still focussing on the specific regional requirements, limiting their use in other regions.

The trends show that there is a market consolidation as some long-term and established players strengthen their position. The tool type development shows a twofold trend. On the one hand, the number of easy-to-use web-based tools, giving relatively easy access to the LCA topics, is growing. On the other hand, the LCA tools are increasingly integrated into other software packages, e.g. CAD with plug-in type of tools. This underlines the need for a higher degree of integration into a workflow.

Most of the tools for whole building's LCA are not considered as complicated, are relatively easy to learn and they do not require special LCA experience. However, general regional focus of the tools with their limitations on applied standards and regulations, as well as on limited language support, are an obstacle to a wider spread use.

A more detailed case study shows that some selected LCA software tools can guide architects in their design workflow, to choose optimal products and materials for ecological and sustainable solutions.

One major problem of some intermediate level tools is the lack of provided material and product data. The used databases do not always support or assist a reasonable selection of materials and construction details. Furthermore, some tools are missing the capability of energy consumption calculations. They do not allow consideration of the predominant energy impact or, alternatively, they require parallel work with other software. Therefore, such tools demand a lot of work on the part of the user or do not give accurate results or guidance towards an optimal solution.

A direct interaction and data transfer with CAD or Energy Simulation Tools (EST) reduces such an effort and time to handle data entries, which makes the design work more efficiently and precisely.

This issue does not only refer to the transfer of geometrical and material data to and from a CAD system. As energy consumption plays a dominant role on the environmental performance of a building during its life cycle, integration with Energy Simulation Tools is important.

For this reason, software tools, like novaEQUER, Eco-Sai and ArchiPHYSIK, are getting attention, as they better fit into the architect's workflow and give faster and more precise results and offer guidance towards better designs.

According to the above described requirements, an ideal LCA software tool would link CAD, EST and LCA capabilities and a broad database support for materials and products. This can be done in the form of combined software packages or plug-in tools, ideally integrated in a framework, like BIM. A software development for different regional and international standards and harmonized regulations as well as a multi-language support could further enhance architects workflows and international applicability.

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List of Abbreviations

AAP	Aquatic Acidification Potential
AIA	The American Institute of Architects
AP	Acidification Potential
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BIM	Building Information Modeling
BNB	Bewertungssystem Nachhaltiges Bauen für Bundesgebäude
BOM	Bill of Materials
CAD	Computer Aided Design
CSV	Comma-separated Values
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen – DGNB e.V.
DHW	Domestic Hot Water
EeBGuide	Energy Efficient Buildings Initiative
EN	Standards by the European Committee for Standardization
ENERBUILCA	Life Cycle Assessment for Energy Efficiency in Buildings
ENSLIC	ENergy Saving thr. promotion of Life Cycle assessment i. bldgs.
EP	Eutrophication Potential
EPD	Environmental Product Declaration
EST	Energy Simulation Tool
FAQ	Frequently Asked Question
FDES	Fiche de déclaration environnementale et sanitaire
GHG	Greenhouse Gas
GUI	Graphical User Interface
GWP	Global Warming Potential
HVAC	Heating, Ventilation and Air Conditioning
IEEE	Institute of Electrical and Electronics Engineers
IFC	Industry Foundation Classes
IFC	Environmental and Social Performance Standards
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCEA	Life Cycle Energy Analysis
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCM	Life Cycle Management
LCSA	Life Cycle Sustainability Assessment
LEED	Leadership in Energy and Environmental Design
MFA	Material Flow Analysis
NIST	National Institute of Standards and Technology (US)
NRPE	Non-Renweable Primary Energy
ODP	Ozone Depletion Potential
ÖGNI	Österreichische Gesellschaft für Nachhaltige Immobilienwirtschaft
OI3	Indicators and guidelines for calculation of ecological codes

ÖIB	Austrian Institute of Construction Engineering
PCF	Product Carbon Footprint
PDM	Product Data Management
PEI	Primary Energy Demand
PENRT	Primary Energy Non-renewable
PEP	Profil Environnemental Produit
POCP	Photochemical Smog Potential
SETAC	Society of Environmental Toxicology and Chemistry
SI	International System of Units
SLCA	Social Life Cycle Assessment
UNEP	United Nations Environment Programme
U-value	Thermal Transmittance (W/m2K)
XML	Extensible Markup Language

