DIPLOMARBEIT

A review of life cycle assessment methods in various building certification systems

ausgeführt zum Zwecke der Erlangung des akademischen Grades einer **Diplom-Ingenieurin**

unter der Leitung von

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KURZFASSUNG

Da die Architektur- und Bauindustrie zunehmend Wert auf Nachhaltigkeit legt, werden umfassendere Methoden entwickelt, um die Umweltauswirkungen von Gebäuden zu bewerten und zu reduzieren. Gebäude bestehen regelmäßig aus einer Vielzahl unterschiedlicher Baumaterialien und -produkte. Diese bilden Gebäudekonstruktionen, und verschiedene Materialien und Produkte erfüllen eigenständig oder in Kombination mit anderen Materialien dedizierte Funktionen. Üblicherweise wird die Auswahl von Baumaterialien von einer Vielzahl von Faktoren wie Design, Anforderungen in verschiedenen Leistungsbereichen (statische Leistung, Wärme-/Energieleistung usw.), der Abhängigkeit der Materialien, den Wünschen und der Budgetsituation der Eigentümer beeinflusst. Eine der Kernideen bei der Entwicklung von Gebäudezertifizierungssystemen war es, die Einhaltung von Grenzwerten in definierten Kriterien zu bewerten. Als solches kann jedes bewertete Gebäude hinsichtlich seiner Leistung in Bereichen wie Energieverbrauch, Umweltauswirkungen und anderen kategorisiert werden. Das Ergebnis solcher Bewertungsroutinen ist regelmäßig ein Label, das nicht nur unterschiedliche Leistungsaspekte identifiziert und kommuniziert, sondern auch weitere mit dem Gebäude verbundene Parameter wie den Immobilienwert beeinflussen soll. Darüber hinaus zielen die Bewertungskriterien in den Gebäudezertifizierungssystemen nicht nur darauf ab, nachhaltiges Planen und Bauen zu unterstützen, sondern können auch als Instrumente zur Qualitätssicherung genutzt werden. Ökobilanzmethoden finden sich häufig in ökologischen Kategorien von Gebäudezertifizierungssystemen und dienen unabhängig von den unterschiedlichen verwendeten Namenskonventionen und der maximalen LCA-Punktzahl dem gleichen Zweck.

Es gibt eine beträchtliche Menge an veröffentlichten Arbeiten auf dem Gebiet der LCA, jedoch ist ein Großteil der Literatur nicht auf dem neuesten Stand. Einige Ressourcen sind in deutscher Sprache verfügbar, einschließlich der LCA-Methoden in österreichischen Gebäudezertifizierungssystemen.

Diese Diplomarbeit zielt darauf ab, die aktuellen Methoden der Gebäudeökobilanz von KlimaAKtiv, ÖGNB, ÖGNI, BREEAM, LEED und DGNB Gebäudezertifizierungssystemen zu überprüfen, indem ihre jeweiligen Gebäudebewertungshandbücher durchsucht werden. Die Diplomarbeit berechnet auch die LCA-Leistung für ein Wohngebäude durch eine LCA-Fallstudie basierend auf den Bedingungen der Gebäudebewertungshandbücher in Bezug auf die in dieser Diplomarbeit behandelten Gebäudezertifizierungssysteme.

Stichwörter

Ökobilanz- Methoden, Gebäudezertifizierungssysteme, Ökobilanzkriterien

ABSTRACT

As architectural and construction industries increasingly emphasize sustainability, more comprehensive methods are being developed to evaluate and reduce environmental impacts by buildings. Regularly, buildings are constituted by a large number of different building materials and products. These form building constructions, and different materials and products deliver dedicated functions whether on their own or in combination with other materials. Usually, the selection of building materials is influenced by a variety of factors such as design, requirements in different performance domains (structural performance, thermal/energy-performance, etc.), the interdependence of materials, the desires and budget situation of the owners. One of the core ideas of developing building certification systems was to evaluate the conformity with threshold values in defined criteria. As such, each evaluated building can be categorized regarding its performance in domains such as energy use, environmental impact, and others. The outcome of such evaluation routines regularly is a label that not only identifies and communicates different aspects of performance, but also should influence further parameters connected to the building such as the real estate values. Additionally, the assessment criteria in the building certification systems not only aim to support sustainable planning and construction but can also be utilized as tools for quality assurance. Life cycle assessment methods are commonly found in ecological categories of building certification systems and regardless of the different naming conventions used and maximum LCA score, they serve the same purpose.

There is a considerable amount of published work in the field of LCA, however much of the literature is not up to date. Some resources are available in German including the LCA methods in Austrian building certification systems.

This thesis aims to review the current building LCA methods belonging to KlimaAKtiv, ÖGNB, ÖGNI, BREEAM, LEED and DGNB building certification systems by sifting through their respective building assessment manuals. The thesis also calculates LCA performance for a residential building through a LCA case study based on the terms of the building assessment manuals related to the building certification systems covered in this thesis.

Keywords

Life Cycle Assessment methods, building certification systems, LCA criteria

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Finally, I am infinitely grateful to my dear parents who passed away whilst I was working on my Master's degree, from whom I have always learned patience in adversity.

I hope with this work I have made a very small contribution to the practice of sustainable development and green building at the most critical time.

TABLE OF CONTENTS

ABBREVIATIONS & TERMS

Abbreviation	Definition
AP	Acidification Potential
BREEAM	Building Research Establishment Environmental Assessment Methodology
BG (English)	Envelope Boundary
BG (German)	Bilanzgrenze
BGF(English)	Gross Building Area
BGF(German)	Bruttogeschossfläche
BZF(English)	Reference-Area
BZF(German)	Bezugsfläche
DGNB (English)	German Sustainable Building Council
DGNB (German)	Deutsche Gesellschaft für Nachhaltiges Bauen
EBF (German)	Energiebezugsfläche
EN	Standards by the European Committee for Standardization
Energieausweis	Energy Certificate
EP	Eutrophication Potential
EPD	Environmental Product Declaration
ERA (English)	Energy reference area
Ergebnisblatt Gebäude	Results Sheet Building
GWP	Global Warming Potential
IBO (English)	Austrian Institute for Healthy Ecological Building
IBO (German)	Ökologisch Bauen Gesund Wohnen
IBU(English)	Institute Construction and Environment
IBU(German)	Institut Bauen und Umwelt
KlimaAKtiv (English)	Building and Refurbishment
KlimaAKtiv (German)	Bauen und Sanieren
LCA (English)	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LEED	Leadership in Energy and Environmental Design
LZA (German)	Lebenszyklusanalyse

MFH (English)	Multi-family house
MFH (German)	Mehrfamilienhaus
NGOs	Non-Governmental Organizations
ODP	Ozone Depletion Potential
ÖGNB (English)	Austrian Sustainable Building Council
ÖGNB (German)	Österreichische Gesellschaft für Nachhaltiges Bauen
ÖGNI (English)	Austrian Sustainable Building Council
ÖGNI (German)	Österreichische Gesellschaft für Nachhaltige Immobilien Wirtschaft
ÖGUT(English)	Austrian Society for Environment and Technology
ÖGUT(German)	Österreichische Gesellschaft für Umwelt und Technik
OI3	Eco Index 3
OI3- Ausweis	OI3 Statement
OIB (English)	Austrian Institute of Construction Engineering
OIB (German)	Österreichisches Institut für Bautechnik
OIB RL6	Basic Documents for the Transcription of the EPBD in the Austrian Regions
ÖNORM(English)	Austrian Standard
ÖNORM(German)	Österreichische Norm
PEnr	Non-Renewable Primary Energy Demand
POCP	Potential Ozone Creation Potential
Sanierung	Renovation
SK(English)	Climate Location
SK(German)	Standortklima
TGH (English)	Thermal Building Envelope
TGH (German)	Thermischen Gebäudehülle
U- value	Thermal Transmittance
USGBC	The U.S. Green Building Council
Wohnbauten	Residential Buildings

1 INTRODUCTION

1.1 Overview

Life cycle assessment is a methodology for evaluating the environmental performance of a service, process, or product, as well as buildings, over their whole life cycle. Interest in using life cycle assessments for entire buildings evaluations has increased in the last decade, and as a consequence building LCA tools are under development in several countries. Environmental performance is an integrated part of these life cycle assessment methodologies of these building certification systems.

Green building rating and certification systems are intended to foster more sustainable building design, construction and operations by promoting a better integration of environmental concerns with cost and other traditional decision criteria. Different building assessment systems approach this task from differing perspectives, but they have certain elements in common. Over the recent decades various public institutions and companies have taken the initiative to develop building rating systems based on international standards. This study concentrates on six LCA methods used in Austria and globally for building certifications, and in turn how to calculate the life cycle of buildings within the framework of green certifications. Due to the importance of understanding the criteria of the building LCA method, the six LCA methods related to these six certifications are reviewed (klimaAKtiv, ÖGNB, ÖGNI, BREEAM, LEED and DGNB). The review describes the different concepts in the frameworks of existing methods and discusses similarities and differences in methods requirements (building types, standards, boundary definitions, LCA phases, environmental indicators, available LCA tools..., etc.) using the available catalogs of criteria for each of the six building certifications. The focus is on specific categories relating to environmental quality. Generally, the method of assessing the life cycle of a building is determined by the category of material. In some certifications, such as KlimaAKtiv, ÖGNI and DGNB, the category of energy is an important part of the life cycle assessment.

For this project, comprehensive research regarding LCA methods in building certification systems has been undertaken covering the available LCA tools developed for national as well as the international building certification systems.

Subsequently, the building LCA case study are applied to multifamily buildings. This research describes and defines the available rating systems both within the Austrian and global markets.

1.2 Motivation

In recent years Life Cycle Assessments (LCA) in the building sector have increasingly gained in importance. They are applied in the certification of sustainable construction (e.g., BREAM, HQE, VERDE, and DGNB), provide a base for environmental declaration of building products (EPD) and progressively serve as a well for decision support. However, the LCA approach across the different labelling certification systems for sustainability in the building sector widely varies in relation to many factors such as methodology, materials considered, energy efficiency and consistency of system boundaries. In the midst of a different number of building certification systems that consider LCA methods in their assessment, a small group of these certifications LCA methods were taken, such as ÖGNB (TQB), ÖGNI, KlimaAKtiv, as Austrian certification systems and for major international certification systems LEED, BREEAM and DGNB are examined in addition.

One of the most important reasons for choosing this topic in particular is to determine the current methods used to calculate the building life cycle assessment as described in their respective manuals. Assessment manuals are subject to continuous updates; thus, the names, weights and assessment requirements change with regard to different assessment requirements.

In this study the focus is on the current LCA criteria belonging to these six assessment manuals. The study gives an overview of the LCA in the respective assessment manuals. In addition to this, the research will support the identification of the proper LCA software tools through a building LCA case study. The objective of the LCA case study is to propose simplified workflow steps to conduct LCA performance for a retrofit building. This is done firstly by deciding on the required improvements using the components catalogue, and then using the building physics software and the recommended LCA tools to calculate the LCA result. Finally, the outcome is converted into award points/credits based on the manuals' assessment of the respective certification systems.

1.3 Building Life Cycle Assessment

Life Cycle Assessment (LCA) had its beginnings in the 1960's. Concerns over the limitations of raw materials and energy resources sparked interest in finding ways to cumulatively account for energy use and to project future resource supplies and use. LCA has first been applied based on ISO 14040-44 standards. However, these standards being too general, more specific guidance was recently released, e.g., the ILCD Handbook edited by the JRC of the European Commission.

In the construction sector, the recent European standards EN 15804 and EN 15978 are based on the LCA International standards ISO 14040-44. These standards define the general framework and general calculation methods for product LCAs and EPDs and building LCAs. Though previous papers on building LCA research perspectives recommend integrating the existing body of knowledge presented above (i.e., ISO 14040-44, ILCD, CEN standards it is unclear how a tool developer or a practitioner can currently undertake this due to inconsistencies within and diverging guidance between these standards. As a consequence, the European landscape of LCA calculation rules is not dominated by harmonized methods, these inconsistencies being also found in available building LCA tools.

The field of LCA studies started to gain momentum in the early 80s of the last century. A plethora of LCA concepts, terminologies and methods were under consideration. However, the whole process was lacking a clear framework which resulted in varying outcomes.

In the 1990s the International Organization for Standards and the Society of Environmental Toxicology and Chemistry (SETAC) started supporting a more theoretical and applicable concept of LCA through workshops and by setting up guidelines on LCA. The period saw also the inclusion of LCA in the policies and legislation. The International Standards Organisation (ISO) classifies the existing environmental labels into three typologies: types I (Ecolabels, ISO 14024), type II (Product Self-declarations, ISO 14021), and type III (EPDs, ISO 14025).

Heading into the first decade of the 21st century interest in the LCA concept further increased with the development of varying methods with respect to system boundaries, mainly due to the fact that ISO never defined detailed LCA methods.

ISO has published a set of guidelines for LCA in order to shape a more structured and internationally accepted method (Aygenç 2019, 19). These guidelines are:

• ISO14040-Principles and Framework (2006)

• ISO 14041 - Goal and Scope Definition and Inventory Analysis (1998) – not in use

• ISO 14042 - Life Cycle Impact Assessment (2000) – not in use

• ISO 14043 - Life Cycle Interpretation (2000) – not in use

• ISO 14044 - Requirements and Guidelines (2006) 19

• ISO 14047 - Illustrative Examples on How to Apply ISO 14044 to Impact Assessment Situations (2012)

• ISO 14048 - Data Documentation Format (2002)

• ISO14049 - Illustrative Examples on How to apply ISO 14044 to Goal and Scope Definition and Inventory Analysis (2012) (Menoufi, 2011)

The collection of ISO standards 14041, 14042 and 14043 are integrated into ISO 14040:2006. As stated in the latter standards LCA serves as a technique for assessing environmental impacts associated with products. The applied methodology to achieve this is to compile the required inputs and outputs associated with a product and then determine the impacts resulting from those inputs and outputs. Ultimately, the outcome of the inventory analysis is interpreted in relation to the objective of the assessment. The steps of LCA are comprised of a goal and scope definition, Life Cycle Inventory (LCI), Life Cycle Impact Analysis and Interpretation (LCIA).

According to the ISO 14040 standard, the life cycle assessment is divided into four main phases (see Figure1-1):

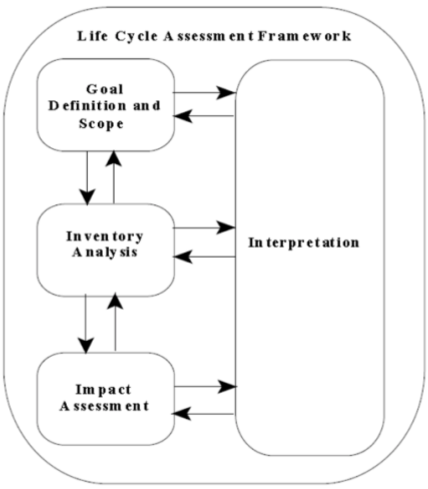

Figure 1-1 Life cycle assessment phases according to the ISO 14040 standard

1) Defining the LCA Goals and Scope

As an initial step, it is important to define the goals and the purpose of the life cycle assessment, which have a significant impact on the following assessment elements. The definition of the goals and scope of the assessment will determine the purpose of the LCA. Subsequently the life cycle is defined by beginning with the extraction of raw material and concluding with end-of-life related tasks of recycling, reusing or disposal.

2) Inventory analysis

In the life cycle inventory analysis, the collection of inputs (such as energy and water consumption and usage of raw material) and outputs (such as emissions e.g. CO_2 and waste) are quantified to determine the building's environmental impact.

3) Impact assessment

This phase is continuing to the Inventory analysis phase. The results extracted from the LCI phase are classified into many different impact categories by virtue of criteria product quality. Normally, the results of the impact assessment phase come in a numerical format which represents the quantitative environmental impact related to the product under assessment. This phase also assesses the environmental impact resulting from energy consumption for the primary energy (renewable and nonrenewable).

4) Interpretation

Life cycle interpretation is a way to assess the extracted results from the life cycle inventory and the LCIA. The final results from this phase is considered as a helpful conclusion for decisions related to the environment.

Life cycle stages

In order to assess the life cycle of a building precisely, the life cycle stages and their system boundaries should be first defined. EN15804 and EN15978 have been established since 2012 (Hauke et al. 2016). In 2013 EN15804 was amended by publishing EN15804+A1. Both norms serve as bases for the specification of rules concerning the preparation of EPDs (Environmental Product Preparation) for construction products, and also for the calculation of the environmental performance of buildings. Both norms are closely linked in the sense that they are based on a shared modular life cycle stage. According to the EN 15804 and EN 15978, the life cycle stages include the following stages: product, construction process, use, end-of-life and benefits and loads stages (see Table 1-1).

Table 1-1 Life cycle stages of buildings in accordance with EN 15804 and EN 15978 (Hauke et al. 2016, 30)

Building Assessment Information				
Building Life-Cycle Information				
Product Stage	**Construction Process Stage**	**Use Stage**	**End-of-Life Stage** (Building)	**Benefits and Loads** Beyond Building Boundaries
A1: Raw Material Supply A2: Transport A3: Manufacturing	A4: Transport A5: Construction-Installation Process	B1: Use B2: Maintenance B3: Repair B4: Replacement B5: Refurbishment B6: Operational Energy Use B7: Operational Water Use	C1: Deconstruction C2: Transport C3: Waste Processing for Reuse, Recovery and Recycling C4: Disposal	D: Reuse-Recovery-Recycling Potential

Product stage (A1-A3)

The stage covers the materials manufacturing process, starting with the extraction of raw materials, transportation of these materials to the factory, the manufacturing process and ends with the finished building products at the factory.

Construction process stage (A4-A5)

The stage includes the transportation of the finished building materials from the factory to the construction site, until completion of whole construction work in the site.

Use stage (B1-B7)

The use stage represents the building operation and the maintenance required through the life span of building. International building certification systems, such as DGNB, often designate building service life as 50 years. LEED and BREEAM however assume a building service life of 60 years in their assessment manuals.

<u>End of Life Stage (C1-C4)</u>

This stage refers to deconstruction of a building and the disposal of the remaining materials at the end of its life. The stage is divided into two main categories:

Category One: This category applies the cradle to cradle approach. It is possible in this category to reuse the building materials in addition to the building structural elements or recycle them.

Category Two: This category applies the Cradle-to-Grave approach. It comprises the elimination of building materials waste to landfills or incineration. The transportation of the waste building materials is also taken into consideration in this stage.

<u>Benefits and loads (D)</u>

This stage refers to the reuse, recovery and recycling potential.

Process Based Life Cycle Assessment Method

LCA was founded to ensure the construction of buildings with a high environmental performance at all phases of construction. In the context of sustainability assessment, it is important to clarify the system boundaries. They can be outlined in the following typical methods:

- Cradle to Grave or (Cradle to Cradle): This approach is considered as a full life cycle assessment. The approach is divided into two sub approaches depending on disposal method of building material at the end of building life cycle. The first sub approach is **cradle to grave;** this approach is used in case of the extraction of the raw materials used to produce the building materials (cradle) ending with disposal of these materials (grave). The second sub approach is **cradle to cradle;** this is used in case of recycled material is reused again. Consequently, this implies that certain materials and products do not have an end of life in the normal sense and are available for future construction works.
- Cradle to Gate: This approach is considered as a partial life cycle assessment. The life cycle assessment of building material takes into consideration from extraction the raw material to the factory gate before being transferred to the consumer.

Environmental impact categories

Environmental impact categories are defined as the quantities of emissions released into the air that have an adverse effect on the environment. These emissions are measured as an expression from the amount of effect per functional unit of the product produced. Each environmental impact category is an indicator of the effective contribution of a product to visible environmental problem.

According to B. Hauke et al. (2016) the most common categories are described below:

Global Warming Potential (GWP)

The gradual accumulation of greenhouse gases (such as the Carbon Dioxide CO_2 and methane CH_4) in the earth's atmosphere is leading to raising temperatures in the lower layer of the earth's atmosphere. The time period of 100 years is usually referring to the contributions to GWP, within this period of time CH_4 has a 25 times greater impact factor than the same mass of CO_2. The global warming potential is expressed in carbon dioxide equivalents [kg CO_2 eq].

Ozone depletion potential (ODP)

Ozone plays as important role for life on earth despite its low concentration. It is expressed in [kg CFC-11 equivalents]. This layer has the ability to absorb UV radiation (short wave) and reemit in a longer wavelength. The ozone layer shields the earth against a large part of the UV-A and UV-B radiation from the sun, preventing excessive warming of the earth’s surface and protects flora and fauna (Hauke et al. 2016). Damage to the ozone layer is produced by the accumulation of the harmful halogenated hydrocarbons in the atmosphere. This in turn leads to human and animal health issues. Additionally, ozone depletion effects the photosynthesis process.

Photochemical Ozone Creation Potential (POCP)

The (POCP) characterize as the harmful trace gases. The interaction between these traces' gasses and UV radiation lead to formation of Ozone at ground level. It is expressed [C_2H_4 equivalents].

Acidification Potential (AP)

The Acidification Potential (AP) of a substance quantifies its acidification impact when emitted. It is expressed in [kg SO_2 - equivalent]. Pollutants such as Sulphur and Nitrogen, dissolve in water in the air resulting in the production of sulphuric and nitric acids. These acids fall to earth in form of acidic rain penetrating (soil and water) and are absorbed by the root systems of plants. Typical consequences are damaged forests and fish mortality. Acid rain attacks buildings and causes abrasions effecting in particular old sandstone buildings.

Eutrophication Potential (EP)

The process of eutrophication describes the steps required to transform water or soil from being oligotrophic to eutrophic. Typical nutrients such as phosphorus or nitrogen compounds can enter the environment during the manufacturing of construction products. An increase in the concentration of phosphorus and nitrogen compounds in the water is a potential source of growth of algae which can lead to fish mortality. It is expressed in [kg PO4 -equivalents].

Non-Renewable Primary Energy Demand (PEnr)

The (PEnr) is specific for three building phases (construction, repair, operation and dismantling/ disposal). It is expressed in [$MJ.m^{-2}{}_{SA}.a^{-1}$], i.e. energy demand per unit area per year.

1.4 Building Certification Systems

Increasing environmental awareness has resulted in an increased emphasis on enhancing building envelops with thermal insulation to improve the energy performance of the object. These thermally insulated buildings achieve a reduction in energy use over their life. The direction of sustainability is shifting toward emphasizing the importance of other ecological qualities in addition to the energy performance. Henceforth, to be classified as sustainable, building projects need to obtain high scores in economic, environmental and social performance (see Figure 1-2).

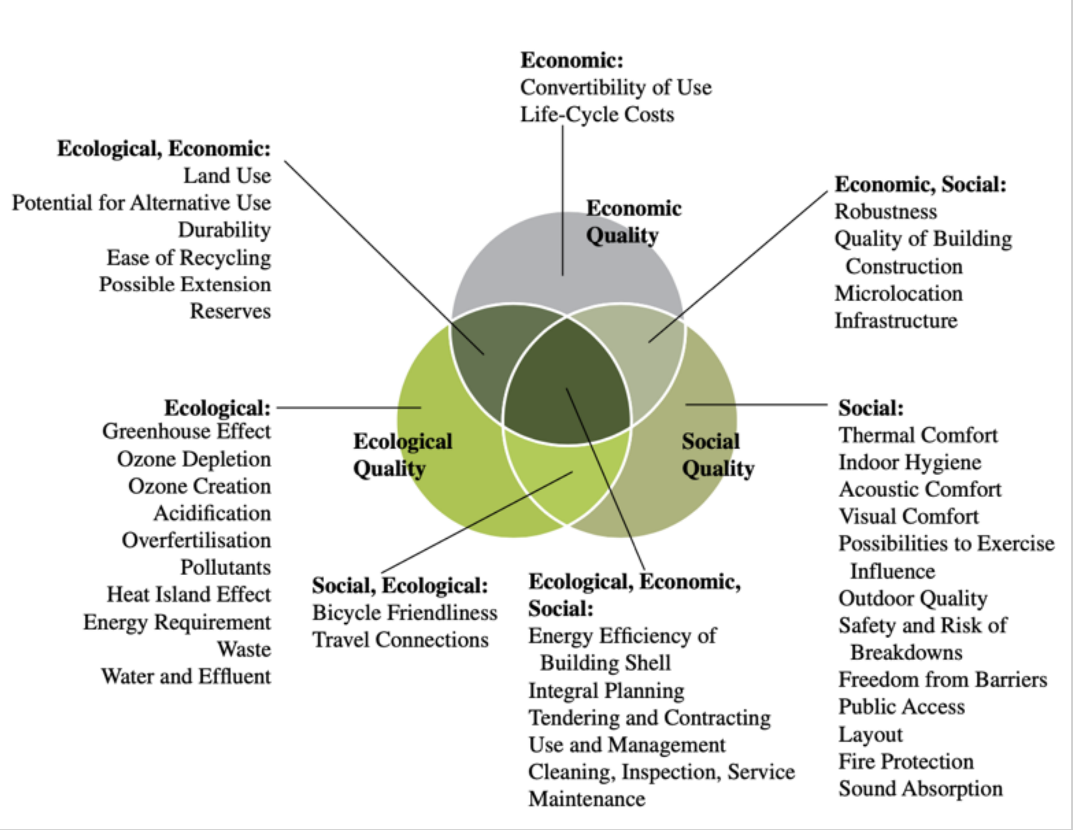

Figure 1-2 Illustration of sustainable buildings and their demands with respect to their ecological, social and economic quality (Hauke et al. 2016, 7)

A very large number of international building certification systems have existed since the 1990s. In Europe building LCAs are the foundation of many building certification systems as well as of Environmental Product Declarations (EPD) for construction products. Yet the metrics and standards currently used in Europe can be interpreted and implemented in many different ways, leading to inconsistencies and lack of comparability.

Building certification systems guidelines aim at endorsing sustainability in buildings by reducing negative environmental impacts and at the same time bolster living quality and comfort. Hence, including the design phase in the building certification systems provides support in obtaining a more desirable outcomes with respect to the environment and cost.

A number of certification systems, such as KlimaAKtiv, BREEAM and DGNB, have concentrated on developing specific criteria catalogs tailored for refurbishment projects. In contrast, other systems have set their focus on creating criteria that can be applied on a case-by-case basis. These criteria are differentiated for new and refurbishment buildings. This approach is adapted by systems LEED and TQB. In Austria, three national certification systems specializing in building assessment currently exist: ÖGNI/ DGNB, KlimaAKtiv and ÖGNB. These certification systems implement different approaches to environmental performance (i.e., complete versus partial use of the LCA methodology). Recently, the demand for building certification has increased significantly, especially for new construction projects as certification can be already addressed in the design phase. However, the demand for certification of refurbishment objects is lower than that of new projects. Renovation is an essential aspect of resource conservation, as it allows the building to be used for a different purpose. Since large parts of the construction has already occurred, a significantly lower amount of material is required compared to that required to produce a new building. A Concise Description of The Austrian and International Building Certification Systems Explored in this Project.

KlimaAKtiv/Austria

KlimaAKtiv was founded by the Federal Ministry of Climate Protection, Environment, Energy, Mobility, Innovation and Technology of Austria and it is also part of the Austrian federal climate strategy. The initiative fosters climate-friendly technologies and services by centering attention on the areas of building and renovation, energy performance, engagement of renewable energies and mobility. The main objective is the reduction of total energy consumption and the CO_2 emissions of buildings during both construction and the operational phase.

ÖGNB (TQB)/Austria

The Austrian Sustainable Building Council (ÖGNB) was initiated and founded in Austria in January 2009, by a number of renowned and independent institutions in the field of sustainable building (Building Biology and Ecology IBO) and the (Austrian Institute for Applied Ecology ÖÖI). In 1998 the Austrian Sustainable Building Council (OEGNB) and the Green Building Challenge launched the Total Quality (TQ) system for Building Design, Building Assessment and Building Certification. This institution aims to encourage the adoption of more environmentally sensitive, user friendly, and cost-efficient approaches in Austria. This assessment system has undergone continuous improvements and has been adapted to accommodate different types of buildings. In 2010 the TQ assessment method was overhauled and changed to Total Quality Building (TQB). The new revised version is built on a set of indicators that are related to societal, ecological and economical sustainability. Its scope was broadened to include non-residential buildings.

ÖGNI/Austria

The Austrian Green Building Council (ÖGNI) was founded in 2009 and is a non-profit organization of the Austrian construction and real estate industry which works in close cooperation with the German Sustainable Building Council DGNB. The ÖGNI building certification system has been adopted from the DGNB certification and is tailored to the Austrian standards. The ÖGNI building certification is applied nationally. It covers existing buildings and can be applied to the construction of residential buildings, offices and administration buildings.

BREEAM/UK

The Building Research Establishment's Environmental Assessment Methodology is an international certification system. It is the first certification that assess the sustainability performance of individual buildings from the United Kingdom, which were developed specifically by British Building Research Establishment (BRE). BREEAM was introduced to the market at the end of 1980s. Initially it served as a national assessment method for residential and office buildings, but is now used globally for various types of buildings and purposes.

LEED/USA

The LEED rating system has been developed since 1998 by the U.S. Green Building Council (USGBC) through an open, consensus-based process led by LEED committees. Each committee is composed of a diverse group of practitioners and experts representing a cross section of the building and construction industry. The assessment method was adapted to different building types (new construction and major renovation, existing buildings, commercial interiors, core & shell, schools, retail, healthcare, homes, neighborhood development) and regional specifics (such as LEED Canada, LEED Emirate). The objectives mainly refer to environmental and economic aspects. LEED can be applied to a wide range of buildings regardless of their location and life cycle stage.

DGNB/Germany

The German Sustainable Building Council (Deutsches Gütesiegel für nachhaltiges Bauen) was founded in 2007 by 16 initiators from various sectors within the construction and real-estate industries. It's a non-profit and non-governmental organization which aims to promote sustainable and economically efficient construction. In 2008 and in close cooperation with the Federal Ministry of Transportation, Building and Urban Affairs the building assessment system DGNB was developed and introduced to the building market. This was followed by a release of a building certification system focusing on the importance of sustainable construction and its impact on the environment. The Certification System can be applied internationally and covers both new construction and existing buildings. In addition, there is the option of simple pre-certification in the planning phase.

2 METHODOLOGY

2.1 Overview

The aims of this study are to review the current LCA methods in the context of six Austrian and international building certification systems and process the findings in terms of a LCA case study. To attain these goals, the assessment manuals for each scheme were used as the main references for this study. A review of current LCA methods was undertaken focusing particularly on ecological criteria.

LCA requirements were extracted and contextualized in relation to a framework of Austrian and international certification systems. The building LCA case study was then assessed according to the requirements of each building certification systems' building assessment manuals.

The initial step in the methodology is reviewing the current status of LCA methods applied in building certification systems by using the current versions of the Austrian and international building assessment manuals and focusing particularly on the ecological criteria reflecting the LCA method. The initial step is done by collecting all building assessment manuals related to the selected building certification systems in this study. The second step is the application of LCA in the framework of national and international certification systems for the building LCA case study based on requirements of the building assessment manuals related to the selected building certification systems. This step is done by assessing the LCA results extracted from building physics software and LCA tools recommended by the assessment manuals. The outcome from the review is to give a brief overview of the building life cycle assessment methods in a similar sequence of building assessment manuals belonging to selected certification systems in this study. Moreover, the building LCA case study provides a proposed simplified workflow to extract the LCA results for a retrofit building starting with selecting the appropriate improvements (Component Catalogue) for building LCA case study and obtain the LCA results using building physics software and LCA tools recommended by the assessment manuals under study. Ultimately, the LCA results are translated into award points/credits based on the same mentioned manuals of the respective certification systems in this study.

2.1.1 Building LCA Methods Review

The review covers the current ecological categories especially the criterion reflecting life cycle assessment method in the framework of three Austrian certifications and three major international certification schemes. This was conducted by describing the ecological criteria of each category of LCA criterion as defined by the relevant assessment manuals. The building certification systems' building assessment manuals detail how each LCA result is evaluated and how boundaries for the assessment are set.

Most of the selected building assessment manuals come in printed form, others are online based tools (e.g., TQB online assessment tool). Some of the international LCA tools provide instant LCA results and presentation of LCA derived from the assessment manuals integrated within the LCA tool. Table 2-1 gives an overview of selected six certification systems in this study and the reference to their related assessment manuals.

Table 2-1 List of the selected Austrian and international building certification system and their related assessment manuals

Building Schemes	Assessment Manuals	Website
KlimaAKtiv	Klimaaktiv Kriterienkatalog 2017	https://www.klimaaktiv.at/
ÖGNB	TQB assessment online tool	https://www.oegnb.net/en/tqb.htm
ÖGNI/ DGNB	ÖGNI Kriterienübersicht 2017	ÖGNI local office
BREEAM	BREEAM New Construction 2018	https://www.breeam.com/
LEED	LEED v4	https://www.usgbc.org/leed
DGNB	DGNB System New buildings criteria set 2018	https://www.dgnb-system.de/de/

2.1.2 Building LCA case study

The criteria representing the LCA results were investigated further by applying the LCA tools recommended by the selected assessment manuals. The tools were used in the context of a sample residential building in Vienna, Austria.

The LCA points/credits are awarded to the sample building by going through the following four steps (see Figure 2-1):

- Description of the building LCA case study.
- Defining the building samples.
- Calculating the energy certificate and OI3 statement.
- Extracting the LCA points/credits in a framework of national and international building certification systems.

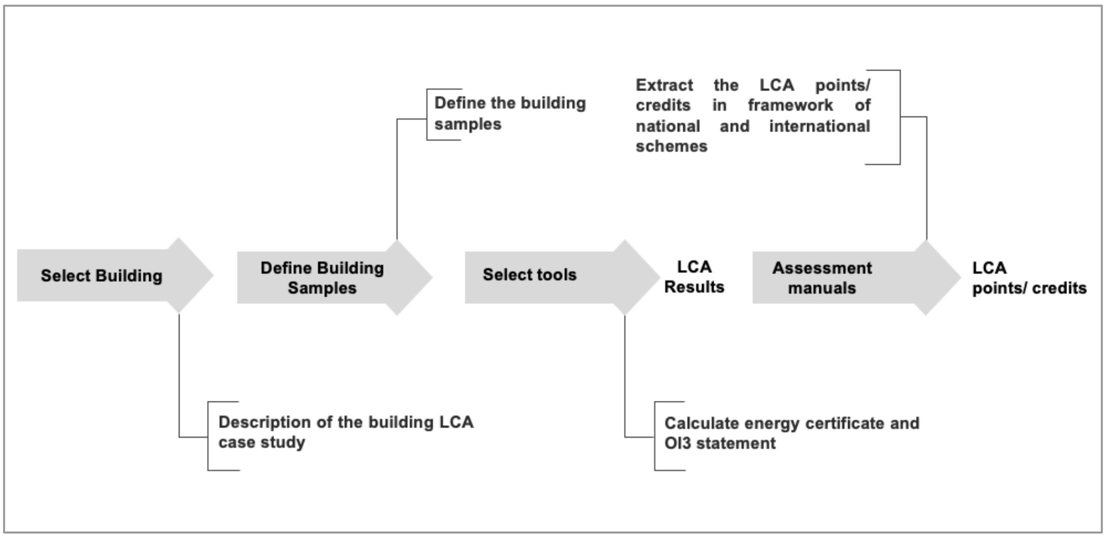

Figure 2-1 Building LCA case study steps

2.1.3 Objective

The researchers and innovators are still looking for the optimum life cycle assessment method. This would improve the quality of a building within the perspective of sustainability, whilst also reducing the building's harmful environmental impact to the fullest extent. The building certification systems support the goal of sustainable construction in the building sector.

Building certification systems assess the different types of buildings through assessment manuals which have a set of defined criteria related to a group of categories revolving around three essential sustainability pillars; ecological (environmental), economic and social sustainability. The assessment manuals set various ecological requirements in the ecological category as part of the assessment criteria.

There is a considerable amount of published work in the field of LCA, however much of this literature provides only a brief overview of the LCA criteria. This research gives a structured review of life cycle assessment methods of major local and international building certification systems in one single place. The knowledge gained from this study offers a comprehensive source of relevant information from the building assessment manuals and provides the practical steps to extract the LCA points/credits for a specific type of building illustrated by a building case study. The findings and results of this research can be built upon to support future research for both the Austrian and international building LCA field.

2.2 Building Sample and Tools Selection for Building LCA Case Study

After fully reviewing the LCA methods requirements of six assessment manuals and their applicability to different types of buildings, the sample building selected was a residential type. The latter building type is prevalent in most of the selected assessment manuals. An existing building that can be renovated has been selected for a refurbishment project that is appropriate for assessment in this study. A sample building was chosen in the west of Vienna. It was built between 1955 and 1957, and is a residential dwelling. Its age makes it a typical example of a refurbishment project. More details on the building sample will be defined further in chapter 4.

To obtain the LCA performance of the retrofit building sample, the LCA results from three tools recommended by the selected building assessment manuals were obtained utilizing the following tools; ArchiPHYSIK, eco2soft and One Click LCA. The ArchiPHYSIK software is chosen to calculate the energy performance certificate for both building samples, existing and refurbishment. The building's energy certificate gives the heating energy demand, which is required information when using the software eco2soft. The refurbishment building supplies' energy certificate gives the primary energy demand and CO_2 emissions values which are required by the KlimaAktiv certification system.

The eco2soft was used to calculate the LCA results for the refurbishment project and the result was delivered in the form of OI3 statement. This includes the ecological index that is required to obtain the LCA points for the material criteria in assessment manual (KlimaAKtiv and ÖGNB certification systems respectively).

The full version of One Click LCA was utilized to calculate the LCA results for the refurbishment project for the three international certification systems BREEM, LEED and DGNB. In the case of BREEAM, only the refurbishment build was input in the tool. Whereas in the case of LEED and DGNB both building samples, existing and refurbishment, were input in the tool. A more detailed review of the tools and building samples selection is presented in the chapters three and four.

2.3 Scope

This review gives an overview of the six currently applied LCA methods used in the three Austrian building certification systems as well as the three major international building certification systems. The review is restricted to the life cycle assessment portion of the ecological category of the building assessment manuals and does not contain any other assessment methods related also to the ecological categories in the same assessment manuals. The LCA application of ÖGNI/ DGNB (Austria) assessment manual in building LCA case study is not included in this study.

3 LCA METHODS REVIEW

3.1 Overview

This chapter provides an updated review of six assessment manuals focusing on the ecological issues in relation to LCA criteria only. As part of the literature review the manuals were either downloaded from building certification systems websites or supplied by the authority responsible for the certification systems. The assessment manuals are divided into two main categories based on the origin of the developer (Austrian and international building certification systems). The review examines the current ecological criteria of each of the building certification systems in relation to the following:

- Definition of the different sustainable group of categories with their weightings.
- Name of the assessment manuals (criteria catalog).
- Definition of the ecological criteria related to LCA criteria.
- Definition of the evaluation topic in the ecological criterion.
- Determine of the LCA maximum points/credits and share of the total score in each selected assessment manual.
- Highlight the allocation of environmental indicators in ecological criterion related to LCA criterion.
- Specify the type of buildings relevant for each LCA criterion.

Moving further, the review dissects the methodological basis of the building life cycle assessment, for the assessment manuals under consideration, by discussing the following aspects when and where applicable:

- Defining the LCA goal and scope
- System boundaries
- Standards
- Data requirements
- LCA method
- Available LCA tools recommended by each assessment manuals

3.2 Life Cycle Assessment Methods Review

3.2.1 The Building and Refurbishment Standard (KlimaAKtiv) (National)

The KlimaAKtiv assessment is divided into four main categories. There is a maximum total of 1000 points (see Figure 3-1):

- (Category A up to 175 points) Location and quality assurance.
- (Category B up to 500 points) Energy and supply.
- (Category C Up to 150 points) Building materials and construction.
- (Category D up to 175 points) Comfort and indoor air quality.