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APPENDIX

A. Software tools

Tables A-1 - Software descriptions

ArchiPHYSIK	
Website	http://www.archiphysik.at/
Tool developer	A NULL-Development GmbH
Country of development	Austria
Language(s)	German
Type of software	Stand-alone
LCA stages	
LCI database	IBO DATABASE
Environmental indicators	• Primary energy consumption • Global Warming Potential (GWP) • Acidification Potential (AP)
Standards	ISO 14040, OIB
Short description	ArchiPHYSIK is a software for certification of abuildings energy performance and to evaluate the environmental performance according to the OI3 index. It is applicable for the area of Austria and for new or existing buildings, or renovations. ArchiPHYSIK contains simplified and detailed calculations for single-zone and multi-zone energy certificates for residential-, non-residential- and other buildings. It can import data from CAD programs like ArchiCAD and SketchUp using add-ons. It incorporates an extensive list of materials, not only from IBO database but from other manufactures also. The results are given in a numerical form and a report with all input and output data including the certification, can be printed as a pdf file.
Target group	Architects, designers, and other stakeholders

Athena Impact Estimator for Buildings	
Website	http://www.athenasmi.org
Tool developer	Athena Sustainable Materials Institute
Country of development	CANADA-N.AMERICA
Language(s)	English
Type of software	Stand-alone
LCA stages	Cradle-to-grave
LCI database	Athena database, US LCI database
Environmental indicators	• Global Warming Potential (GWP) • Acidification Potential (AP) • Human Health Respiratory Effects Potential • Ozone Depletion Potential (ODP) • Photochemical Smog Potential • Eutrophication Potential (EP) • Fossil Fuel Consumption
Standards	ISO 14040 and ISO 14044
Short description	Athena IE is a software for the ecological assessment of whole buildings and assemblies. It is applicable in North America for industrial, institutional, commercial and residential designs - both for new buildings and major renovations. It takes into account the environmental impacts of: • Material manufacturing, including resource extraction and recycled content • Related transportation • On-site construction • Regional variation in energy use, transportation and other factors • Building type and assumed lifespan • Maintenance and replacement effects • Demolition and disposal Operating energy demand, although not included, can be considered as the user can enter the results of another thermal simulation tool in order to compute the fuel cycle burdens. The results is provided in form of tables and graphs by assembly group and life cycle stage. The unit system is in SI and Imperial.
Target group	Architects, engineers and constructors.

BEES	
Website	http://ws680.nist.gov/Bees
Tool developer	NIST
Country of development	USA
Language(s)	English
Type of software	Web-based
LCA stages	Cradle-to-grave, cost analysis
LCI database	Data collected for BEES 4.0, US LCI Database
Environmental indicators	• Global Warming Potential (GWP) • Acidification Potential (AP) • Human Health Respiratory Effects Potential • Ozone Depletion Potential (ODP) • Photochemical Smog Potential • Eutrophication Potential (EP) • Fossil Fuel Consumption • Water consumption • Human toxicity
Standards	ISO 14040, ASTM
Short description	The BEES Online web application is a software to measure the environmental and economic performance of building products. Economic performance is measured using the ASTM standard life-cycle cost method, which covers the costs of initial investment, replacement, operation, maintenance, repair, and disposal. It is applicable for the USA region and the unit system is in SI and Imperial.
Target group	Architects, designers and product manufacturers

CAP'EM Compass	
Website	www.capemcompass.eu
Tool developer	Interreg IVB project
Country of development	France , German, United Kingdom, Netherlands
Language(s)	English
Type of software	Web-based
LCA stages	Cradle-to-grave
LCI database	GaBi datasets
Environmental indicators	• Primary energy consumption • Global Warming Potential (GWP) • Acidification Potential (AP) • Ozone Depletion Potential (ODP) • Photochemical Smog Potential • Eutrophication Potential (EP) • Water consumption • Aquatic eco-toxicity • Abiotic resources (non-renewable) • Abiotic resources (renewable)
Standards	ISO 14040 and ISO 14025
Short description	The CAP'EM tool allows comparing the environmental impact of eco building products. CAP'EM Compass is based on Life Cycle Analysis results of the CAP'EM project. It enables the user to find the construction products based on users preferences and to compare them. The user can filter the products based on the user's location, calculate the ecological footprint and displays the results in a graph for easy overview. The results are only for specific element (e.g. foundation, wall) and for specific materials.
Target group	Architects, constructors, and other stakeholders

CMLCA	
Website	www.cmlca.eu
Tool developer	Reinout Heijungs, Leiden University
Country of development	Netherlands
Language(s)	English
Type of software	Stand-alone
LCA stages	Cradle-to-grave
LCI database	CML-IA
Environmental indicators	• Global Warming Potential (GWP) • Acidification Potential (AP) • Ozone Depletion Potential (ODP) • Photochemical Smog Potential • Eutrophication Potential (EP) • Water consumption • Aquatic eco-toxicity • Abiotic resources (non-renewable) • Abiotic resources (renewable) • Cost,
Standards	ISO 14040, 14044
Short description	CMLCA is a software tool that supports the technical steps of the Life Cycle Assessment. The focus of the program is on advanced computational aspects of life cycle inventory calculations. it supports the calculation of: life cycle assessment (LCA), including social life cycle assessment (SLCA) and life cycle sustainability assessment (LCSA) input-output analysis (IOA), life cycle costing (LCC) and eco-efficiency analysis (E/E). it is for free and it has no help desk, no graphical interface and the data must be downloaded or be bought. (http://www.cmlca.eu/)
Target group	LCA specialists, students, scientists

COCON	
Website	http://www.eosphere.fr/COCON-comparaison-solutions-constructives-confort.html
Tool developer	Eosphere SARL
Country of development	France
Language(s)	French
Type of software	Stand-alone
LCA stages	Cradle-to-grave
LCI database	PEP Ecopasseport. INIES, OEKEBAU, Kbob, EcoInvent.
Environmental indicators	• Primary energy consumption • Global Warming Potential (GWP) • Acidification Potential (AP) • Ozone Depletion Potential (ODP) • Photochemical Smog Potential • Eutrophication Potential (EP) • Water consumption • Aquatic eco-toxicity • Abiotic resources (non-renewable, renewable)
Standards	ISO 14040, EN 15804, NF P01-010, DVS
Short description	COCON is an estimation software for Environmental Building Quality. It helps to develop efficient design solutions for thermal and environmental perspective, not only for new buildings but also for their renovation. It uses data from many sources as the FDES (Sheets of Environmental and Health Declaration) recorded partly in the INIES database but also for other home building products manufacturers. COCON is an Excel program
Target group	Architects, constructors, and other stakeholders

COCON-BIM	
Website	http://www.cocon-bim.fr/Tarifs-du-logiciel-Cocon-BIM.html
Tool developer	Eosphere SARL
Country of development	France
Language(s)	French
Type of software	Plug- in
LCA stages	Cradle-to-grave
LCI database	PEP Ecopasseport. INIES, OEKEBAU, Kbob, EcoInvent.
Environmental indicators	• Primary energy consumption • Global Warming Potential (GWP) • Acidification Potential (AP) • Ozone Depletion Potential (ODP) • Photochemical Smog Potential • Eutrophication Potential (EP) • Water consumption • Aquatic eco-toxicity • Abiotic resources (non-renewable, renewable)
Standards	ISO 14040, EN 15804, NF P01-010, DVS
Short description	COCON-BIM is a whole building software tool for LCA studies of the environmental quality of buildings and materials through the interpretation with the digital model (BIM). It is a new software that it is expected to be available in the market after March of 2016. It is the “follower” of the previous Excel COCON and has technological developments relating to the digital model through reading the BIM files (IFC) and 3D navigation. COCON-BIM allows creating different scenarios of the same building, or comparing solutions such as new construction and renovation. The results may also concern the thermal performance or environmental performance. They are presented in a graphical and numerical form and can be exported as images (graphs) or CSV format in Excel (tables).
Target group	Architects, constructors, and other stakeholders