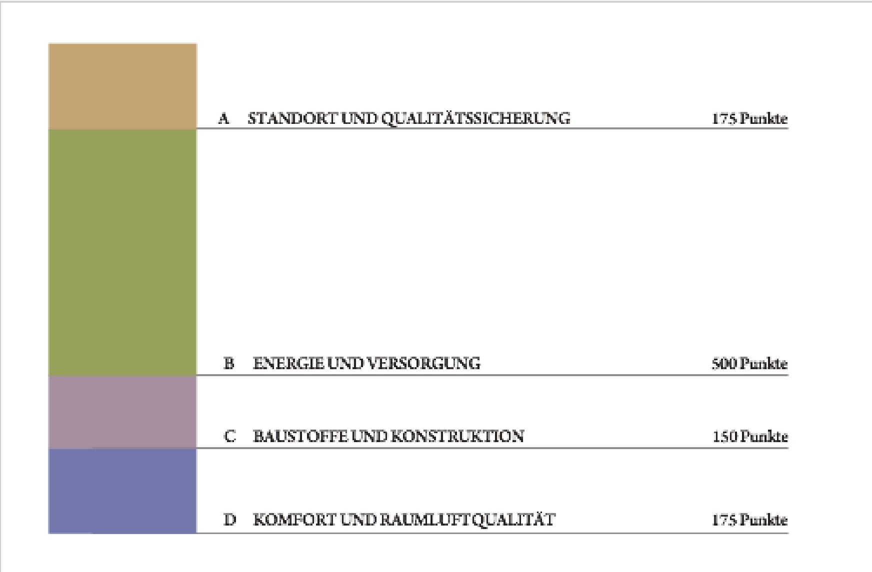

Figure 3-1 Assessment categories klimaAktiv / assessment manual

The KlimaAKtiv assessment manuals assign two criteria related to life cycle assessment, one related to category B and the other related category C. Each criterion has a different share (weighting) compared to the KlimaAKtiv total score. The KlimaAKtiv building standard categories are Bronze, Silver and Gold. Through this review, the four criteria (B2a, B3a, C2.1a and C2.1b) are highlighted and Its available in the KLIMAAKTIV KRITERIENKATALOG FÜR WOHNBAUTEN 2017 [www.klimaaktiv.at] (see Figure 3-2).

NEUBAU UND SANIERUNG			
NR.	TITEL	MUSS-KRITERIUM	ERREICHBARE PUNKTE
A	Standort und Qualitätssicherung		max. 175
A 1	Infrastruktur und umweltfreundliche Mobilität		max. 60
A 1.1	Infrastruktur in Standortnähe	M	2 bis 30
A 1.2a	Umweltfreundliche Mobilität	alternativ a od. b	0 bis 50
A 1.2b	Konzepte		50
A 2	Qualitätsnachweise für Planung und Ausführung		max. 130
A 2.1	Wirtschaftlichkeit		15 bis 30
A 2.2a	Qualitätssicherung Energiebedarfsberechnung und Verbrauchsprognose OIB	alternativ a od. b	30 bis 40
A 2.2b	Qualitätssicherung Energiebedarfsberechnung und Verbrauchsprognose PHPP		50 bis 60
A 2.3	Gebäudehülle luftdicht	M	0 bis 30
A 2.4	Energieverbrauchsmonitoring	M ab 1.000m²	0 bis 40
B	Energie und Versorgung (Nachweisweg OIB)		max. 500
B 1a	Heizwärmebedarf OIB	M	100 bis 200
B 2a	Primärenergiebedarf OIB	M	25 bis 100
B 3a	CO_2-Emissionen OIB	M	50 bis 200
B 4a	Gesamtenergieeffizienzfaktor OIB		25 bis 75
B	Energie und Versorgung (Nachweisweg PHPP)		max. 500
B 1b	Heizwärmebedarf PHPP	M	150 bis 250
B 2b	Primärenergiebedarf PHPP	M	25 bis100
B 3b	CO_2-Emissionen PHPP	M	75 bis 200
B 4b	Erzeugung PV-Strom		10 bis 50
C	Baustoffe und Konstruktion		max. 150
C 1	Baustoffe		max. 90
C 1.1	Ausschluss von klimaschädlichen Substanzen	M	5
C 1.2	Ausschluss von besonders besorgniserregenden Substanzen		5
C 1.3	Vermeidung von PVC und anderen halogenorganischen Verbindungen	M	5 bis 60
C 1.4	Einsatz von Produkten mit Umweltzeichen		0 bis 40
C 2	Konstruktion und Gebäude		max. 100
C 2.1a	Ökoindex des Gesamtgebäudes - BG3	M alternativ a od. b	0 bis 75
C 2.1b	Ökoindex der thermischen Gebäudehülle - BG1		0 bis 50
C 2.2	Entsorgungsindikator EI/EI10		0 bis 50
D	Komfort und Raumluftqualität		max. 175
D 1	Thermischer Komfort im Sommer	M	15 bis 50
D 2	Komfortlüftung mit Wärmerückgewinnung		60
D 3	Einsatz schadstoff- und emissionsarmer Bauprodukte / Schadstoffuntersuchung		0 bis 60
D 4	Messung der Innenraumluftqualität	M ab 2.000m²	0 bis 40
		GESAMT	1.000

Figure 3-2 klimaAktiv catalog of criteria

Energy and Supply (Category B) (Residential Buildings/ New & Refurbishment)

Category B plays an important role in the klimaAktiv assessment manual which has the highest weighting of the categories. Two LCA criteria (*B_{2a} and B_{3a}*) related to Category B, specified according to OIB Guideline 6, 2015 can be seen in Table 3-1. Note that the LCA criteria according to the Passive House Planning Package

are not included in this review.

KlimaAKtiv Criterion B.2a Primary Energy Demand (PEB, Primärenergiebedarf) (25 to 100 points): This is a mandatory criterion. The criterion assesses the energy requirements (operation energy) of the building including domestic electricity based on location climate. The result for the criterion can be obtained from the energy certificate's calculated, which are calculated in accordance with OIB-Guideline 6 (2015). The dedicated attainable LCA points within the KlimaAktiv assessment manual are 100 of the total 1000 points. This criterion makes up 10% of the whole KlimaAKtiv certification system.

KlimaAKtiv Criterion B.3a CO_2- Emissions (50 to 200 points): This is a mandatory criterion. It evaluates the CO_2 emissions resulting from the final energy demand of the building. It is expressed in kg CO_2 equiv./m^2 $_{BGF}$a. The dedicated attainable LCA points within the KlimaAktiv assessment manual are 200 of the total 1000 points. This the criterion makes up 20% of the whole KlimaAKtiv certification system.

Table 3-1 LCA criteria / Category B (OIB)/ KlimaAKtiv assessment manual

Evaluation Topics	**Building Type**	**Criterion no.**	**Criterion**	**Maximum points**	**Share of the total score**
Energy and supply	Residential Building	B.2a	Primary energy demand (PEB)	100	10 %
		B.3a	CO_2-Emissions OIB	200	20%

Building Materials and Construction (Category C) (Residential buildings/ New& Refurbishment)

Category C has no less importance than previous mentioned category but in terms of assessment, the Category C has less maximum points available compared to Category B. Two LCA criteria (*$C_{2.1a}$ and $C_{2.1b}$*) related to Category C, which mainly deal with the environmental impact of construction, can be seen in Table 3-2. The ecological quality assessment of building materials is assessed using the Oekoindex 3, which includes the following three of life cycle assessment indicators; global warming potential, acidification potential, and consumption of non-renewable energetic resources.

KlimaAKtiv Major criterion C.2.1a Ecological Index of the Entire Building Based on eco-index3, BG3 (0 to 75 points): This criterion evaluates the Eco-efficiency within the life cycle of the building, based the ecological index (OI3 index). The dedicated attainable LCA points within the KlimaAktiv assessment manual is 75 of the total 1000 points. This the criterion makes up 7.5 % of the whole KlimaAKtiv certification system. The objective of the assessment within this criterion is to minimize the flow of material, the required energy and the emissions resulting from the production of the building and the construction material used.

KlimaAktiv Alternative Criterion C.2.1b Ecological Index of the Thermal Building Envelope Based on Eco-index3, BG1(0 to 50 points): The criterion is also based on the ecological index (OI3) except that it considers the balance limit 1 (BG1) instead of balance limit 3 (BG3) in the assessment process. The dedicated attainable LCA points within the KlimaAktiv assessment manual are 50 of the total 1000 points. The criterion makes up 5 % of the whole KlimaAKtiv certification system.

Table 3-2 LCA criteria / Category C (BG3& BG1)/ KlimaAktiv assessment manual

Evaluation Topics	Criteria no.	Criterion	Maximum points	Share of the total score
Use of ecological building materials and constructions	C.2.1a	OI3 index (BG3)	75	7.5 %
	C.2.1b	OI3 index (BG1)	50	5 %

To conclude, the maximum achievable LCA points in the KlimaAktiv assessment manual for residential buildings is divided into 300 for the energy criterion and 50 (BG1) or 75 (BG3) for the material criterion C.2.1a or C.2.1.b respectively. Summing up the total possible achievable points of both criteria would be 350 or 375 of the 1000 total available points in the KlimaAktiv assessment manual. Thus, the weighting of the LCA is 35% or 37.5% of the whole KlimaAKtiv certification system.

Life Cycle Assessment Method- KlimaAKtiv

The life cycle assessment method for the residential buildings (New & Refurbishment) is divided into two main assessment tasks, which are energy and material assessments. The life cycle assessment of buildings in KlimaAKtiv assessment manual depends on the representative indicators within the field energy performance and particularly the PEB_{sk} and CO_{2sk}. The latter values are obtained from energy certificate according to OIB-Guideline 6 (2015).

The KlimaAktiv assessment manual assigns points based on the outcome value of PEB_{sk}. The minimum requirement for new buildings is a PEB_{sk} of maximum 115 $kWh.m^{-2}{}_{BGF}.a^{-1}$. Whereas for retrofit buildings, the indicator outcome value should not exceed 175 $kWh.m^{-2}{}_{BGF}.a^{-1}$. With relation to the CO_2 indicator the manual defines a clear set of requirements to award points based on the building types. As for new buildings, the threshold is set at 16 $kg.m^{-2}{}_{BGF}.a^{-1}$. On the other side, the indicator value should not exceed 24 $kg.m^{-2}{}_{BGF}\,a^{-1}$ for retrofit buildings.

The ecological quality of materials in KlimaAKtiv assessment manual depends on the Ecological Index 3 (OI3) of the thermal building envelope with the balance limit 3 ($OI3_{BG3,\,BZF}$) or balance limit 1 ($OI3_{TGH,BGF,BG1}$) (BG1) to determine the assessment points. The reference area BZF (Bezugsfläche) comprises the gross floor area (conditioned area) plus 50% of the non-conditioned area (e.g., basements, winter gardens, etc.) and the BGF (Bruttogeschossfläche) area is defined as the gross surface area of all stories, which is calculated according to the OIB guideline 6. In the case of life cycle consideration, the determination of the OI3 indicators of a building is calculated using the envelope boundary concept, which is referred to as the balance border method for buildings (see Figure 3-3).

BG0	structures of the thermal building envelope
	incl. Intermediate floors
	excl. damp proofing (in the floor slab and in the roof outside the insulation layer)
	excl. rear-ventilated façade elements
	excl. roof cladding
BG1	Basing on BG0
	all structures of the thermal building envelope
BG2	Basing on BG1,
	incl. inside walls (dividing elements)
BG3	Basing on BG2,
	incl. inside walls (all inside walls)
	incl. complete basement
	incl. non-heated buffer spaces (complete building)
	excl. direct access
BG4	Basing on BG3,
	incl. direct access (stairways, covered walkways etc.)
BG5	Basing on BG4,
	incl. housing technology
BG6	Basing on BG5,
	incl. all accesses
	incl. adjoining buildings

Figure 3-3 Flexible balance boundaries concept

according to OI3- guideline, 2011

For new residential buildings, the mandatory criterion eco-index ($OI3_{BG3,BZF}$) for the whole building with balance limit 3 (BG3) or alternative criterion eco-index ($OI3_{TGH,BGF,BG1}$) with balance limit 1 (BG1) are classified in accordance with the OI3-guideline 2016.

Eco-index ($OI3_{BG3,BZF}$): If the eco- efficiency total score is less than 300 points it is considered as best assessment and between 300 to 800 points is regarded as acceptable (Minimum requirement).

Eco-index ($OI3_{TGH,BGF,BG1}$): If the eco- efficiency is less than 60 points it is considered as best assessment and less than 280 points is regarded as acceptable (Minimum requirement). The score to be assigned for points between (300 and 800) or (60 and 280) are calculated using linear interpolation.

For retrofit residential buildings, the assessment of renovated dwellings applies the same process as for new buildings with exceptions the ecological Index is called OI3 $S_{BG3,BZF}$ or OI3 $S_{TGH,BGF,BG1}$ where the capital S letter refers to first letter of German language expression for retrofit building (Sanierung).

System Boundaries and Data Requirements for Calculating Building LCA-KlimaAktiv

The system boundaries to assess the value of $OI3_{BG3,BZF}$ are: construction phase of the building (A1- A3) raw material supply, transport and manufacturing according to EN 15804 and the usage phase (B2- B5) maintenance, repair, replacement, and refurbishment with exception of building services.

As for $OI3_{TGH,BGF,BG1}$ the boundary is limited to the construction life cycle phase of building (A1-A3). For both values the transportation of material and installation processes on the construction site are not included. The data required for calculating building life cycle assessment can be obtained from baubook database. The baubook is a free web-based comprehensive information and communication portal for energy-efficient and ecological building. This database provides ecological properties of building materials of different manufacturers, assisting in the assessment of a construction in terms of its environmental impact.

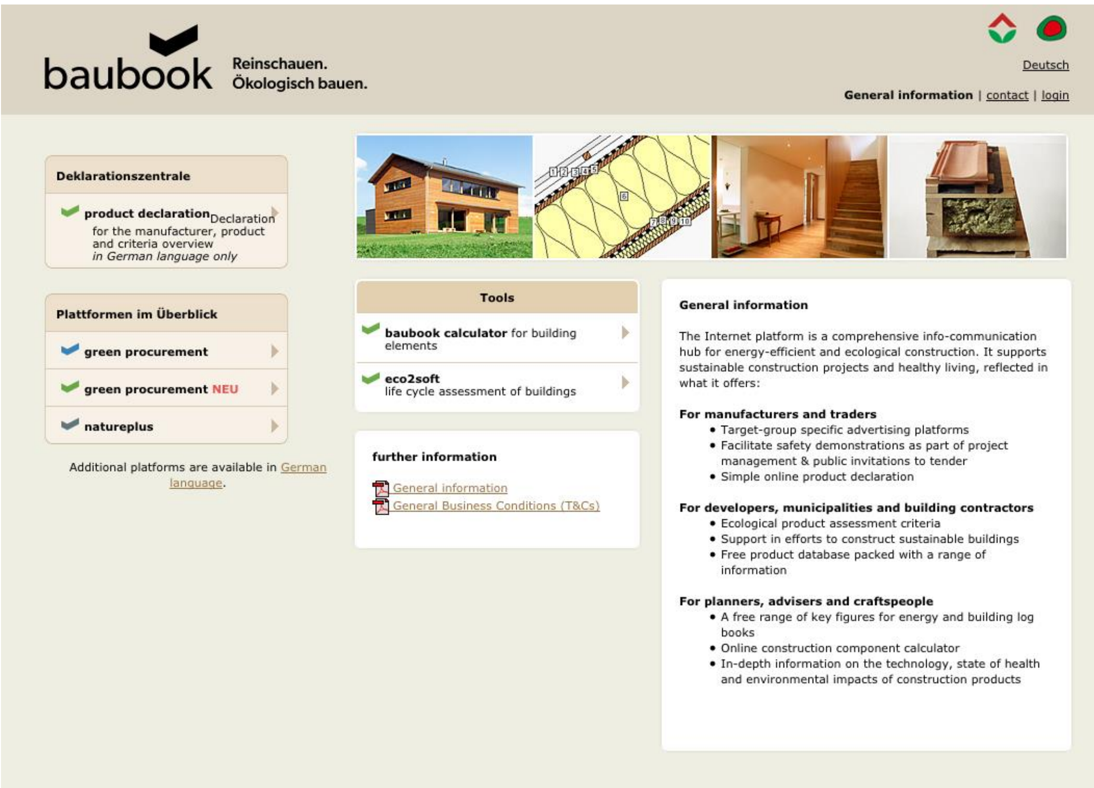

Figure 3-4 baubook 2021

LCA Tools- KlimaAktiv

To calculate building life cycle assessment in KlimaAktiv certification, two type of tools can be used; eco2soft is typically used in relation with the material criterion whereas ArchiPHYSIK is used to assess both energy and material criteria.

ArchiPHYSIK

ArchiPHYSIK is one of the standard software tools for standard-compliant building physics reports and certificates on heat, sound, vapor diffusion, energy certificates and ecology for single, multi-zone residential and non-residential buildings. The tool is developed by A NULL- development GmbH, Vienna, Austria and it is available in German language only.

The tool contains simplified and detailed calculations for single-zone and multi-zone energy certificates. The calculation of residential buildings, non-residential buildings and other buildings is in accordance with the current OIB guideline 6.

eco2soft

eco2soft is an online LCA tool created by IBO (The Austrian Institute for Healthy and Ecological Building) for use in the Austrian market. The Database of the tool is based on Austrian IBO Database for building materials. The tool was developed to serve as fast and reliable life cycle assessment calculator. It can be used alone or in conjunction with other programs in the field of energy performance. The tool can be utilized in research, educational as well as professional projects. The institute offers a free version for educational purposes with limited number of projects and can be used in two languages; German and English. eco2soft facilitates the calculation as required for the Austrian Oekoindex life cycle assessment method by considering the different assessment limits and system boundaries and the six main environmental impact categories.

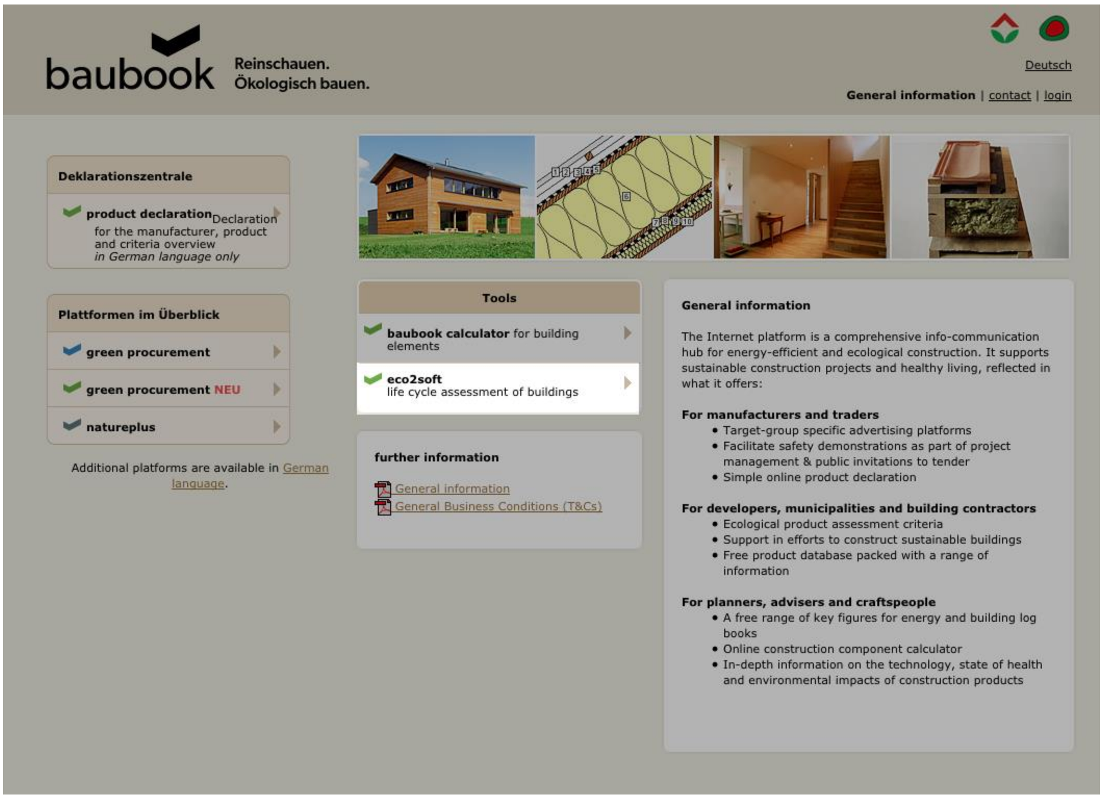

Figure 3-5 baubook 2021- eco2soft

3.2.2 The Austrian Sustainable Building Council ÖGNB (TQB) (National)

TQB is a free of charge online based planning and assessment tool. It's applicable for the different types of buildings in the Austrian construction market. The tool is accessible at www.oegnb.net.

The assessment is divided into five main categories with total points of 1000 points (see Figure 3-6):

- (A) Location and Facilities.
- (B) Economical and Technical Quality.
- (C) Energy and Supply.
- (D) Health and Comfort.
- (E) Resource Efficiency.

The ÖGNB assigns one criterion related to life cycle assessment based on the widely used Austrian ecological index OI3.