Eco2Soft	
Website	www.ibo.at/de/ecosoft.htm
Tool developer	IBO
Country of development	AUSTRIA
Language(s)	German, English
Type of software	Web-based
LCA stages	Cradle-to-grave
LCI database	IBO Database
Environmental indicators	• Global Warming Potential (GWP) • Acidification Potential (AP) • Primary energy content (PEC)
Standards	ISO 14040, ASTM
Short description	Eco2soft is a new baubook-tool that allows the calculation of ecological figures for buildings, including HVAC, transportation and recycling. All building elements of the baubook component calculator can be imported, including the examples and the IBO passive house catalogue. The results can be exported as a pdf file.
Target group	Designers, architects, constructors

ECODESIGN+	
Website	http://ecodesignplus.com
Tool developer	ECODESIGN company GmbH
Country of development	Austria
Language(s)	English
Type of software	Web-based
LCA stages	Cradle-to-grave
LCI database	ECODESIGN company GmbH
Environmental indicators	Carbon footprint (GWP)
Standards	ISO 14040, ISO 14044
Short description	ECODESIGN+ allows calculating, understanding, comparing, improving and communicating the Product Carbon Footprint of a product. In one of the versions, CAD files, spreadsheets and information from PDM Databases can be imported. Existing bills of materials can be incorporated and automatically connected to appropriate environmental datasets. The results are both graphical and numerical and are shown automatically as soon as data is entered.
Target group	Product developers, designers

Eco-Sai	
Website	www.eco-sai.ch/en/index_en.html
Tool developer	E4tech Software SA
Country of development	Switzerland
Language(s)	French
Type of software	Stand-alone
LCA stages	Cradle-to-grave
LCI database	DEAM, ELCD database and can import Ecoinvent
Environmental indicators	• Primary energy consumption • Global Warming Potential (GWP) • Acidification Potential (AP) • Ozone Depletion Potential (ODP) • Photochemical Smog Potential • Eutrophication Potential (EP) • Water consumption • Aquatic eco-toxicity • Abiotic resources (non-renewable, renewable)
Standards	ISO 14040,
Short description	The USai and Eco-bat software tools have been merged to facilitate the work of professionals in the building sector. The result is the first software allowing to analyze the U-value, thermal inertia and life cycle assessment of a construction (homogeneous and inhomogeneous). Eco-Sai evaluates the characteristics of a building during the draft stage or the project phase. It also provides data to support the decision making process in building renovation projects. Eco-Sai is connected to the product databases of several major building materials suppliers through thematerialsdb.org system. Eco-Sai has different versions with different cost: i) basic version, ii) USai module, building physics, iii) ECO module, life cycle assessment.
Target group	Architects, constructors

Eco-Sai plug-in for REVIT	
Website	http://www.eco-sai.ch/en/Eco-Sai-revit_en.html
Tool developer	E4tech Software SA
Country of development	Switzerland
Language(s)	English, French, German, Italian
Type of software	Plug-in
LCA stages	Cradle-to-grave
LCI database	DEAM, ELCD database and can import Ecoinvent
Environmental indicators	• Primary energy consumption • Global Warming Potential (GWP) • Acidification Potential (AP) • Ozone Depletion Potential (ODP) • Photochemical Smog Potential • Eutrophication Potential (EP) • Water consumption • Aquatic eco-toxicity • Abiotic resources (non-renewable, renewable)
Standards	ISO 14040,ISO 13786, SIA2032
Short description	In collaboration with the company "Mensch und Maschine", a version of Eco-Sai was developed being compatible with the CAO Autodesk® Revit® software. Life Cycle Assessment calculation is in accordance to the SIA2032 standard and there is a connection to the materialsdb.org database. Results are presented in graphical and numerical form and it has multi-language capability.
Target group	Architects, constructors, and other stakeholders

e-LICCO	
Website	https://e-licco.cycleco.eu
Tool developer	Cycleco
Country of development	France
Language(s)	French
Type of software	Web-based
LCA stages	Cradle-to-grave
LCI database	Own database
Environmental indicators	• Global Warming Potential (GWP) • Acidification Potential (AP) • Ozone Depletion Potential (ODP) • Photochemical Smog Potential • Eutrophication Potential (EP) • Water consumption • Aquatic eco-toxicity • Abiotic resources (non-renewable) • Abiotic resources (renewable) • Ionizing radiation on human health
Standards	ISO 14040-44
Short description	e-LICCO is a web-based software allowing to compare the results from different building scenarios for different indicators. It is applicable for different type of buildings like individual house, academic building or office building. It is a whole building software tool which takes into account the building envelope, HVAC, energy consumption, occupancy, demolition, waste transportation and waste treatment. The results are presented in graphical and numerical form with different level of detail (component, ratios, LCA categories), chart type, impact category.(e-Licco 2016)
Target group	Designers, architects, project managers

ELODIE	
Website	http://www.elodie-cstb.fr/
Tool developer	CSTB
Country of development	France
Language(s)	French , English
Type of software	Web-based
LCA stages	Cradle-to-grave
LCI database	INES
Environmental indicators	• Primary energy consumption • Water consumption • abiotic resources (non-renewable) • Global Warming Potential (GWP) • Acidification Potential (AP) • Ozone Depletion Potential (ODP) • Photochemical Smog Potential • Eutrophication Potential (EP)
Standards	ISO 14040
Short description	ELODIE is a software for whole building LCA. For the calculations all life cycle stages are taken into account, including the energy demand, the occupancy, the impact of the construction site and the waste. The results are presented in graphical and numerical form, for a specific indicator or for different options (whole building, assembly, whole project). They can be exported to Excel or shared with other design teams
Target group	Architects, designers, constructors, stakeholders

eve-BIM ELODIE	
Website	http://www.elodie-cstb.fr/
Tool developer	CSTB
Country of development	France
Language(s)	French , English
Type of software	Plug-in
LCA stages	Cradle-to-grave
LCI database	INES
Environmental indicators	• Primary energy consumption • Water consumption • abiotic resources (non-renewable) • Global Warming Potential (GWP) • Acidification Potential (AP) • Ozone Depletion Potential (ODP) • Photochemical Smog Potential • Eutrophication Potential (EP)
Standards	ISO 14040
Short description	eve-BIM ELODIE is a software for whole building LCA. For the calculations all life cycle stages are taken into account, including the energy demand, the occupancy, the impact of the construction site and the waste. The results are presented in graphical and numerical form, for a specific indicator or for different options (whole building, assembly, whole project). eve-BIM ELODIE is compatible with BIM, reducing the necessary time and effort to enter the building data.
Target group	Architects, designers.

eToolLCD™	
Website	http://etoolglobal.com
Tool developer	eTool
Country of development	Australia
Language(s)	English
Type of software	Web-based,
LCA stages	Cradle-to-grave
LCI database	AusLCI and the Ecoinvent 2.2 background modified with AusLCI inputs.
Environmental indicators	• Global Warming Potential (GWP) • Acidification Potential (AP) • Ozone Depletion Potential (ODP) • Photochemical Smog Potential • Eutrophication Potential (EP) • Water consumption • Aquatic eco-toxicity • Abiotic resources (non-renewable, renewable)
Standards	ISO 14040, EN 15978
Short description	eToolLCD is an open-use, web-based, whole building life cycle assessment (LCA) and design software. The results are provided both in graphical and numerical form. Reports are compliant with international standards EN 15978 and ISO 14044. It is applicable for small houses, multi-residential or other buildings for development. It is also related with rating schemes as Green Star, UK Rating Schemes and other international schemes like LEED.
Target group	Architects, Developers and real estate industry