The OI3 index is comprised of three Life cycle assessment indicators:

1. Global Warming Potential (GWP) (for 100 years, as of 1994).
2. Acidification Potential (AP).
3. Consumption of non-renewable energetic resources (PEI n.e.).

The review highlights the criteria E.3.1 OI3 Calculation as leading indicator for the eco efficiency of the building, which is implemented in the TQB tool. It is available on the official website. It is designed to be used for the Austrian market.

	GENERAL BUILDING INFORMATION		
A	LOCATION AND FACILITIES	200	0
B	ECONOMY AND TECHNICAL QUALITY	200	0
C	ENERGY AND SUPPLY	200	0
D	HEALTH AND COMFORT	200	0
E	RESOURCE EFFICIENCY	200	0
E.1	Avoidance of critical material	50	0
E.2	Regionality, recycling share, certified products	50	0
E.3	Eco-efficiency of entire building	60	0
E.3.1	OI3 Calculation as leading indicator for the eco efficiency of the building	60	0
E.4	Disposal	60	0

Figure 3-6 Assessment categories/ TQB online assessment tool for building

ÖGNB Criterion E.3.1: OI3 Calculation as Leading Indicator for the eco efficiency of the building

The criterion ***E.3.1*** evaluates the Eco-efficiency within the life cycle of the building based the ecological index (OI3 index). The objective of the assessment within this criterion is to minimize the flow of material, the required energy and the emissions resulting from the production of the building and the construction material used. The maximum LCA rating comprises maximum 60 points in TQB (Total Quality Building) assessment from the total possible assessment points of 1000 which makes up 6% of the whole ÖGNB certification system (see Table 3-3).

Table 3-3 LCA criterion/ TQB assessment tool

Evaluation Topics	Criteria no.	Criterion	Maximum points	Share of the total score
Eco- efficiency of entire building	E.3.1	OI3 index (BG3)	60	6 %

Life Cycle Assessment Method - ÖGNB (TQB)

The method of calculating the building life cycle in TQB online assessment tool depends on the Ecological Index 3 of the thermal building envelope with the balance limit 3 ($OI3_{BG3,BZF}$) only. The outcome is in form of points, where eco-efficiency less than 300 points is considered as very good and more than 900 points is regarded as posing a higher ecological impact on the environment. In order to reach the final assessment stage, the value of the environmental index is converted to a number of points calculated by the TQB online-tool. If the ($OI3_{BG3,BZF}$) value is less than or equal to 300 then the building is awarded 60 points, whereas if the this value is higher than or equal to 900 then the building will receive zero score points. In case of index values between (300 and 900) the score points are calculated by the software using linear interpolation.

System Boundaries and Data Requirements for Calculating Building LCA-ÖGNB

The system boundaries include the following phases (see Figure 3-7): product phase (modules A1-A3) and use phase (modules B1, B2, B3, B4) based on the phases described in the building assessment DIN EN 15978 (seeTable1-1 and Figure 3-7).

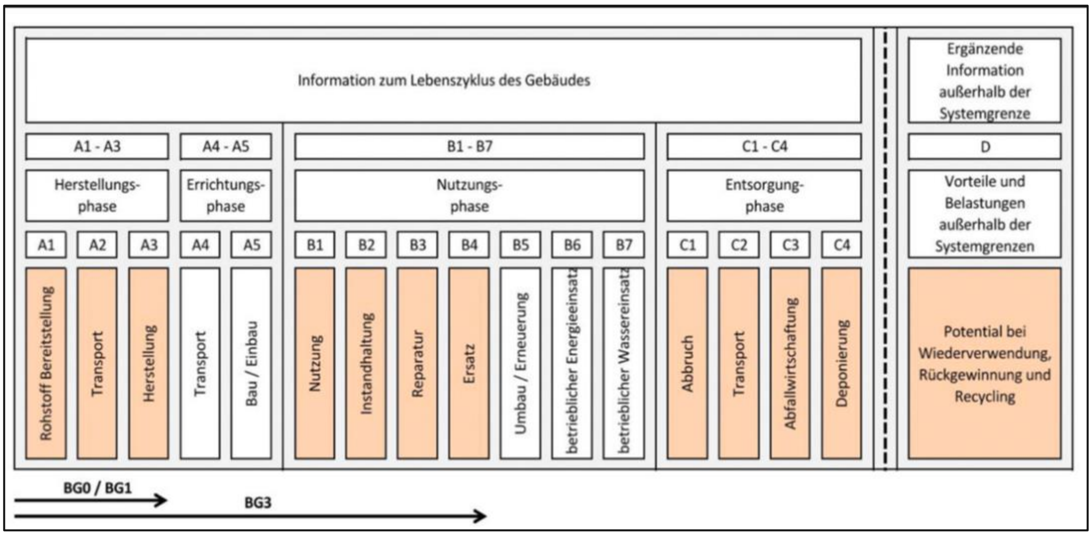

Figure 3-7 Building LCA phases- ÖGNB certification system

LCA tools- ÖGNB

The LCA tool used by ÖGNB is the same tool used for KlimaAktiv certification.

3.2.3 The Austrian Green Building Council (ÖGNI /DGNB) (National)

The sustainable assessment in the ÖGNI /DGNB certification system is divided into six quality groups corresponding to the DGNB certification system. The environmental quality group (Ökologische Qualität) (ENV) (22.5%) is the highest weighted topic in the (ÖGNI /DGNB) assessment manual. It consists of six criteria (see Figure 3-8), each criterion has different share (weight) compared to the (ÖGNI /DGNB) total score.

Themenfeld	Kriteriengruppe	Kriterien-nummer	Kriterienbezeichnung	Bedeutungsfaktor	Anteil an der Gesamtbewertung
Ökologische Qualität (ENV)	Wirkungen auf globale und lokale Umwelt (ENV10)	ENV1.1	Ökobilanz - Emissionsbedingte Umweltwirkungen	7	7,9%
		ENV1.2	Risiken für die lokale Umwelt	3	3,4%
		ENV1.3	Umweltverträgliche Materialgewinnung	1	1,1%
	Ressourceninanspruchnahme und Abfallaufkommen (ENV20)	ENV2.1	Ökobilanz - Ressourcenverbrauch	5	5,6%
		ENV2.2	Trinkwasserbedarf und Abwasseraufkommen	2	2,3%
		ENV2.3	Flächeninanspruchnahme	2	2,3%

Figure 3-8 Assessment categories (ÖGNI /DGNB) for building

The review highlights the two criteria (ENV1.1 and ENV2.1) in the ecological quality group, which is available in ÖGNI scheme, 2017 (German language only) and offered by ÖGNI/DGNB for national use in Austria.

ÖGNI/DGNB Criterion ENV1.1: Life Cycle Assessment- The Environmental Impact of Emissions

In general, buildings release emissions during the whole life cycle phases (product, construction, use and end of life). This in turn affects the environment, particularly air, water, and soil. The objective of the criterion is to reduce the impact of these emissions as much as possible (see Table 3-4). The ENV1.1 criterion is addressed with the following indicators:

1. Climate change: Global Warming Potential (GWP), measured in kg CO_2-equivalents
2. Ozone Depletion Potential (ODP), measured in kg R11 equivalent / m^2SA*a
3. Photochemical Ozone Creation Potential (POCP), measured in kg C_2H_4-equivalents
4. Acidification Potential (AP), measured in kg SO_2-equivalents
5. Eutrophication Potential (EP), measured in kg PO_4-equivalents

Table 3-4 LCA criterion ENV1.1- ÖGNI /DGNB manual assessment

Evaluation Topics	Criteria no.	Criterion	Maximum points	Share of the total score
Effects on the global and local environment (ENV10)	ENV 1.1	Environmental impact of emissions	7	7.9 %

ÖGNI /DGNB ENV 2.1 Criterion Life Cycle Assessment - Resource Consumption

The ENV2.1 criterion evaluates all requirements of the primary energy of a building. There is a particular value, which is aimed to reduce the overall consumption of the primary energy and replace it as much as possible with the highest quantities of renewable sources, for example, solar energy, geothermal energy, hydroelectric power, wind power and biomass. The energy requirements of user equipment are not considered. The objective of the criterion is the overall fulfilment of the legal regulations to the benefit of global protection of the climate and resources (see Table 3-5).

The ENV2.1 criterion evaluates the following indicators:

1. Non-renewable primary energy requirement (PEne)
2. Total primary energy requirement (PE ges)
3. Proportion of renewable primary energy

Table 3-5 LCA criterion ENV2.1- ÖGNI /DGNB manual assessment

Evaluation Topics	Criteria no.	Criterion	Maximum points	Share of the total score
Resource consumption and waste generation (ENV20)	ENV 2.1	LCA- Resource Consumption	5	5.6 %

Life cycle assessment method- (ÖGNI/DGNB)

The LCA method in the ÖGNI /DGNB assessment manual is divided into two elements related to the criteria ENV1.1 and ENV 2.1. Both criteria (ENV1.1 and ENV2.1) have similar methods in the life cycle assessment of building, at the same time each criterion produces different results due to each criterion's differing objectives. Regarding the criterion ENV1.1, the predicted annual environmental impact for constructed building during building operation is based on the final energy demand according to (OIB Guideline 6, March 2015). The energy requirements of user equipment during the same phase, derived from the final energy demand of the defined equipment is available in ÖGNI scheme, 2017. As for criterion ENV2.1, the predicted annual average of primary energy demand (non-renewable) during the operation of the building is based on same mentioned guideline. The predicted annual non-renewable primary energy demand for the user equipment during the building operation is derived from the final energy demand of the defined equipment, which is available in the same mentioned assessment manual. The ÖGNI assessment manual provides two main benchmarks for the reference period (50 years), one for the building materials constructions benchmarks and the other for energy consumption of building use.

- **Benchmarks for Building Materials (Constructions Benchmarks)**

The ÖGNI manual presents different benchmarks for building materials for seven environmental indicators related to LCA in one level: Reference value.

- **Benchmarks for Energy Consumption of Building Use**

The ÖGNI manual presents different benchmarks for (energy in use) for seven environmental indicators related to LCA in three levels: Target value (T), Reference value (R) and Limit value (L).

System Boundaries and Data Requirements for Calculating Building LCA

The system boundaries include the following phases: Product phase (modules A1-A3), Use phase (modules B2, B4, B6), end of life cycle phase (modules C1-C4 and D) as illustrated in Figure 3-9. The modules label and designations A1 to D are based on the phases described in the building assessment DIN EN 15978 (see Table1-1). The Energy consumption during operation Module B6 is extracted from calculation of the energy demand according to the (Austrian institute of construction engineering) (OIB Guideline 6, March 2015). The energy requirements of user equipment during the same phase is derived from the final energy demand of the defined equipment, which is available in ÖGNI scheme, 2017.

TABELLE 1 Lebenswegphasen

LEBENSWEG-PHASEN	A 1-3			A 4-5		B 1-7							C 1-4				D
	HERSTEL-LUNGSPHASE			ERRICHT-UNGS-PHASE		NUTZUNGSPHASE							ENDE DES LEBENS-ZYKLUS				VORTEILE UND BELASTUNGEN AUSSERHALB DER SYSTEM-GRENZE
	Rohstoffbeschaffung	Transport	Produktion	Transport	Errichtung / Einbau	Nutzung[1]	Instandhaltung[2]	Instandsetzung	Austausch[3]	Modernisierung	Energieverbrauch im Betrieb[4]	Wasserverbrauch im Betrieb	Rückbau / Abriss	Transport	Abfallverwertung	Entsorgung	Potential für Wiederverwertung, Rückgewinnung und Recycling
MODULE GEMÄSS ÖNORM EN 15978	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
DEKLARIERTE MODULE	X	X	X				(X)[2]		(X)[3]		X	(X)[5]			X	X	X

Figure 3-9 Processes and phases- ÖGNI /DGNB assessment manual

The data required for calculating building life cycle assessment can be obtained from two different sources; EPD and ÖKOBAUDAT and are explained in detail in the DGNB assessment manual data requirements for calculating building LCA.

LCA tool- ÖGNI /DGNB

The building LCA assessment software tool used by ÖGNI certification is performed by local Excel-based software.

3.2.4 The Building Research Establishment's Environmental Assessment Methodology (BREEAM) (International)

BREEAM uses a weighting system derived from a combination of consensus-based weightings and rankings by a panel of experts within the categories.

The BREEAM assessment is divided in 10 quality categories (see Table 3-6):

Table 3-6 BREEAM Categories/ BREEAM assessment manual

Category No.	Field
Category One	Energy
Category Two	Health and Wellbeing
Category Three	Innovation
Category Four	Land use
Category Five	*Materials (environmental effects and impacts of the construction materials used during life cycle)*
Category Six	Management
Category Seven	Pollution
Category Eight	Transport
Category Nine	Waste
Category Ten	Water

According to the latest method of evaluation, BREEAM International New Construction buildings 2018, the Material category consists of six criteria:

- (Mat 01) Environmental impacts from construction products- Building life cycle assessment (LCA)
- (Mat 02) Environmental impacts from construction products- Environmental Product Declarations (EPD)
- (Mat 03) Responsible sourcing of construction products
- (Mat 05) Designing for durability and resilience
- (Mat 06) Material Efficiency.

In this review the **(Mat 01)** is highlighted (see Table 3-7).

Table 3-7 BREEAM environmental sections and assessment issues

Management	Health and Wellbeing
– Man 01 Project brief and design – Man 02 Life cycle cost and service life planning – Man 03 Responsible construction practice – Man 04 Commissioning and handover – Man 05 Aftercare	– Hea o1 Visual comfort – Hea 02 Indoor air quality – Hea 04 Thermal comfort – Hea 05 Acoustic performance – Hea 06 Security – Hea 07 Safe and healthy surroundings
Energy	**Transport**
– Ene 01 Reduction of energy use and carbon emission – Ene 02 Energy monitoring – Ene 03 External lighting – Ene 04 Low carbon design – Ene 05 Energy efficient cold storage – Ene 06 Energy efficient transportation systems – Ene 07 Energy efficient laboratory systems – Ene 08 Energy efficient equipment	– Tra 01 Transport assessment and travel plan – Tra 02 Sustainable transport measures
Water	**Materials**
– Wat 01 Water consumption – Wat 02 Water monitoring – Wat 03 Water leak detection – Wat 04 Water efficient equipment	– Mat 01 Environmental impacts from construction products - Building life cycle assessment (LCA) – Mat 02 Environmental impacts from construction products - Environmental Product Declarations (EPD) – Mat 03 Responsible sourcing of construction products – Mat 05 Designing for durability and resilience – Mat 06 Material efficiency

Waste	Land Use and Ecology
– Wst 01 Construction waste management – Wst 02 Use of recycled and sustainably sourced aggregates. – Wst 03 Operational waste – Wst 04 Speculative finishes (Offices only) – Wst 05 Adaptation to climate change – Wst 06 Design for disassembly and adaptability	– LE 01 Site selection – LE 02 Ecological risks and opportunities – LE 03 Managing impacts on ecology – LE 04 Ecological change and enhancement – LE 05 Long term ecological management and maintenance
Pollution	**Innovation**
– Pol 01 Impact of refrigerants – Pol 02 Local air quality – Pol 03 Flood and surface water management – Pol 04 Reduction of night time pollution – Pol 05 Reduction of noise pollution	– Inn 01 Innovation

The criterion ***Building Life Cycle Assessment (LCA) (Mat 01)*** has the highest value of credits (7 credits) compared to the other criteria within (Materials) category. The aim of integrating this criterion to the BREEAM assessment manual is to reduce the environmental impact of construction products. This is done through distinguishing and encouraging the measure of construction product efficiency and at the same time selecting of building materials is limited to low level (including embodied carbon) environmental impact through the entire life cycle phases of the different types of buildings. The max score and share of the total score are up to 7 credits (see Table 3-8):

Table 3-8 LCA criterion based on BREEAM rating score 2018 of the building materials

Evaluation Topic	Criteria No.	Maximum credits	Proportion of total score
Environmental impacts from construction products- Building life cycle assessment (LCA)	Mat 01	Up to 7 credits	6.79 %

The building life cycle assessment credit is addressed with the seven following impact categories for reduction with their units:

- Global warming potential (greenhouse gases), in kg CO_2e
- Acidification of land and water sources, in moles H+ or kg SO_2
- Eutrophication, in kg nitrogen or kg phosphate
- Depletion of the stratospheric ozone layer, in kg CFC-11
- Formation of ozone of lower atmosphere, in kg NOx, kg O_3 eq
- Non-hazardous waste disposed, in kg
- Biogenic carbon storage, in kg CO_2e bio

Life Cycle Assessment Method - BREEAM

The BREEAM International New Construction Buildings 2018 life cycle assessment method mainly relies on two methods, BREEAM LCA Benchmark and Option Appraisal.

The first method of BREEAM assessment criterion is based on the BREEAM LCA Benchmark (performance comparator) which is defined as an average of environmental impact of a given building use type. BRE EN EcoPoints represents a single value for a set of individual environmental indicators for building elements. They are used to set up the results in form of award credit achieved by assessment criteria (Mat 01). The second method of BREEAM assessment criterion relies on life cycle assessment tools, which provide an analysis of life cycle impacts that is more robust and detailed than the first method.

LCA Tools- BREEAM

The two LCA methods mentioned above can be applied in types of LCA tools recommended by BREEAM assessment manual as follows:

BREEAM Simplified Building LCA Tool

The BREEAM Simplified Building LCA tool is an elemental construction level LCA tool that is free to use for BREEAM Assessors and design team members working on a registered BREEAM assessment. This tool has the different ranges of building elements descriptions based on that the credits are awarded. It has been designed to simplify LCA by reducing the information that needs to be entered by the user and the amount of time required.

IMPACT Compliant LCA Tool

The IMPACT Compliant LCA tool has been tested for compliance with the IMPACT specifications. It is designed to be integrated into 3D CAD/BIM software. It utilizes the IMPACT database which represents the average UK construction material database licensed by BRE.

One Click LCA Tool

One Click LCA tool is an easy to use, fully browser-based sustainability assessment tool for building projects. It does not require LCA expertise from the user. It was developed and released by Bionova Ltd. The software was developed for the purpose of calculating the environmental impact of construction projects and products. It is widely used by LCA and green building professionals, architects, structural engineers and quantity surveyors. This software is also used by others for infrastructure construction assessments, site tracking, use phase emissions. It supports EN 15804 compliant Environmental Product Declaration (EPDs).

Its user-friendly interface is one of the main advantages of the software as it makes LCA less time consuming.

Another advantage of the software is its data integration ability. Life cycle assessment information can be uploaded to the software from BIM, Excel, gbXML, etc.

The databases utilized by the software cover Europe, North America, Asia and the Pacific, the Middle East, and South America. The information in the databases is gathered from manufacturers and environmental product category (EPDs). The LCA results and emission categories are presented in tables, graphs and reports

3.2.5 Leadership in Energy and Environmental Design (LEED) (International)

There are four main phases of development in LEED (BD+C) rating systems such as:

1. LEED for Building Design+Construction
2. LEED for Interior Design+Construction
3. LEED for Building Operations+Maintenance
4. LEED for Neighborhood Development

According to the LEED v4 Reference Guide for Building Design and Construction, 2013 Edition, the criteria for an assessment according to the LEED rating system is divided into nine main credit categories:

- Category one: Integrative process.
- Category Two: Location and transportation (LT).
- Category Three: Sustainable sites (SS).
- Category Four: Water efficiency (WE).

- Category Five: Energy and Atmosphere (EA).
- **Category six: Materials and Recourses (MR).**
- Category Seven: Indoor Environmental Quality (EQ).
- Category Eight: Innovation (IN).
- Category Nine: Regional priority (RP).

Each category has number of sub-criteria inside the system. The Materials and Recourses credit category consists of seven sub-criteria:

- Storage and collection of recyclables.
- Construction and demolition waste management planning.
- **Building life-cycle impact reduction. *(LCA relevant)***
- **Building product disclosure and optimization – environmental product declarations (EPD). *(LCA relevant)***
- Building product disclosure and optimization – sourcing of raw materials.
- Building product disclosure and optimization – material ingredients.
- Construction and demolition waste management.

The two MR credits, namely Building Life Cycle Impact Reduction (Option 4) and Building Product Disclosure and Optimization – environmental product declarations (Option 1 and Option 2) in LEED v4 Building Design and Construction (LEED BD+C) are highlighted (see Table 3-9 and Table 3-10):

MR Credit 1: Building life- cycle impact Reduction, (Option 4)

Table 3-9 LCA criterion based on LEEDv4 Building Design and Construction (LEED BD+C)

Credit no.	**Name of the credit**	**Maximum points**	**Share of the total score**
MRc1	Building life-cycle impact reduction Option 4. whole-building life cycle assessment	3 points	3.1 %

The credit aims to decrease the embodied energy and environmental impacts for a service life of 60 years through all stages (whole life cycle) of construction including: material extraction, processing, transport, maintenance and disposal of construction materials and increase of resource efficiency in the form of additional points.

The whole building life cycle assessment (option 4) credit is addressed with the six following impact categories for reduction with their units:

- Global warming potential (greenhouse gases), in kg CO_2e
- Depletion of the stratospheric ozone layer, in kg CFC-11
- Acidification of land and water sources, in moles H+ or kg SO_2
- Eutrophication, in kg nitrogen or kg phosphate
- Formation of tropospheric ozone, in kg NOx, kg O_3 eq, or kg ethene
- Depletion of nonrenewable energy resources, in MJ

MR Credit 2: Building Product Disclosure and Optimization (Option1 and / or Option 2)

Table 3-10 LCA Criteria based on LEEDv4 building design and construction (LEED BD+C)

Credit No.	Name of the credit	Maximum points	Share of the Total Score
MRc2	Building Product Disclosure and Optimization- *Option 1.* Environmental Product Declaration (EPD)	1 point	2.1 %
	AND / O**R**		
	Building Product Disclosure and Optimization- *Option 2. Multi-attribute Optimization*	1 point	

The credit aims to encourage the use of products and martials by manufacturers in form of life-cycle information and to reward those manufacturers who target a significant improvement in their products with EPDs, and satisfy the local product criteria in the field of environmental life-cycle impacts. Option 2 addresses the same impact categories for reduction which are used by option 4.

Life Cycle Assessment Method - LEED v4

Based on LEED official website, the explanation of LCA method inside each LEED v4 credits is as follows:

MRc1: Building Impact and Life Cycle Reduction: For New Buildings or Portions of Buildings

Option 4. Whole- Building Life Cycle Assessment (3 points)

This credit is based mainly on the precept of comparison between the suggested building design versus a **baseline** building in terms of size, function, orientation, gross area, system boundary, operating energy performance, service life (at least 60 years) and (LCA software tools and data sets). The system boundary for the (baseline and proposed) buildings should correspond to ISO 21930 determination including the modules: A1 - A4, B1 - B7 and C1 - C4 through entire life cycle stages (cradle to grave) for building elements. The data sets must correspond to ISO 14044.

1- Should achieve a minimum 10% reduction by 1 of the impact categories GWP (mandatory) and at least 2 of the other impact categories compared to a baseline building.

2- No impact category assessed may exceed more than 5% compared with the baseline building.

MRc2: Building Product Disclosure and Optimization

Option1. Environmental Product Declaration (EPD) (1 point)

This is rewarded to the project teams who use at least 20 different permanently installed products sourced from at least five different manufacturers that meet one of the disclosure criteria below:

Disclosure Criteria 1: Product- specific Declarations (LCA) = 1⁄4 of a product

Disclosure Criteria 2: Industry-wide (generic) EPDs = 1⁄2 of a product

Disclosure Criteria 3: Product- specific Type III EPD = 1 product

Option 2. Multi-attribute Optimization (1 point)

This is awarded to projects which use permanently installed products, accounting for 50% of total cost, that demonstrate impact reduction compared to an industry average in three impact categories of the six mentioned impact categories.

LCA Tool- LEED v4 (Option 4 only)

ATHENA Impact Estimator, Envest 2 and LCA Design

Design team LCA tools are simple and are intended for non-LCA practitioners.

These programs use simplified calculation methods whereas the LCA calculation runs in the background and does not allow users to modify or add data.

One Click LCA (LEED v4 BD+C)

In North America, One Click LCA utilizes different sources for the material database. The content of the database is based on a dynamic algorithm which ensures users are only able to choose data that is in conformity with the data quality requirements of the target certification they are working towards, such as LEEDv4 in North America. The company offers three differently priced versions of the software which vary in the tools, functionality and reporting capabilities provided. Additional licenses for BIM software like Autodesk REVIT can be obtained.

SimaPro and GaBi

These LCA practitioner tools require an LCA specialist, who is familiar with calculating factors and choosing appropriate datasets. This tool/software allows more flexibility where the LCA is based on product-by-product assessment, and requires different methodologies for each of the products examined. The practitioner aggregates all products into a whole building life-cycle assessment.

3.2.6 German Sustainable Building Council (DGNB) (International)

Each quality group in DGNB certification system has different criteria. The **environmental quality group** is considered to be of one of the 3 pillars of the sustainability (environmental quality, economic quality and socio-cultural and functional quality) in the certification. It consists of six criteria (see Figure 3-10). Each criterion has different share (weighting) compared to the DGNB total score (scoring systems), which are translated at the end of certification route into a certification at the Bronze, Silver and Gold levels (DGNB). The building life cycle assessment in DGNB manual considers all environmental impacts over the life cycle of the building. The energy consumption in construction, ongoing operation, and end-of-life of the materials are also expressed with the following Life cycle assessment indicators:

1. Climate Change: Global Warming Potential (GWP), measured in kg CO_2-equivalents
2. Ozone Depletion Potential (ODP), measured in kg R11 equivalent / m^2SA*a
3. Photochemical Ozone Creation Potential (POCP), measured in kg C_2H_4-equivalents
4. Acid Potential (AP), measured in kg SO_2-equivalents
5. Eutrophication Potential (EP), measured in kg PO_4-equivalents
6. Non-renewable Primary Energy Demand (PEnr)
7. Total Primary Energy Demand (PEtot)
8. Proportion of Renewable Primary Energy
9. Abiotic Resource Consumption (ADP elements)
10. Fresh Water (FW) consumption

According to DGNB System - New Buildings Criteria Set Version 2018 the Criteria ENV1.1/ BUILDING LIFE CYCLE ASSESSMENT in the Environmental Quality Group will be highlighted.

Overview of the criteria

TOPIC	CRITERIA GROUP	CRITERIA NAME
ENVIRONMENTAL QUALITY (ENV)	EFFECTS ON THE GLOBAL AND LOCAL ENVIRONMENT (ENV1)	**ENV1.1** Building life cycle assessment
		ENV1.2 Local environmental impact
		ENV1.3 Sustainable resource extraction
	RESOURCE CONSUMPTION AND WASTE GENERATION (ENV2)	**ENV2.2** Potable water demand and waste water volume
		ENV2.3 Land use
		ENV2.4 Biodiversity at the site

Figure 3-10 DGNB System - New building criteria set

DGNB Criterion ENV1.1/ BUILDING LIFE CYCLE ASSESSMENT

The criterion ENV1.1 Building Life Cycle Assessment evaluates the environmental quality of a building. It considers one of the three criteria in the criteria group: EFFECTS ON THE GLOBAL AND LOCAL ENVIRONMENT (ENV1). The objective of this assessment is to ensure a consistent life cycle approach to the planning of buildings, in addition to reducing emissions related to environmental impacts, and the consumption of non- renewable resources, as much as possible through all life cycle phases of buildings.

The life cycle approach should be conducted as early as the building planning phase. The building life cycle assessment assists building commissioners and designers in making environmental decisions in addition to providing a consistent method for improving the environmental quality of different type buildings. This method is helpful in reporting the relevant environmental indicators for each building, such as CO_2 emissions or energy demand through all LCA phases.

It is to be noted that as per the DGNB guide 2018, the criterion building life cycle assessment does not entail the inclusion of construction materials, which are used in the building.

The construction products can be evaluated with other certifications like the Blue Angel or Cradle-to-Cradle certificate. The latter certifications indicate the degree of absence of pollutants in the construction products. The life cycle assessment overview as per DGNB certification is shown below (see Figure 3-11).

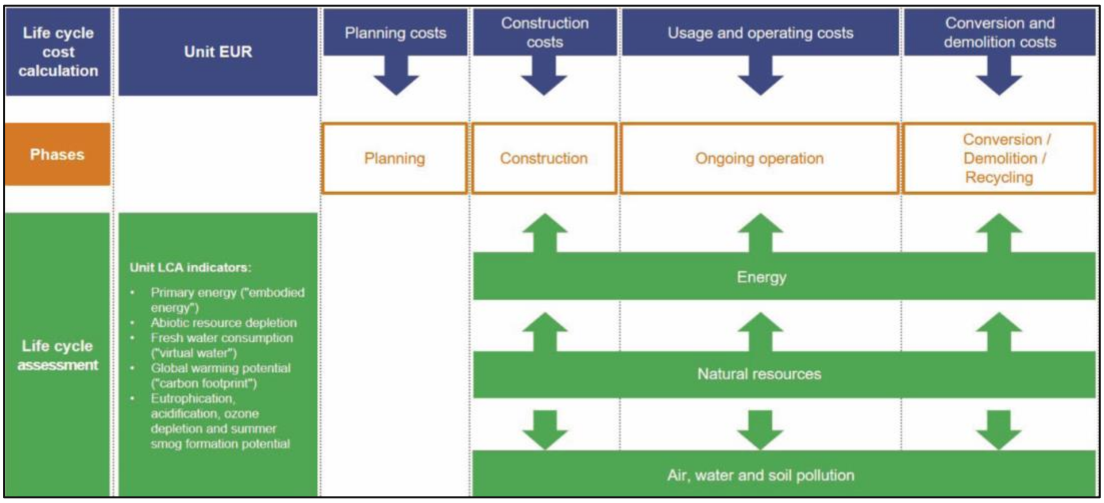

Figure 3-11 How the life cycle assessment works- DGNB certification

The DGNB manual provides the whole building life cycle assessment method with the weighting factor of different building type See Table 3-11 below.

Table 3-11 LCA criterion- DGNB assessment manual

Criteria no.	Evaluation Topics	Criterion	Building type	Weighting factor	Share of the total score
ENV 1.1	Environmental quality	BUILDING LIFE CYCLE ASSESSMENT	Office Education Residential Hotel	8	9.5 %
			Consumer-market Business premises Logistics Production	8	9.0 %
			Shopping Centre		

Life Cycle Assessment Method - DGNB

The DGNB assessment manual version 2018 provides fixed reference value benchmarks dedicated for the construction and operation phases. The construction phase includes production of the materials/ replacement and end of life. The operation phase includes the electricity demand and energy demand, but the energy requirements of user equipment are not considered. The results of the building LCA, which is under evaluation is compared with these benchmarks.

System Boundaries and Data Requirements for Calculating Building LCA

The system boundaries include the following phases: Product phase (modules A1-A3), Use phase (modules B2, B4, B6), and the End of Life Cycle phase. Modules (C1-C4 and D) are illustrated in Figure 3-12. The modules label and designations A1 to D are based on the phases described in the building assessment DIN EN 15978 (see Table1-1).

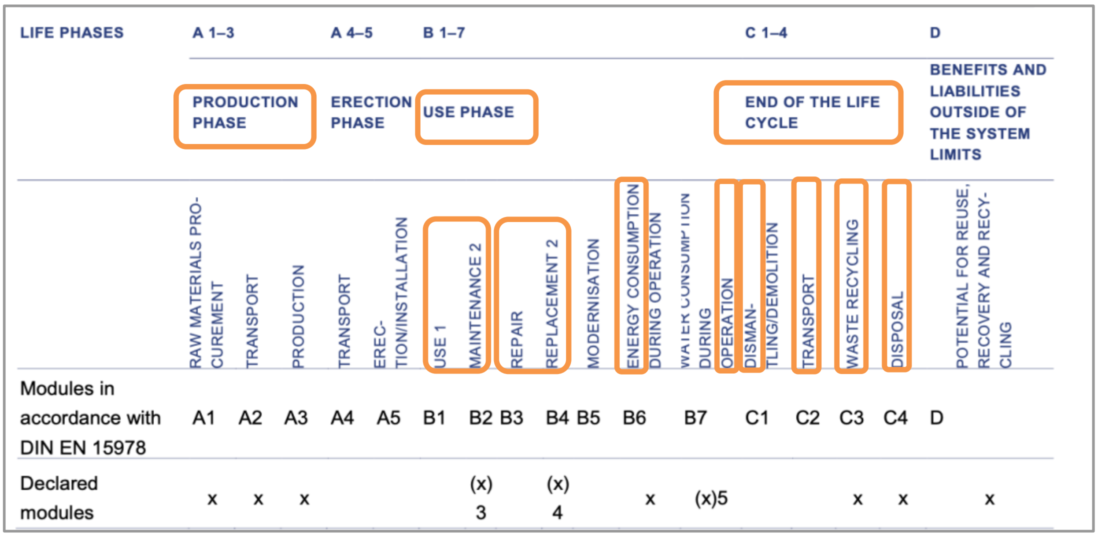

Figure 3-12 Processes and phases - DGNB assessment manual

The data required for calculating building life cycle assessment can be obtained from three different sources:

ÖKOBAUDAT: The ÖKOBAUDAT is a DIN EN 15804-compliant database from the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (www. ökobaudat.de). The database provides both general, generic, product-specific and manufacturer-specific data. It supplies life cycle assessment results in the form of environmental indicator values.

Environmental Product Declaration (EPD): Construction products are an essential part of the environmental performance assessment. Environmental Product Declarations document a manufacturers' collection of construction materials, giving eco relevant information such as recyclability, service intervals and energy consumption. In order to assess the buildings under the DGNB certification, it is necessary to consider the material products used in the certification. In Germany, the Institute of Construction and Environment provides the IBU data base, which contains LCA-based data taken from EPDs of manufacturers of building materials. The data is available as EPD-online tool (www.epd-online.com) and also is obtainable in digital EPD datasets in XML-Format (www.ibu-epd.com/ibu-data-start).

ECO platform: This Brussels based platform supports the continuous development of EPD of European produced building materials (www.eco-platform.org). The platform plays an important role in coordinating the work with regard to three aspects, which are: technical part, material quality management and its role in building certification system in addition the communication part.

LCA Tool- DGNB

To calculate building life cycle assessment in DGNB, different LCA software tools can be applied. There are five software tools from Germany and based on the German LCA Database Öekbau.dat and one international LCA tool outside of Germany as follow:

CAALA Computer Aided Architectural Life- Cycle Assessment (www.caala.de)

CAALA Is a fairly new software tool which can calculate the energy requirements for the operation, production, replacement and disposal of building materials already at the early design phase.

eLCA (www.bauteileditor.de)

eLCA is a flexible online based tool, which facilitates the creation of life cycle assessments by utilizing templates of construction elements and materials. It was initiated and is maintained by the Federal Institute for Research on Building, Urban Affairs and Spatial Development in Germany. The tool is open source and accessible free of charge through the main website.

LEGEP (www.legep. de)

LEGEP is a construction software tool for the integrated planning of sustainable buildings. The Tool supports planning teams in the phases of design, construction, quantity surveying and evaluation of new as well as existing buildings.

oekobilanz-bau.de (www.tool.oekobilanz-bau.de)

The online tool provides the opportunity for planners and DGNB auditors to do life cycle assessment for buildings from production to demolition. It has pre-configured products, 80 typical construction elements but also allows a user to create additional elements.

SBS online tool (www.sbs-onlinetool.com)

Sustainable Building Specifier is an LCA assessment tool developed at the Fraunhofer Institute of Building Physics, Germany. The tool can be used for labelling in accordance with the rules of the German Sustainability Council and the European research projects.

One Click LCA (www.oneclicklca.com)

One Click LCA tool is an easy to use, fully browser-based sustainability assessment tool for building projects which doesn't require LCA expertise from the user. Moreover, One Click LCA can be used to calculate the credit "*ENV1.1 Building life cycle assessment"* in DGNB assessment manual 2018.

4 LCA CASE STUDY

4.1 Overview

To further investigate the LCA portion of the building certification systems as part of this thesis, a case study was conducted on an existing residential building which was built in Vienna between 1955 and 1957.

The reason for choosing this type of construction is that most of the popular building certification systems can accommodate it. As modifying the construction materials can change the Energy and the Environmental Performance, the building can be easily assessed by mentioned (LCA criteria) (Chapter 3) over its lifespan. Another reason for this choice is that the age of the building is suitable for a building refurbishment project.

To understand and analyze the outcomes of the LCA assessment method related to the different criteria in the framework of the certification systems, the case study is broken into national and the international building assessment groups. Three LCA criteria in the framework of the two Austrian certification systems and three LCA criteria in the framework of the three international certification systems were chosen.

4.2 Austrian and International Certification systems/ Life Cycle Assessment

The case study for the selected multi-family residential building in Vienna is broken into two parts:

1 -Austrian assessment certification systems.

2 -International assessment certification systems.

Austrian Certification Systems Group (KlimaAKtiv & ÖGNB)

The life cycle assessment for the selected building is divided into two main assessment tasks as follows:

The energy demand was estimated using the building physics software ArchiPHYSIK based on the IBO database. The software tool is to be used to extract the energy certificate of the existing building and its retrofit. The energy certificate of the retrofit building contains two necessary values (PEB_{sk} and CO_{2sk}), which were analyzed by the KlimaAKtiv LCA assessment criteria.

The material assessment was conducted using eco2Soft (based on the IBO database) to obtain the $OI3S_{BG3,BZF}$ indicator from OI3 Statement, which represents the LCA result for retrofit building and then was analyzed by the KlimaAKtiv assessment manual and ÖGNB(TQB) online assessment tool. It is to be noted that both tasks were conducted for the life cycle assessment criteria of KilmaAktiv assessment manual and ÖGNB(TQB) online assessment tool. As for ÖGNI, the building LCA assessment software is excel-based and is not available for students and researchers. Hence, due to this limitation it was not be included in the LCA case study.

Table 4-1 summarizes all dataset, limitations and system boundaries relevant for the LCA case study required for the Austrian assessment manuals.

As it can be seen from the summary table, the KilmaAKtiv assessment manual and ÖGNB(TQB) online assessment tool share the same requirements for the life cycle assessment.

Table 4-1 KlimaAKtiv & ÖGNB / Documentation requirements preceding building LCA results

KlimaAKtiv/ Energy/ life cycle assessment
• Database: baubook. • Building physics software: ArchiPHYSIK. • Calculation method of the energy performance: OIB (Austrian guideline). • Relevant construction elements of the building: BG1.
(KlimaAKtiv&ÖGNB)/ Material/ life cycle assessment

• Database: baubook.
• LCA software tool: eco2soft.
• Assessment methodology: OI3- calculation.
• Environmental indicators (OI3 Index based on 3 Indicators) (OI3- guideline 2016)
    ○ Global Warming
    ○ Potential Acidification
    ○ Potential Consumption of non-renewable energetic resources
• Relevant construction elements of the building: BG3.
• Service life according to EN 15804 standard (The building life-span to be evaluated is within study period 100 years).
• Life cycle stages based on EN 15804: Manufacturing phase (A1-A3) and Use phase (B1-B4).
 	
It is worth noting that for the test alternative criteria KlimaAKtiv, the boundary definition BG3 is adopted instead of thermal building envelope's based BG1.

International Certification Systems Group (BREEAM, LEED and DGNB)

The life cycle assessment for the building in the study was divided into two main categories, energy in DGNB and material in BREEAM and LEED. The life cycle assessment for the building in the study was divided into two main categories, energy in DGNB and material in BREEAM and LEED. As the LEED certification differs in the scope of LCA as well as the system limit, the tool One Click LCA was used. This system can evaluate the sample within the life cycle stages of each assessment system. This tool specializes in calculating the life cycle of buildings, supports building certifications for assessment including the main certifications used in this study BREEAM, LEED and DGNB, and also offers the option to connect to the Austrian baubook and the German ÖKOBAUDAT databases. Additionally, the environmental impact categories are available in One Click LCA. They are; global warming, acidification, eutrophication, ozone depletion potential, and the formation of ozone in the lower atmosphere. The outcome criteria extracted from the tool's LCA results were evaluated against the mentioned international building assessment manuals to estimate the final credits.

Table 4-2 Summarizes all datasets and system boundaries as required in the One Click LCA tool and the BREEAM, LEED and DGNB building international assessment manuals.