GaBi	
Website	www.gabi-software.com
Tool developer	Thinkstep (previous PE INTERNATIONAL)
Country of development	Germany
Language(s)	English
Type of software	Stand-alone
LCA stages	Cradle-to-grave
LCI database	GaBi database, Ecoinvent, U.S. LCI, database on demand
Environmental indicators	• Primary energy consumption • Global Warming Potential (GWP) • Acidification Potential (AP) • Ozone Depletion Potential (ODP) • Photochemical Smog Potential • Eutrophication Potential (EP) • Water consumption • Aquatic eco-toxicity • Abiotic resources (non-renewable) • Odors • Radioactive waste • Human toxicity
Standards	ISO14044, CSA Group
Short description	GaBi is a generic LCA software tool to model any element of an industrial product or process. It is one of the leading expert systems detailing the environmental, energy and cost impact of all implicated materials and processes of a product. There are different licenses including educational and the cost depends on the license. A free trial of 30 days is also available.
Target group	LCA specialists, designers, product manufactures

LeGep®	
Website	http://legep.de/produkte/legep-okobilanz/
Tool developer	WEKA
Country of development	Germany
Language(s)	German
Type of software	Stand-alone
LCA stages	Cradle-to-grave
LCI database	Ecoinvent, Ökobau.dat , SIRADOS database,
Environmental indicators	• Primary energy consumption • Global Warming Potential (GWP) • Acidification Potential (AP) • Ozone Depletion Potential (ODP) • Photochemical Smog Potential • Eutrophication Potential (EP) • Water consumption • Aquatic eco-toxicity • Abiotic resources (non-renewable) • Human toxicity
Standards	ISO 14040/14044
Short description	LeGep® is a tool supporting planning teams for the design, construction, quantity surveying and evaluation of new or existing buildings. All information is structured along the life cycle phases (construction, maintenance, operation, cleaning, refurbishment and demolition). The LeGep® database contains the description of all elements of a building (based on DIN 276), their life cycle costs (LCC) based on DIN 18960 and on the calculation rules of the German DGNB and BNB Sustainability Certification. The results are provided in numerical and graphical form. The preset documentation allows the presentation of the material and energy flows, or the effect balances of your building.
Target group	Architects, Developers and real estate industry.

novaEQUER	
Website	www.izuba.fr/logiciel/novaequer
Tool developer	IZUBA energies
Country of development	France
Language(s)	French
Type of software	Stand-alone
LCA stages	Cradle-to-grave
LCI database	Ecoinvent v2.2
Environmental indicators	• Primary energy consumption • Global Warming Potential (GWP) • Acidification Potential (AP) • Ozone Depletion Potential (ODP) • Photochemical Smog Potential • Eutrophication Potential (EP) • Water consumption • Aquatic eco-toxicity • Abiotic resources (non-renewable) • Odors • Radioactive waste • human toxicity
Standards	ISO 14040, XP P01-020-3
Short description	novaEQUER is a new version of the EQUER software. It is linked to Comfie, the calculation engine STD PLEIADES. The results are presented in graphs or as tables. The tool also provides graphical comparison of projects to visualize the environmental impact or to compare a design with another one or with a reference project. The results can be displayed as radar or histogram graph, this with respect to the whole life cycle or for specific steps.
Target group	Architects, designers, product manufacturers

OpenLCA	
Website	http://www.openlca.org/openlca
Tool developer	GreenDelta GmbH
Country of development	Germany
Language(s)	English
Type of software	Web-based,
LCA stages	Cradle-to-grave
LCI database	openLCA Nexus, Ecoinvent , GaBi databases, ProBas+
Environmental indicators	• Global Warming Potential (GWP) • Acidification Potential (AP) • Ozone Depletion Potential (ODP) • Photochemical Smog Potential • Eutrophication Potential (EP) • Water consumption • Aquatic eco-toxicity • Abiotic resources (non-renewable, renewable)
Standards	ISO 14040, 14044
Short description	openLCA is a free, Life Cycle Assessment (LCA) and Footprint software with a broad range of functions and available databases. It is an open source software, i.e. its source code is freely available and can be modified by anyone. It is applicable for LCA, LCC and EPDs . It links into many databases which can be imported, some of them are for free and others, like Ecoinvent, have a fee. The results are presented in form of tables, graphs, and Sankey diagrams.
Target group	LCA specialists, product developers, designers