Table 4-2 BREEAM, LEED&DGNB/ Documentation requirements preceding building LCA results

BREEM/ Material/ life cycle assessment
• Database: baubook and ÖKOBAUDAT. • LCA software tool: One Click LCA tool. • Service life according to BREEAM (The building lifespan to be evaluated is within study period 60 years). • Life cycle stages: Product stage (A1-A3), Construction process stage (A4-A5), Material replacement and refurbishment (B4-B6), End of life (C1-C4) and Benefits and loads beyond the system boundary (D).
LEED/ Material/ life cycle assessment
• Database: baubook and ÖKOBAUDAT. • LCA software tool: One Click LCA tool. • Service life according to LEED (The building lifespan to be evaluated is within study period 60 years). • Life cycle stages: Product stage (A1-A4), Maintenance and material replacement (B1- B5), End of life (C1- C4).
DGNB/ Material and Energy/ life cycle assessment
• Database: ÖKOBAUDAT. • LCA software tool: One Click LCA tool. • Service according to DGNB (The building lifespan to be evaluated is within study period 50 years). • Life cycle stages: Product stage (A1-A3), Use stage (B4), Operational energy (B6), End of life (C3-C4) and Benefits and liabilities outside of the system limits (D).

4.3 Building LCA case study

4.3.1 Description of the Building LCA Case Study

The building in the case study is a multi-family house which is part of a five residential buildings complex, it consists of a cellar, car parks, twenty flats spread on five floors. It is located in the west of Vienna, Austria. The total building area (gross floor area) is 1.622,8 m^2. It was constructed between 1955 and 1957. The building's thermal envelope is constructed of crushed brick masonry and the ceilings are made of concrete. The roof is a flat roof and windows are double glazed with wooden frames (see Figures 4-1, 4-2 and 4-3). The dimensions of the building were obtained from the floor plans, which were provided by the Baupolizei (Magistratsabteilung 37) in Vienna.

Figure 4-1 Case study building

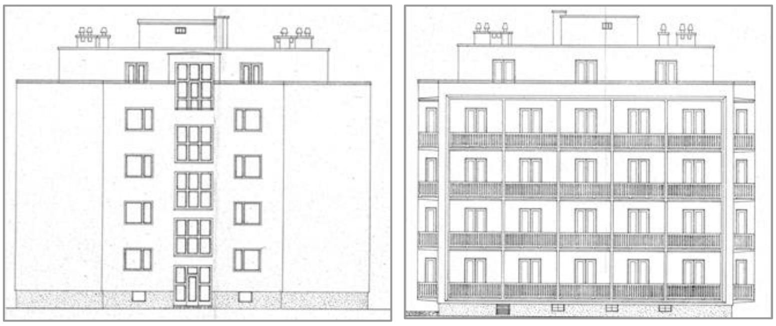

Figure 4-2 Façade street and south view of the building

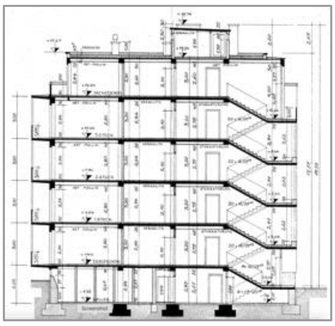

Figure 4-3 Section view of the building

4.3.2 Defining the Building Samples

Two construction samples were assessed using five different assessment manuals:

Sample E (Existing Building): The building with its current structure and materials were defined as the reference building for determining the starting point for improvement, and conforming to the assessment requirements required in each building assessment manuals.

Sample R (Retrofit Building): The building structure is enhanced with additional layers of suggested material for specific building elements. Most of the building assessment manuals have LCA points/credits for new and refurbishment buildings, in which the assessment of the building's life cycle relates to energy or materials or both of them.

4.3.3 Building LCA Case Study Results

Energy Certificate

The energy certificates of the samples E and R, were calculated using the software ArchiPHYSIK v16. Prior to entering the data in ArchiPHYSIK for calculating the energy certificates the relevant information of the geometry and material were prepared for the entry.

The following building elements to be taken into consideration are:

- External walls
- Flat roof to outside air
- Floor to unheated space
- Ceiling to unheated space
- Windows
- Doors

The total area of the building thermal envelope in square meters was calculated by Microsoft Excel based on information shown in the construction floor plans. Due to the lack of data concerning the building elements layers in sample E, assumptions regarding thermal properties such as U-Values [W.m^{-2}K^{-1}] suitable for the age and type of the building were derived from the OIB guideline 6, 2015 (see Figure 4-4).

Epoche / Gebäudetyp	KD	OD	AW	DF	FE	g	AT
vor 1900 EFH	1,25	0,75	1,55	1,30	2,50	0,67	2,50
vor 1900 MFH	1,25	0,75	1,55	1,30	2,50	0,67	2,50
ab 1900 EFH	1,20	1,20	2,00	1,00	2,50	0,67	2,50
ab 1900 MFH	1,20	1,20	1,50	1,00	2,50	0,67	2,50
ab 1945 EFH	1,95	1,35	1,75	1,30	2,50	0,67	2,50
ab 1945 MFH	1,10	1,35	1,30	1,30	2,50	0,67	2,50
ab 1960 EFH	1,35	0,65	1,20	0,55	3,00	0,67	2,50
ab 1960 MFH	1,35	0,65	1,20	0,55	3,00	0,67	2,50
Systembauweise	1,10	1,05	1,15	0,45	2,50	0,67	2,50
Montagebauweise	0,85	1,00	0,70	0,45	3,00	0,67	2,50

Bei den angegebenen Werten handelt es sich grundsätzlich um Mittelwerte aus der Erfahrung und nicht um schlechtest denkbare Werte.

Legende:

- KD ... Kellerdecke
- OD ... Oberste Geschoßdecke
- AW ... Außenwand
- DF ... Dachfläche
- FE ... Fenster
- g ... Gesamtenergiedurchlass-grad
- AT ... Außentüren
- EFH ... Einfamilienhaus
- MFH ... Mehrfamilienhaus

Systembauweise ... Bauweise basierend auf systemisierter Mauerwerksbauweise o.ä.

Montagebauweise ... Bauweise basierend auf Fertigteilen aus Beton mit zwischenliegender Wärmedämmung

Für alle nicht erwähnten Bauteile wie z.B. Kniestockmauerwerk, Abseitenwände, Abseitendecken sind grundsätzlich die entsprechenden Werte für Außenbauteile zu verwenden.

Figure 4-4 Default U-values [W.m-2K-1] of Building Elements

All the data was then fed into ArchiPHYSIK to obtain the energy certificate of the building in sample E. The Primary energy demand PEBsk [kWh.m^{-2}.a^{-1}] and CO_2 emissions [kg.m^{-2}.a^{-1}], were calculated with the ArchiPHYSIK, resulting in 330.77 kWh.m^{-2}a and 64.89 kg .m^{-2}.a^{-1} for the sample E (see Figure 4-5).

As for sample R, the same geometry layers were used as in sample E. However, as sample R is considered a retrofit the building using proposed insulation layers from the Catalogue of Ecologically Rated Constructions for Renovation. The construction materials of the refurbishment that were selected were typical of the era within which the sample building was built. This information is available in chapter three of Building Tasks (Buildings of the 1950s and 1960s) page (137 - 147).

The purpose of using the materials in this catalogue is to improve energy levels so that they conform to the requirements of sustainable construction, and can be assessed with Austrian certification systems. The Primary energy demand PEBsk [kWh.m-2.a-1] and CO2 emissions [kg.m-2.a-1], are calculated with the ArchiPHYSIK, resulting in 130.78 kWh.m-2.a-1 and 24.55 kg.m-2.a-1 for the sample R (see Figure 4-5).

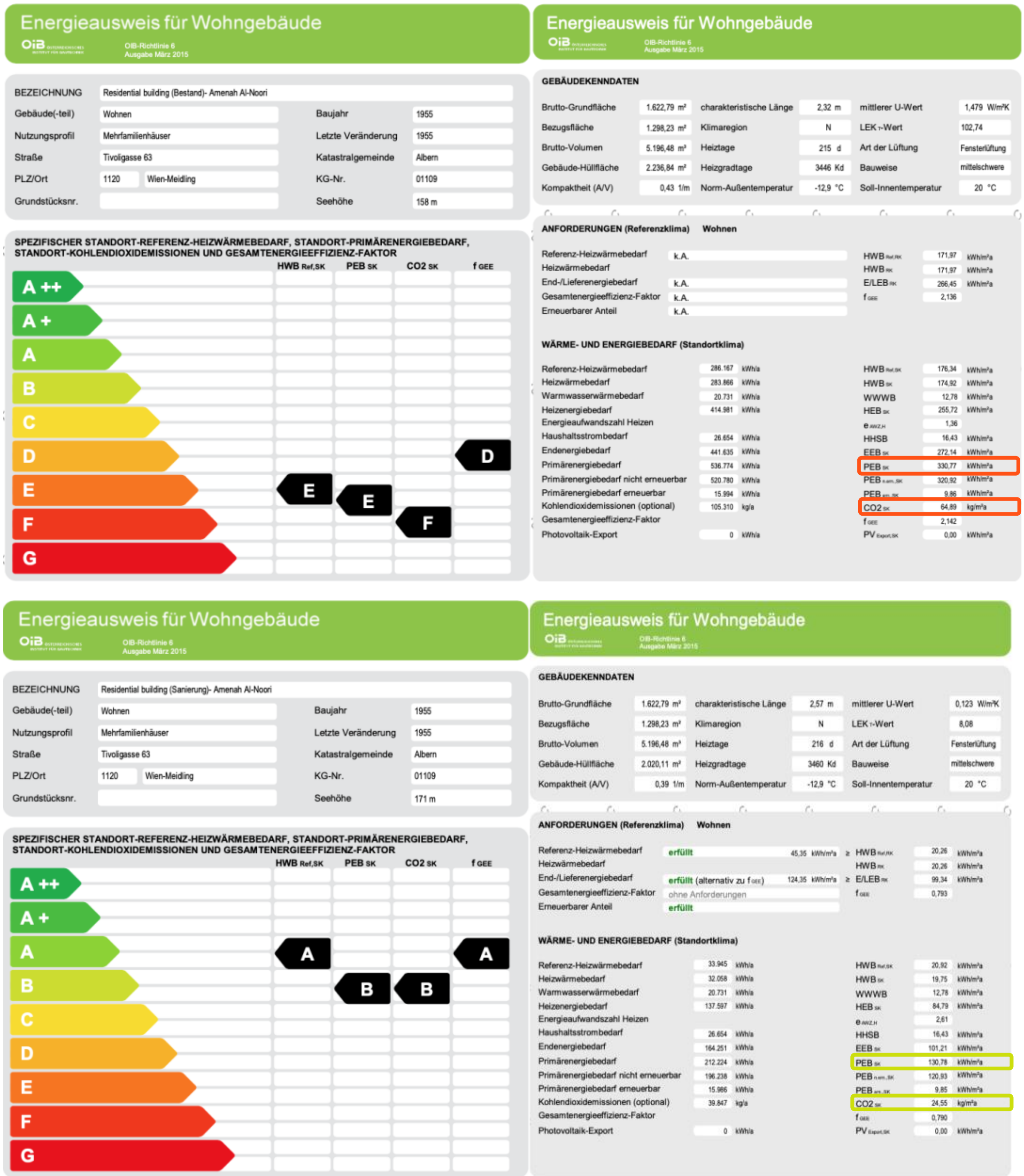

Figure 4-5 Energy certificate for sample E and sample R

OI3 Statement

The OI3 index assesses the ecological quality of building materials based on three environmental impact categories (global warming potential, acidification potential and consumption of non-renewable energetic resources), which are combined into a single characteristic value $OI3_{BGX,BZF}$.

The ecological index approved in Austria and used in assessing the building life cycle for Austrian certification systems is ecological index $OI3_{BG3,BZF}$.

According to OI3- guideline V4.0 2018 (available in German language only) the building elements (BG3) to be considered in the calculation of ecological index $OI3_{BG3,BZF}$ in eco2soft are:

- External walls
- Load- bearing internal walls
- Non-load bearing internal walls
- Floor to unheated space
- Roof
- Windows
- Doors
- Basement Load bearing internal walls
- Basement Non-load bearing internal walls

According to the guidelines, the BZF is defined as the gross floor area (conditioned area) plus 50% of the non-conditioned area, i.e., basement in this case study.

Given the absence of clearly defined LCA criterion for existing buildings in Austrian assessment manual such as KlimaAKtiv, there is no ecological index value for sample E.

As for sample R, the energy data was extracted from the energy certificate calculated for sample E in ArchiPHYSIK.

The $OI3_{BG3,BZF}$ was calculated with eco2soft, considering the building envelope BG3 and using the building elements as listed above enhanced with layers of materials as proposed in the catalogue of ecologically rated constructions for renovation, chapter three (Building Tasks) (Buildings of the 1950s and 1960s) page (137 - 147). The final value of ecological index of BG3 ($OI3_{BG3,BZF}$) is 115 points, as depicted on the OI3 Statement generated from eco2soft for sample R (see Figure 4-6).

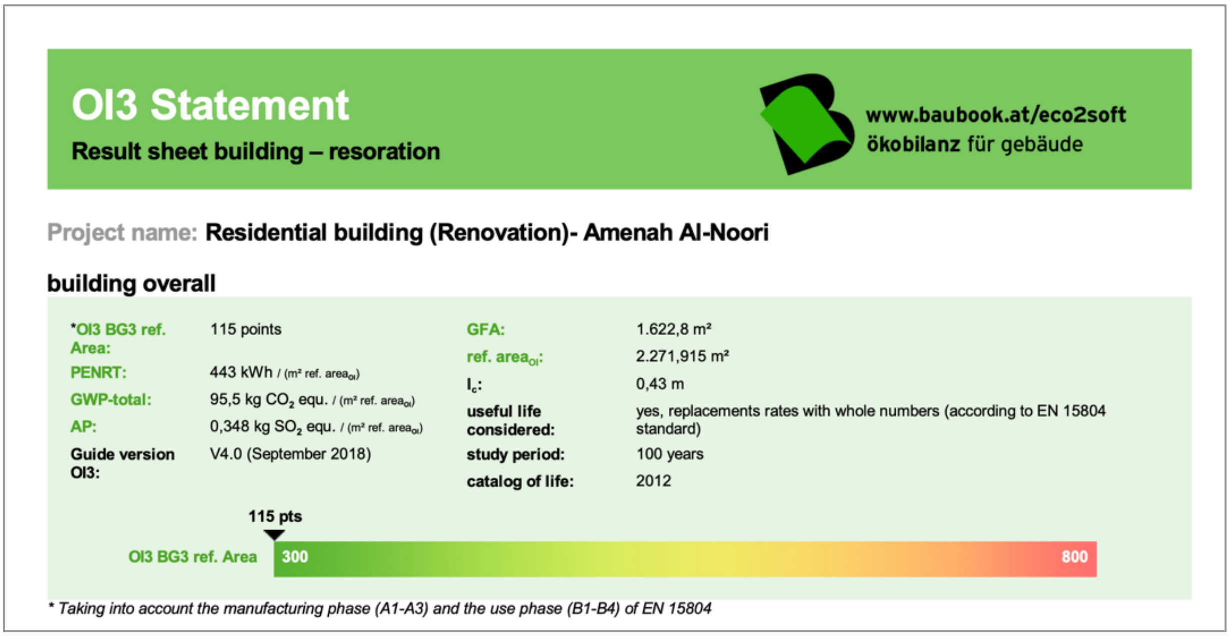

Figure 4-6 OI3 Statemen/ LCA results

Derived LCA performance in the Framework of National Certification Systems Group

The criteria under study were reviewed and their relationship to the LCA methodology was identified. The criteria directly involved in the LCA results were investigated further and points were awarded based on the respective building assessment manuals.

For the point estimation the existing building sample E was used as a reference building and points were only awarded for the retrofit building sample R based on the technical specific results from previous Energy Certificate and OI3 Statement.

LCA Points/ KlimaAktiv

The catalog KLIMAAKTIV KRITERIENKATALOG FÜR WOHNBAUTEN, version 2017 was used for the LCA analysis. Three assessment criteria were identified, which reflect the LCA results; Primary energy demand PEBsk (OIB), CO_2 Emission (OIB) and Ecological Index of the entire building based on eco-index3, BG3.

Sample E:

As per the requirements of KlimaAKtiv, existing buildings are not awarded with points.

Sample R:

In the ***Primary energy demand (PEBsk)*** criterion, the building received **64 points** from (25-100 points).

In the ***CO_2 Emission*** criterion, the building received **50 points** from (50- 200 points). In the ***Ecological Index of the entire building*** criterion, the building received the maximum points achievable of **75 points** (see Table 4-3).

Table 4-3 LCA results and Points/ KlimaAktiv assessment manual

Criteria no.	**Criterion**	**LCA results (sample R)**	**LCA points (sample R)**
B.2a	PEBsk	130.78 kWh.m^{-2}.a^{-1}	64 points
B.3a	CO_2 Emissions	24.55 kg.m^{-2}.a^{-1}	50 points
C.2.1a	OI3 $_{\text{BG3 ref. Area}}$	115 points	75 points

4.3.4 LCA Points/ ÖGNB

The TQB building assessment online tool was used for the LCA analysis and the focus was on one assessment criteria; the Ecological Index of the entire building based on eco-index3, BG3.

In the *Eco- efficiency of entire building* criterion, the building received the maximum points achievable of **60 points** (see Table 4-4).

Table 4-4 LCA Results and Points/ TQB Assessment Tool

Criteria no.	**Criterion**	**LCA results (sample R)**	**LCA points (sample R)**
E.3.1	OI3 $_{\text{BG3 ref. Area}}$	115 points	60 points

4.4 Extracted LCA Performance in the Framework of International Certification Systems Group

The process of determining the achieved credit goes through calculating the relevant environmental indicators, which is conducted using the One Click LCA tool.

To provide a comparison the existing as-is serves as the baseline and is referred to as sample E. The other side of the comparison will be an enhanced version of the baseline building and will be referred to as sample R. The relevant building materials for both samples are derived from the Catalogue of Ecologically Rated Constructions for Renovation, Chapter Three (Building Tasks) (Buildings of the 1950s and 1960s) page (137 - 147). The One Click LCA purchased version provides direct action to baubook database which serves as the source of the building materials required. However, as data on some catalogue materials are is not available in the baubook database when using this the tool, similar alternative materials or items from ÖKOBAUDAT database were selected and used instead. The ÖKOBAUDAT database contains a wide range of options for building materials that are similar to the Austrian materials. The comparison between two samples is applicable in the case of LEED and DGNB. As for BREEAM, the calculation was done for sample R only.

The building elements to be considered in the calculation are:

- Foundation
- Exterior walls
- Load- bearing internal walls
- Non load- bearing internal walls
- Floor to unheated space
- Ceiling
- Roof
- Windows
- Doors
- Staircases

The foundation and staircases are not mandatory building elements in BREEAM manual only. External areas, site elements and building technology are not covered in the case study.

4.4.1 LCA Credits/ BREEAM

The **BREEAM International New Construction**, **2016** assessment manual was undertaken with the purchased One Click LCA. The reason behind skipping the later version, BREEAM UK New Construction, 2018 is that One Click LCA supports the latter for UK local use only. The criterion identified that reflects the life cycle assessment results is Mat 01 Life cycle impacts. It is worth noting that the manual is not designed for existing buildings. Thus, the building in the case study is treated as new so that the life cycle can be assessed

The materials layers of building in each selected building elements were used for one case only (sample R), according to the Catalogue of Ecologically Rated Constructions for Renovation, which proposes additional material layer which would lead to environmental improvement of the building in line with the year of construction.

The Figure 4-7 summarizes the outcome of the assessment for each life cycle stage and category for sample R using One Click LCA. The Figure 4-8 shows the environmental impact indicators broken into the life cycle stages.

Life-cycle assessment results for BREEAM International versions as per EN 15978

	Result category	Global warming kg CO_2e	Acidification kg SO_2e	Eutrophication kg PO_4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Non hazardous waste disposed kg	Biogenic carbon storage kg CO_2e bio	
A1-A3	Construction Materials	6,826E5	1,472E3	3,757E2	1,279E−2	5,292E2	1,085E5	5,934E3	Details
A4	Transportation to site	1,331E4	6,124E1	1,334E1	2,629E−3	7,576E−1	4,054E1		Details
A5	Construction/installation process	4,922E4	1,78E2	1,079E2	7,032E−3	6,029E0	1,306E4		Details
B4-B5	Material replacement and refurbishment	3,578E5	8,693E2	1,58E2	2,8E−3	2,164E2	6,292E4		Details
B6	Energy use	1,657E6	8,104E3	1,183E3	1,495E−1	4,119E2	7,623E4		Details
C1-C4	End of life	2,61E5	5,338E1	1,29E1	3,809E−4	2,879E0	1,871E5		Details
D	External impacts (not included in totals)	−1,741E4	−1,585E2	−2,849E1	−2,037E−3	−6,997E0	−3,183E3		Details
	Total	**3,021E6**	**1,074E4**	**1,851E3**	**1,751E−1**	**1,167E3**	**4,478E5**	**5,934E3**	
	Results per denominator								
	Gross Internal Floor Area (IPMS/RICS) 1622.0 m²	1,862E3	6,62E0	1,141E0	1,079E−4	7,195E−1	2,761E2	3,658E0	

Assessment period fixed to 60 years.

Figure 4-7 Life cycle assessment results for BREEAM by One Click LCA

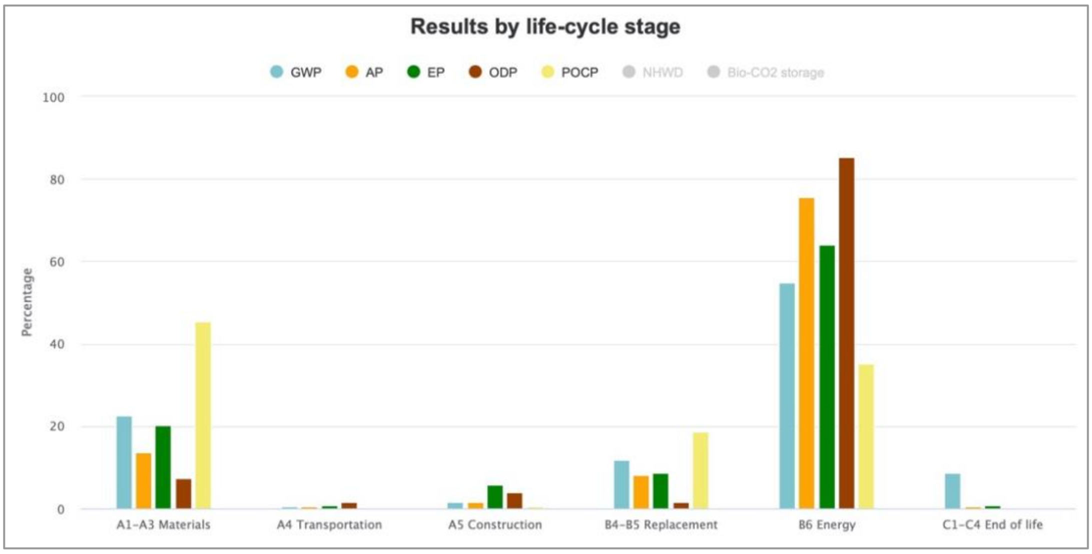

Figure 4-8 Life cycle stage of total impact indicators

The Excel based Mat 01 calculator offered by the BRE portal was used to obtain the maximum potential score the LCA tool could achieve for the building (see Figure 4-9). In a real-world scenario, the extracted results from One Click LCA (report) and the Mat 01 calculator form are submitted to BREEAM official website for verification after which the BREEAM sustainability certification label can be issued.

BREEAM International New Construction 2016 Mat 01 Calculator BREEAM®

Assumptions for LCA tool approval

This template confirms the maximum potential score the LCA tool can achieve, for the rigour of the assessment (left hand side) and assessment scope (right hand side). The design team should confirm with evidence submitted with the report (as detailed in the technical guide) that, for the geographic applicability, methodology and the assessment scope aspects, the tool has been used to the extent listed below. If the tool has not been used to this extent, the template should be amended, to confirm the extent that the tool has been used. Please also see CN1 as the score will change depending on the number of applicable elements present in the building/assessment.

Materials Assessment tool/method and data

Note: where 'M' is indicated against a section heading, at least one item must be indicated 'Y'.

	Mandatory	Maximum	Included in LCA tool?
Output Indicators available		Sum:-	
Embodied carbon (CO2e)	M	2	Y
Embodied water OR waste processing		2	N
AND any two additional indicators		4	N
	Points	8	2
(M) Output Life stage(s) available (for all indicators selected)		Score:-	
Cradle to Gate total		2	N
Cradle to Gate total AND End of Life		4	N
Cradle to Grave total		6	N
Cradle to Grave total WITH operational energy (reported separately)		8	N
Cradle to grave with separate life stage reporting* to:- a. Product stage b. Construction process stage c. Use stage (with operational energy reported separately) d. End of life		12	Y
*see guidance tab	Points	12	12
(M) Assessment level(s). Life cycle impact comparisons possible (and made) at the:		Sum:-	
Elemental level*		4	N
Whole Building Level		4	N
Whole building level; with user product-level specification (e.g. thickness, service life) and reporting aligned to (the current version of) EN 15978.		2	Y
*see guidance tab	Points	10	2
(M) Source LCA data quality - Geographic applicability and age Majority of individual materials/products in the tool are assessed:		Sum:-	
Using LCA data of unknown geographic applicability OR not compensated to local conditions		0	N
Using local LCA data or LCA data that has been compensated to a comprehensive range of regional differences*		5	N
Using data no older than 10 years (generic) or 5 years (manufacturer specific)		5	Y
*see guidance tab	Points	10	5
(M) Source LCA data quality - Methodologies/PCRs* Majority of individual materials/products in the tool:		Sum:-	
Are assessed using data of unknown methodology/PCR		0	N
Are each assessed to any publicly available methodology/PCR compliant with (the current version of) ISO 14040 & ISO 14044		4	N
Are each assessed to any publicly available AND peer reviewed methodology/PCR compliant with (the current version of) ISO 14040 & ISO 14044		4	N
Are each assessed to any publically available AND peer reviewed methodology/PCR that is compliant with (the current version of):			
ISO 21930 (may be awarded 'Y' if EN 15804 is awarded 'Y')		4	N
EN 15804		4	Y
Are all assessed to the same publically available AND peer reviewed methodology/PCR that is compliant with ISO 21930 or EN 15804.		4	N
*see guidance tab	Points	20	4
(M) Source LCA data quality - Verification* Majority of individual materials/products in the tool are assessed using:		Score:-	
LCA data/data of unknown level of verification		0	N
Verified/peer reviewed LCA data		6	Y
Verified/peer reviewed LCA data AND majority of EPD used (manufacturer or trade association) are verified to ISO 14025, ISO 21930 or EN 15804		10	Y
*see guidance tab	Points	10	10
	Total points	70	35

Materials Assessment Scope

	Mandatory (if present)	Present in building?	Maximum	Included in assessment?
Building elements included				
Fabric:-			Sum:-	
External walls (envelope, structure and finishes)	M	Y	2,00	Y
External windows and rooflights	M	Y	2,00	Y
Foundations (including excavation)		N		Y
Internal floor finishes (incl. access floors)	M	Y	2,00	Y
Structural frame (vertical)		N		Y
Upper floors (including horizontal structure)	M	Y	2,00	Y
Basements/retaining walls (including excavation)		N		Y
External solar shading devices, access structures etc.		N		Y
Ground/lowest floor		N		Y
Internal ceiling finishes (incl. suspended/access ceilings)		N		Y
Internal walls and partitions	M	Y	1,00	Y
Roof (including coverings)	M	Y	1,00	Y
Stairs and ramps		N		Y
Balustrades and handrails		N		Y
Internal doors		N		Y
Internal wall finishes		N		Y
Internal windows		N		Y
Building Services:-				
Heat Source, Space Heating, Air Conditioning, Ventilation		N		Y
Communication, Security and Control Systems		N		Y
Electrical Installations		N		Y
Fire and Lightning Protection		N		Y
Lift and Conveyor Installations / Systems		N		Y
Water and waste installations		N		Y
Sanitary Installations		N		Y
Landscaping				
Hard Landscaping, Roads, Paths and Pavings		N		Y
Hard Landscaping, Fencing, Railings and Walls		N		Y
		Total Points	10,0	10,0

Note: As building-level data is gathered, element weightings will be refined.

Percentage of Mat01 points achieved:	**56,3%**
Select building type:	All others
Credits achieved	**1**

Note: Please see guidance tab to confirm credits achieved when using BREEAM-NOR 2016 scheme

Figure 4-9 MAT 01 Calculator Offered by BREEAM

The Mat01 maximum achievable score is up to 6 credits as stated in the BREEAM Assessment Manual 2016. The sample R in this study achieved 1 credit out of the possible 6.

Table 4-5 LCA Credits/ BREEAM assessment manual

Issue	**LCA Credit (sample R)**
Mat01 Life cycle impacts	1 credit

4.4.2 LCA Points/ LEED

The **LEED v4 Building Design and Construction (LEED BD+C)** assessment manual was undertaken using One Click LCA. The criterion including the life cycle assessment results is Building Life-cycle Impact Reduction (Option 4. whole- building life- cycle assessment).

The essential difference in the calculation of the results of the building life cycle assessment from BREEAM is the comparison of the results of the baseline building (sample E) against those of the proposed building (sample R). The building layers for both samples were extracted from the catalogue by considering the year of construction.

To obtain credits, the percentage improvement difference from the baseline against the proposed building in at least three environmental impact categories, where GWP is mandatory, should be at least 10% percent.

The Figure 4-11 shows compares the two sample buildings on the environmental impact indicators in each life cycle stage.

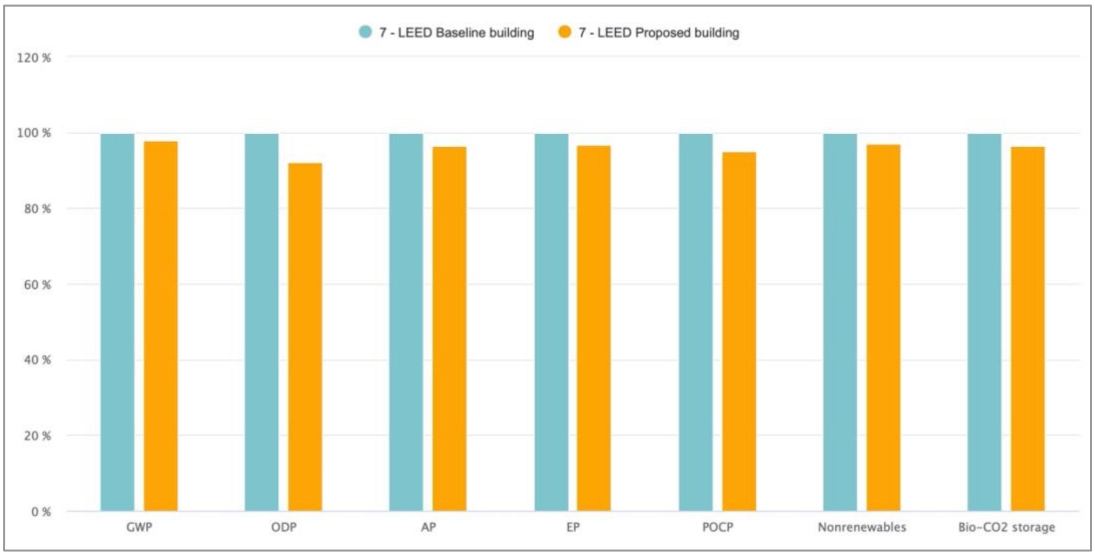

Figure 4-10 Life cycle stage of total impact indicators

baseline and proposed building (LEED)

Whole-building Life Cycle Assessment, ISO 14040 & ISO 14044 (CML 2002; November 2012)

	Result category	Global warming kg CO_2e	Ozone depletion potential kg CFC11e	Acidification kg SO_2e	Eutrophication kg PO_4e	Formation of ozone of lower atmosphere kg Ethenee	Depletion of nonrenewable energy MJ	Biogenic carbon storage kg CO_2e bio	
A1-A3	Construction Materials	601 336,62 | -2,8 %	0,01 | -9,8 %	1 024,64 | -4,4 %	477,06 | -4 %	90,95 | -5,6 %	4 754 483,93 | -3,9 %	4 087,69 | -3,4 %	Details
A4	Transportation to site	13 947,94 | -1,1 %	0 | -1,1 %	64,24 | -1,1 %	13,99 | -1,1 %	0,79 | -1,1 %	396 377,95 | -1,1 %		Details
B1-B5	Maintenance and material replacement	209 492,14 | 0 %	0 | 0 %	230,85 | 0 %	77,26 | 0 %	13,33 | 0 %	1 391 137,12 | 0 %		Details
C1-C4	End of life	6 090,86 | -15 %	0 | +3 %	43,76 | -3,7 %	8,63 | -3,6 %	3,91 | -4,1 %	117 089,34 | -3,4 %		Details
	Total	**830 867,56**	**0,02**	**1 363,49**	**576,94**	**108,97**	**6 659 088,35**	**4 087,69**	
	Comparing total results with: 7 - LEED Baseline building								
	7 - LEED Baseline building Total	849 313,86	0,02	1 413,2	597,11	114,58	6 858 127,27	4 231,53	
	7 - LEED Proposed building compared with 7 - LEED Baseline building	-2,2 %	-7,8 %	-3,5 %	-3,4 %	-4,9 %	-2,9 %	-3,4 %	
	Results per denominator								
	Gross Internal Floor Area (IPMS/RICS) 1622.0 m^2	512,25	0	0,84	0,36	0,07	4 105,48	2,52	

Figure 4-11 Life cycle assessment outline (percentage difference)

for LEEDv4 by One Click LCA

The maximum achievable score is 3 points when the proposed building a minimum of 10% reduction of three environmental indicators, compared with a baseline building as stated in the LEEDv4 manual. Given the resulting percentage difference between the two samples none of the of the impact categories demonstrated the minimum desired improvement of 10%. Consequently, sample R did not receive any credit points.

4.4.3 LCA Points/ DGNB

The DGNB System - New Buildings Criteria Set 2018 Assessment Manual was selected using the One Click LCA tool. The manual does not assess existing buildings and consequently the tool does not offer this option. Hence, for the sake of the study the building was assumed to be new and not yet constructed. The assessment criterion identified to reflect the LCA results is ENV1.1 Building Life Cycle Assessment.

The DGNB manual provides fixed reference values (benchmarks) in form of sevens indicators, which includes GWP, ODP, POCP, AP, EP, PENREN and PE TOT for construction stage that are also available in One Click LCA. The reference values for heat and electricity use required for the assessment were derived from OIB Austrian Guideline 6, 2015 (See figure 4-12).

DGNB International's reference building performance

	Result category	Global warming kg $CO_2e/m^2/a$	Ozone depletion potential kg $CFC11e/m^2/a$	Formation of ozone of lower atmosphere kg $Ethenee/m^2/a$	Acidification kg $SO_2e/m^2/a$	Eutrophication kg $PO_4e/m^2/a$	Total use of non renewable primary energy $kWh/m^2/a$	Total use of renewable primary energy $kWh/m^2/a$	Total use of primary energy $kWh/m^2/a$	
DGNB-C-Ref	Construction, maintenance, disassembly and disposal	9,4E0	5,3E−7	4,2E−3	3,7E−2	4,7E−3	3,417E1	7,778E0	4,194E1	Details
DGNB-H-Ref	Heat use	1,315E1	1,723E−9	1,791E−3	1,778E−2	1,102E−3	5,492E1	3,779E−1	5,53E1	Details
DGNB-E-Ref	Electricity use	1,035E1	5,124E−8	1,272E−3	1,719E−2	1,656E−3	4,07E1	6,861E0	4,757E1	Details
DGNB-Reference	Total reference value	3,29E1	5,83E−7	7,263E−3	7,197E−2	7,458E−3	1,298E2	1,502E1	1,448E2	Details

Figure 4-12 DGNB reference values for construction and use stages

The basic building data needed for DGNB building life cycle assessment are: the materials layers of the construction in each selected building elements for both cases sample E and sample R in the study were used as in the previous LEED LCA calculation. The annual heating demand and electricity demand for the samples in study derived from the Energy certificate for sample E. These results were also used for the life cycle assessment of the national certification systems group.

The Life-cycle assessment for DGNB presented the results in two main stages: construction stage, maintenance, disassembly & disposal, and the use stage which includes the annual heating and electricity demand for building as illustrated in Figure 4-13 and Figure 4-14.

Life-cycle assessment results for DGNB International's ENV1.1. and ENV2.1.

	Result category	Global warming kg $CO_2e/m^2/a$	Ozone depletion potential kg $CFC11e/m^2/a$	Formation of ozone of lower atmosphere kg $Ethenee/m^2/a$	Acidification kg $SO_2e/m^2/a$	Eutrophication kg $PO_4e/m^2/a$	Total use of non renewable primary energy $kWh/m^2/a$	Total use of renewable primary energy $kWh/m^2/a$	Total use of primary energy $kWh/m^2/a$	
A1-A3	Construction Materials	1,494E1	6,525E−9	1,723E−3	1,46E−2	3,15E−3	2,214E1	8,573E0	3,071E1	Details
B4	Material replacement	6,17E0	1,885E−13	3,705E−4	6,852E−3	1,754E−3	1,046E1	5,31E0	1,577E1	Details
B4-waste	Material replacement waste handling	4,664E−1	2,587E−15	2,238E−4	2,951E−3	3,321E−4	1,884E0	2,475E−1	2,132E0	Details
B6	Energy use	2,761E1	2,491E−6	6,864E−3	1,351E−1	1,971E−2	1,166E2	5,943E1	1,76E2	Details
C3	Waste processing	4,203E−1	2,957E−10	7,828E−5	8,614E−4	1,479E−4	6,313E−1	7,22E−2	7,035E−1	Details
C4	Waste disposal	3,872E−1	4,089E−11	1,865E−4	2,459E−3	2,768E−4	1,57E0	2,06E−1	1,776E0	Details
D	External impacts	−1,7E−1	−3,816E−10	−9,534E−6	−2,486E−4	−5,195E−5	−6,739E−1	−1,712E−1	−8,451E−1	Details
	Total	**4,983E1**	**2,497E−6**	**9,437E−3**	**1,625E−1**	**2,532E−2**	**1,526E2**	**7,367E1**	**2,263E2**	

Figure 4-13 Life-cycle assessment results for DGNB by One Click LCA

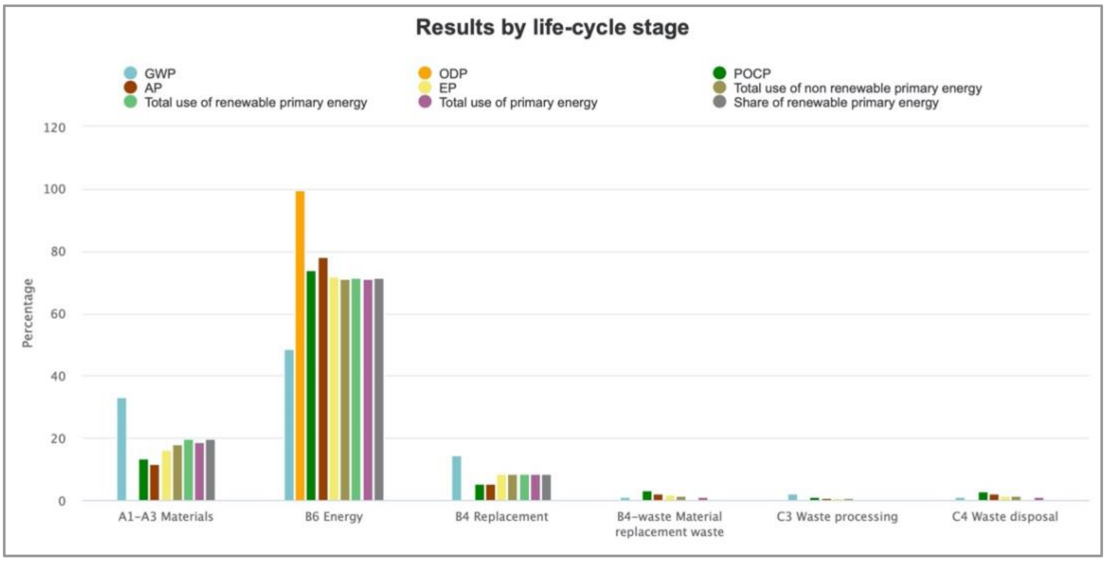

Figure 4-14 Life cycle stage of total impact indicators

baseline and optimized building (DGNB)

To obtain LCA achieved points, the results of the building LCA under evaluation were assessed against these benchmarks (reverence values) discussed above.

Based on the manual's requirements, sample E and sample R obtained 0 and 10 points respectively (see Figures 4-15, 4-16 and Table 4-6).

— Points, DGNB 2018

UPDATED V2018-The indicator sub-points have been converted into checklist points (CLP) with the appropriate weighing keys. The maximum achievable CLP's is 100. Check the results before submission.