SimaPro	
Website	https://simapro.com
Tool developer	PRé Sustainability
Country of development	Netherlands
Language(s)	English
Type of software	Stand-alone
LCA stages	Cradle-to-grave
LCI database	Ecoinvent, US LCID, and many others
Environmental indicators	• Primary energy consumption • Global Warming Potential (GWP) • Acidification Potential (AP) • Ozone Depletion Potential (ODP) • Photochemical Smog Potential • Eutrophication Potential (EP) • Water consumption • Aquatic eco-toxicity • Abiotic resources (non-renewable) • Odors • Radioactive waste • Human toxicity
Standards	ISO14044
Short description	SimaPro is a professional LCA software tool for product design. It can compare and analyze complex products and processes. The software can be used for a variety of applications, such as sustainability reporting, carbon foot printing , product design, generating environmental product declarations and determining key performance indicators (SimaPro 2016). SimaPro has a multi-user feature which allows several people to work on the same project simultaneously. It uses various databases and methods. There are different licenses including an educational version. The license fee depends on the license. A free trial of 30 days is also available.
Target group	LCA specialists, designers, product manufactures

Tally®	
Website	choosetally.com
Tool developer	KT Innovations, Thinkstep, and Autodesk®.
Country of development	USA
Language(s)	English
Type of software	Plug-in
LCA stages	Cradle-to-grave
LCI database	GaBi datasets
Environmental indicators	• Primary energy consumption • Global Warming Potential (GWP) • Acidification Potential (AP) • Ozone Depletion Potential (ODP) • Photochemical Smog Potential • Eutrophication Potential (EP) • Water consumption • Aquatic eco-toxicity • Abiotic resources (non-renewable) • Abiotic resources (renewable)
Standards	ISO 14040-14044.
Short description	The Tally® application allows architects and engineers working in Revit® software to quantify the environmental impact of building materials for whole building analysis as well as comparative analyses of design options. While working on a Revit® model, the user can define relationships between BIM elements and construction materials from the Tally® database. The result is Life Cycle Assessment on demand, and an important layer of decision-making information within the same time frame, pace, and environment that building designs are generated. (http://choosetally.com/overview/)
Target group	Architects, engineers , designers

TEAM™	
Website	http://ecobilan.pwc.fr/en/boite-a-outils/team.html
Tool developer	PwC Ecobilan Experts
Country of development	France
Language(s)	French
Type of software	Stand-alone
LCA stages	Cradle-to-grave
LCI database	DEAM, ELCD database and can import Ecoinvent
Environmental indicators	• Primary energy consumption • Global Warming Potential (GWP) • Acidification Potential (AP) • Ozone Depletion Potential (ODP) • Photochemical Smog Potential • Eutrophication Potential (EP) • Water consumption • Aquatic eco-toxicity • Abiotic resources (non-renewable) • Abiotic resources (renewable)
Standards	ISO 14040,
Short description	TEAM™ is a professional tool for evaluating the life cycle and the environmental and economic performance of products. The user can export the results of the whole or part of its project to simple text files and exchange them with other users easily. The entire LCA project, from the modeling to the calculation of environmental impacts and running of simulations can be made in a single exe file which does not require any installation and can be used from a USB stick (TEAM™ 2016). A multiuser license and an online demo version are available.
Target group	Architects, product designers, researchers

Umberto	
Website	www.ifu.com/en/products/umberto
Tool developer	Ifu Hamburg
Country of development	Germany
Language(s)	German, English
Type of software	Stand-alone
LCA stages	Cradle-to-grave
LCI database	Ecoinvent, Gabi datasets
Environmental indicators	• Primary energy consumption • Global Warming Potential (GWP) • Acidification Potential (AP) • Ozone Depletion Potential (ODP) • Photochemical Smog Potential • Eutrophication Potential (EP) • Water consumption • Abiotic resources (non-renewable)
Standards	GHG Protocol, ISO/TS 14067, and PAS 2050
Short description	Umberto is a software for material and energy flow calculation and analysis. There are four different versions, depending on the specific requirements. For Life Cycle Assessment the Umberto NXT LCA version is used which links to Ecoinvent and Gabi LCI databases, creates graphic models of the product LCA, analyses all environmental impacts and gives the ability for a free combination of impact indicators. The results are presented in form of tables, graphs, and Sankey diagrams.
Target group	LCA specialists, designers, product manufactures