Result category	Global warming kg $CO_2e/m^2/a$	Formation of ozone of lower atmosphere kg Ethenee/m^2/a	Acidification kg $SO_2e/m^2/a$	Eutrophication kg $PO_4e/m^2/a$	Total use of non renewable primary energy kWh/m^2/a	Total use of primary energy kWh/m^2/a	Share of renewable primary energy %/m^2/a	
Maximum available points	40	10	10	10	15	10	5	Details
Points achieved	0	0	0	0	0	0		Details

Figure 4-15 LCA Points/ Actual building/ DGNB

— Points, DGNB 2018

UPDATED V2018-The indicator sub-points have been converted into checklist points (CLP) with the appropriate weighing keys. The maximum achievable CLP's is 100. Check the results before submission.

Result category	Global warming kg $CO_2e/m^2/a$	Formation of ozone of lower atmosphere kg Ethenee/m^2/a	Acidification kg $SO_2e/m^2/a$	Eutrophication kg $PO_4e/m^2/a$	Total use of non renewable primary energy kWh/m^2/a	Total use of primary energy kWh/m^2/a	Share of renewable primary energy %/m^2/a	
Maximum available points	40	10	10	10	15	10	5	Details
Points achieved	0	4	0	0	6	0		Details

Figure 4-16 LCA Points/ Optimized building/ DGNB

Table 4-6 LCA Points/ DGNB Assessment Manual

Criterion	**LCA Points (sample E)**	**LCA Points (sample R)**
ENV1.1 Building life cycle assessment	0 points	10 points

5 DISCUSSION

5.1 Overview

The aim of this thesis was to review the current LCA criteria belonging to six assessment manuals related to various Austrian and international building certification systems in relation to the weighting of LCA method in these certifications. The building case study provided concrete steps for building life cycle assessment for specific type of buildings by using specially designed tools where the result can be evaluated by the selected LCA criteria and then receive the final LCA points/credits. The review showed the LCA methods in framework of national as well as international building certification systems. While reviewing the LCA methods of three Austrian certification systems it was evident that the expression 'LCA' isn't commonly used. This resulted in difficulties in identifying the relevant sections revolving around the topic of LCA in the Austrian assessment manuals. Additionally, the review showed crucial differences among the assessment manuals.

The KlimaAKtiv Assessment Manual considers the energy criteria to be part of the life cycle assessment, with a quite high weighting in the overall assessment manual.

The ÖGNB(TQB) online assessment tool uses the same energy criterion as KlimaAKtiv assessment manual, however the criterion is not considered as a part of life cycle assessment. Both manuals assess materials using criteria from the Austrian ecological index. KlimaAKtiv however has the option of conducting a material assessment based on the building elements scope balance limit 1 (BG1) as well as balance limit 3 (BG3), whereas ÖGNB(TQB) online assessment tool's building elements scope accepts only balance limit 3 (BG3).

ÖGNI is adapted from the DGNB certification to suit the Austrian building guidelines with regard to the calculation of energy consumption of buildings. The ÖGNI Assessment Manual Version 2017 is still based on the older version of the DGNB manual in that it has the LCA criteria split into ENV 1.1 and ENV 2.1, which is not applied in the new versions of DGNB manual anymore.

A clear difference between the ÖGNI method KlimaAKtiv and ÖGNB methods is that for the ÖGNI method only new buildings can be assessed.

It is worth mentioning that the Austrian certification systems KlimaAKtiv and ÖGNI do not offer English versions of their assessment manuals. Consequently, non-German speaking researchers or assessors will be challenged to understand or work with the latter manuals.

Ordering the assessment manuals by the LCA proportion of total score shows that the KlimaAKtiv assessment manual has the highest portion of LCA among the three assessment manuals in study, followed by ÖGNI and ÖGNB manuals (see Table 5-1).

Table 5-1 Maximum LCA Score Percentage in Austrian Assessment Manuals

Austrian certification systems	Assessment manuals (version)	Proportion of total score
KlimaAKtiv	2017	37,5% (BG3) or 35% (BG1)
ÖGNI	2017	13,5%
ÖGNB	2018	6%

The BREEAM UK New Construction Buildings, 2018 does include life cycle assessment in more meaningful way compared to its 2016 version. This 2016 version was used in the case study, however the newer assessment manual is intended for United Kingdom only. In addition, the version of manual 2018 is still offered for new construction buildings as previous version. The essential difference between manuals versions of 2016 and 2018 lies in the material assessment method. The BREEAM assessment manual 2016 is based on The Green Guide's Ecopoint method. The BREEAM Manual 2018 comprises two methods, BREEAM LCA benchmark applied using the BREEAM Simplified Building LCA tool and option appraisal which is used in IMPACT Compliant tools as described in chapter 3.

In the LEEDv4 method the Materials and Resources category (MRc1) contains different options of assessment, one of the options more relevant to building life cycle assessment is Option 4: Whole Building Lifecycle assessment. As in the BREEAM assessment manual, LEED's option v4 is actually designed for new construction. The highest score is awarded if the building under assessment shows a minimum percentage improvement difference of 10% in three environmental impact categories, where GWP is mandatory, between a baseline and proposed building.

The DGNB assessment manual requires whole life cycle assessment of a construction across all of its phases in the 2018 version of the building life cycle assessment is defined with one criterion only. This criterion describes the building life cycle assessment method as well as the reference values for phase construction, maintenance and recovery/disposal for different types of buildings. As in BREEAM and LEED, the DGNB manuals are designed for life cycle assessment for new construction.

Ordering the assessment manuals by the LCA proportion of total score, the DGNB manual has the highest portion of LCA among the three assessment manuals in study, followed by BREEAM and LEED manuals (see Table 5-2).

Table 5-2 Maximum LCA Score Percentage in International Certification Systems

International certification systems	Assessment manuals (version)	Proportion of total score
DGNB	2018	9.5%
BREEAM	2018	6.79%
LEED	Version 4	5.2%

The life cycle assessment process of a retrofit building case study goes through the steps of determining the specific assessment manual including the required LCA criteria. Consequently, utilizing the supporting appropriate LCA tool that implements the theoretical LCA method stipulated in each assessment manuals separately to obtain the assessment outcome. Austrian building certification systems (such as KlimaAKtiv) support retrofit projects because of the intention to preserve existing buildings instead of demolishing and rebuilding.

To aid the life cycle assessment process, the IBO- Austrian Institute for Healthy and Ecological Building offers a catalogue of ecologically rated constructions for renovation that supports both designers and builders in the implementation process. The catalogue offers various refurbishment examples organized by the period of construction and type of construction building material. The building material elements suggestion in this catalogue are available in the baubook database. The latter is integrated in national assessment tool such as ArchiPHYSIK and eco2soft as well as international LCA tool such as the purchasable One Click LCA. One exception to be mentioned, the DGNB uses ÖKOBAUDAT, which is included in the full version of One Click LCA.

By utilizing the catalogue's recommended ecological materials, the LCA points for (sample R) are 75 and 60 points (maximum points) out of total 1000 points in KlimaAktiv assessment manual and ÖGNB (TQB) online assessment tool respectively. Although the building is built out of brick, the recommended insulation materials used makes the difference and hence the refurbishment building's LCA points is considered as best and very good assessment in KlimaAktiv and ÖGNB respectively.

In the primary energy demand criteria, sample R building achieved a total of 64 points out of the 1000 points of the KlimaAKtiv manual. On the energy LCA the possible attainable points range between 25 to 200 of the total KlimaAktiv manual. This LCA points is above the minimum requirement. Looking at the CO_2 emissions resulting from the total final energy demand of the building, the sample R building received 50 points. When placing the result on the possible CO_2 LCA range which is 50-200, the building fulfilled the minimum requirements.

On the international manual level, the Mat01 maximum achievable score is 6 credits as stated in the BREEAM manual. As a result of the material assessment tool including the method and data used and on the other hand the presumed material assessment scope in the case study submitted together to Mat 01 calculator. The building sample R received one credit point due to an investigation input which is unrelated to the LCA results from the LCA tool.

One Click LCA results can be in form of a report without getting the LCA achieved points as in the DGNB assessment. The report usually is forwarded to BREEAM who provide the building certification certificate.

In the LEED manual, the maximum achievable score is 3 points, when the proposed building demonstrates a minimum of 10% reduction of three environmental indicators, compared with a baseline building as stated in the LEEDv4 manual. All of sample R's impact categories showed a numerical reduction compared to sample E. Nevertheless, it was insufficient to fulfill LEED's building life cycle assessment minimum requirement of at least 10% reduction in GWP.

The DGNB manual requires reference buildings to work towards achieving its performance.

In this study sample E did not receive any points in any of the weighting keys for the environmental indicators. Sample R is rewarded with a very low number of points. This is due to the estimated reference building performance values used in the building assessment.

From the perspective of the building in the study, the assessments of the Austrian certification systems show more accuracy and are more appropriate than international certification systems. The international certifications' focus on assessing new constructions and preferred use is for starting at the design stage. They do however offer assessment building refurbishment assessment manuals but these are generally only applicable in the country of origin (e.g., BREEAM). This posed a challenge in obtaining accurate LCA results for the case study residential building when using the

LCA tool available in the market. The LCA methods review and case study shows the similarities in ecological criteria while highlighting the differences in the assessment procedure in the framework of selected assessment manuals.

5.2 Research Limitations

There are some limitations in this study. The selected assessment manuals are limited to special type of buildings as in national certification KlimaAktiv. The Klimaaktiv Kriterienkatalog für Wohnbauten 2017 was used in this study. However, there is also a dedicated catalog related for office buildings (KLIMAAKTIV KRITERIENKATALOG FÜR BÜROGEBÄUDE UND BILDUNGSEINRICHTUNGEN 2017) containing also LCA criteria, which are not reviewed as part of this study. This may limit a broader view of building life cycle assessment for non-residential buildings in this certification. The second limitation concerns the case study. There is a lack of data concerning the building elements layers for the existing building (sample E) in the original plans, which is necessary as input data for ArchiPHYSIK to calculate and obtain the energy certificate for the exiting building. Assumptions regarding thermal properties (U-Values) were derived from the OIB guideline 6, 2015 relevant to the age and type of the building can lead to inaccurate heat energy demand value which also serve as necessary input data for eco2soft and One Click LCA to get LCA results for retrofit building.

6 CONCLUSION

In this thesis the current building LCA methods belonging to six different certification systems for the environmental impact of buildings have been studied and empirically compared. Thereby, not only content and rating systems, as well as system borders, and similar aspects have been analyzed and discussed in their extent of the six systems. Hence, to see the differences and common elements, a case study has been conducted through extracting the LCA results for residential building.

It is clear that assessment methods vary substantially across the different building certification systems and that there is a varied selection of LCA methods in building certification systems, which can serve as bases for further research in Austria and the rest of world.

The general buildings' design approach in the past concentrated on meeting construction cost budget requirements. As interest in environmental awareness has grown, designers and contractors have started putting more emphasis on the thermal insulation of building envelopes to meet the regulations of local building directives. Consequently, there has been a reduction in energy consumption and emissions through the life cycle of buildings. It is also important to consider the long-term resource efficiency and the sustainability of building materials used. Thus, for buildings to be considered as sustainable, it is imperative that they reach high levels of environmental, economic and social performance. To ensure this, it is essential to assess the building on its life cycle.

The guidelines for sustainable buildings as well as life cycle assessments are gathered into building certification systems with the aim of reducing negative environmental impacts and maximizing operational quality. By utilizing credit-based systems the environmental effects can be quantified and incentives can be given to improve and develop efficient and environmentally more friendly buildings starting at the design stage.

In terms of material databases some international LCA connect to local databases such as in the case of the purchasable One Click LCA and IBO. The Austrian LCA tools also support this interface to construction material databases such as eco2soft and IBO.

In the process of putting together the required layers of construction materials with the proposed ecologically enhanced material for the retrofit project, some of the materials were not available in the database. When conducting the assessment with the Austrian and international certification systems, it is challenging to locate all the construction materials in the material databases, which are connected to the tools.

Prior to engaging with the assessment when using most of the LCA tools, it is essential to prepare the energy certificate results for the building under consideration with building physics software. This increases the time and effort required to carry out the building life cycle assessment process properly especially with regard to energy criteria.

The building LCA case study results showed that the proposed insulation layers for sample R had a noticeable effect on Ecological Index 3 (OI3) in the balance limit 3 ($OI3_{BG3,\ BZF}$) as a life cycle assessment result from eco2soft tool. This in turn led to a maximum LCA points for material assessment in framework of national certification systems group. In the framework of international certification, the full version of One Click LCA used for calculating the LCA results for sample R in the three international certification systems BREEM, LEED and DGNB played a major role in facilitating the assessment process. This is also partly to be credited to the possibility to connect the tool to the Austrian baubook database. The sample building considered in this study is an old residential building. It is challenging to define the baseline building according to international manual assessment requirements due to lack of real data of the building materials used at the time of construction. Consequently, the minimum requirement for extracting the LCA score in framework of international certification systems group is not possible.

The Austrian building certification systems must harmonize the criteria of LCA for ease of understanding and application in real life scenarios. Greater efforts have to be put into creation of additional guides dedicated for using the building life cycle assessment. In the international field of assessment manuals, more focus should be put on enhancing the certification to support more refurbishment projects in all use types of buildings and therefore the LCA method will be an integral part of these manuals. In terms of assessing retrofit buildings, the database of materials ought to be complimented with all materials used in Austria for each relevant period. Moreover, to reach a wider spectrum of audience especially in the research field, it would be of great benefit if more free LCA tools, which can be connected to local material databases are supported and offered.

7 INDEX

7.1 List of Figures

7.2 List of Tables

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9 APPENDIX

A. Building Assessment Criteria Catalogs

Table A-1: Klimaaktiv Bewertungskategorien Und Kriterien Gewichtung (für Wohnbauten Neubau und Sanierung, Version 2017) (German Language)

Source: KlimaAKtiv, Kriterienkatalog, 2017, P.9.

NEUBAU UND SANIERUNG			
NR.	TITEL	MUSS-KRITERIUM	ERREICHBARE PUNKTE
A	**Standort und Qualitätssicherung**		**max. 175**
A 1	**Infrastruktur und umweltfreundliche Mobilität**		**max. 60**
A 1.1	Infrastruktur in Standortnähe	M	2 bis 30
A 1.2a	Umweltfreundliche Mobilität	alternativ a od. b	0 bis 50
A 1.2b	Konzepte		50
A 2	**Qualitätsnachweise für Planung und Ausführung**		**max. 130**
A 2.1	Wirtschaftlichkeit		15 bis 30
A 2.2a	Qualitätssicherung Energiebedarfsberechnung und Verbrauchsprognose OIB	alternativ a od. b	30 bis 40
A 2.2b	Qualitätssicherung Energiebedarfsberechnung und Verbrauchsprognose PHPP		50 bis 60
A 2.3	Gebäudehülle luftdicht	M	0 bis 30
A 2.4	Energieverbrauchsmonitoring	M ab 1.000m²	0 bis 40
B	**Energie und Versorgung (Nachweisweg OIB)**		**max. 500**
B 1a	Heizwärmebedarf OIB	M	100 bis 200
B 2a	Primärenergiebedarf OIB	M	25 bis 100
B 3a	CO_2-Emissionen OIB	M	50 bis 200
B 4a	Gesamtenergieeffizienzfaktor OIB		25 bis 75
B	**Energie und Versorgung (Nachweisweg PHPP)**		**max. 500**
B 1b	Heizwärmebedarf PHPP	M	150 bis 250
B 2b	Primärenergiebedarf PHPP	M	25 bis100
B 3b	CO_2-Emissionen PHPP	M	75 bis 200
B 4b	Erzeugung PV-Strom		10 bis 50
C	**Baustoffe und Konstruktion**		**max. 150**
C 1	**Baustoffe**		**max. 90**
C 1.1	Ausschluss von klimaschädlichen Substanzen	M	5
C 1.2	Ausschluss von besonders besorgniserregenden Substanzen		5
C 1.3	Vermeidung von PVC und anderen halogenorganischen Verbindungen	M	5 bis 60
C 1.4	Einsatz von Produkten mit Umweltzeichen		0 bis 40
C 2	**Konstruktion und Gebäude**		**max. 100**
C 2.1a	Ökoindex des Gesamtgebäudes - BG3	M alternativ a od. b	0 bis 75
C 2.1b	Ökoindex der thermischen Gebäudehülle - BG1		0 bis 50
C 2.2	Entsorgungsindikator EI/EI10		0 bis 50
D	**Komfort und Raumluftqualität**		**max. 175**
D 1	Thermischer Komfort im Sommer	M	15 bis 50
D 2	Komfortlüftung mit Wärmerückgewinnung		60
D 3	Einsatz schadstoff- und emissionsarmer Bauprodukte /Schadstoffuntersuchung		0 bis 60
D 4	Messung der Innenraumluftqualität	M ab 2.000m²	0 bis 40
		GESAMT	**1.000**

Table A-2: ÖGNB Assessment categories and Weighting of the criteria (for Residential buildings, Version 2018) (English Language)

Source: https://www.oegnb.net/de/tqbtest.htm

A	LOCATION AND FACILITIES	200	0
A.1	Infrastructure [click for more information]	50	0
A.2	Location safety and building land quality	50	0
A.3	Facilities quality [click for more information]	50	0
A.4	Accessibility [click for more information]	50	0
B	ECONOMY AND TECHNICAL QUALITY	200	0
B.1	Profitability within the life cycle	100	0
B.2	Construction site management	30	0
B.3	Flexibility and durability	40	0
B.4	Fire protection	30	0
C	ENERGY AND SUPPLY	200	0
C.1	Energy demand	75	0
C.2	Energy generation	75	0
C.3	Water demand and water quality	50	0
D	HEALTH AND COMFORT	200	0
D.1	Thermal comfort	50	0
D.2	Indoor air quality	50	0
D.3	Sound insulation	50	0
D.4	Daylight and sunlight	50	0
E	RESOURCE EFFICIENCY	200	0
E.1	Avoidance of critical material	50	0
E.2	Regionality, recycling share, certified products	50	0
E.3	Eco-efficiency of entire building	60	0
E.4	Disposal	60	0

Table A-3: ÖGNI Bewertungskategorien Und Kriterien Gewichtung (für Neubau Wohngebäude, Version 2017) (German Language)

Source: office@ogni.at

Themenfeld	Kriteriengruppe	Kriterien-nummer	Kriterienbezeichnung	Bedeutungsfaktor	Anteil an der Gesamtbewertung
Ökologische Qualität (ENV)	Wirkungen auf globale und lokale Umwelt (ENV10)	ENV1.1	Ökobilanz - Emissionsbedingte Umweltwirkungen	7	7,9%
		ENV1.2	Risiken für die lokale Umwelt	3	3,4%
		ENV1.3	Umweltverträgliche Materialgewinnung	1	1,1%
	Ressourceninanspruchnahme und Abfallaufkommen (ENV20)	ENV2.1	Ökobilanz - Ressourcenverbrauch	5	5,6%
		ENV2.2	Trinkwasserbedarf und Abwasseraufkommen	2	2,3%
		ENV2.3	Flächeninanspruchnahme	2	2,3%
Ökonomische Qualität (ECO)	Lebenszykluskosten (ECO10)	ECO1.1	Gebäudebezogene Kosten im Lebenszyklus	3	11,3%
	Wertentwicklung (ECO20)	ECO2.1	Flexibilität und Umnutzungsfähigkeit	2	7,5%
		ECO2.2	Marktfähigkeit	1	3,8%
Soziokulturelle und funktionale Qualität (SOC)	Gesundheit, Behaglichkeit und Nutzerzufriedenheit (SOC10)	SOC1.1	Thermischer Komfort	5	5,9%
		SOC1.2	Innenraumluftqualität	3	3,6%
		SOC1.4	Visueller Komfort	3	3,6%
		SOC1.5	Einflussnahme des Nutzers	2	2,4%
		SOC1.6	Aufenthaltsqualitäten Innen/Außen	2	2,4%
		SOC1.7	Sicherheit	1	1,2%
		SOC1.8	Mikroklima	1	1,2%
	Funktionalität (SOC20)	SOC2.1	Barrierefreiheit	2	2,4%
Technische Qualität (TEC)	Qualität der technischen Ausführung (TEC10)	TEC1.2	Schallschutz	2	4,1%
		TEC1.3	Wärme- und feuchteschutztechnische Qualität der Gebäudehülle	2	4,1%
		TEC1.4	Anpassungsfähigkeit der technischen Systeme	2	4,1%
		TEC1.5	Reinigungs- und Instandhaltungsfreundlichkeit des Baukörpers	2	4,1%
		TEC1.6	Rückbau- und Recyclingfreundlichkeit	2	4,1%
	Mobilität (TEC30)	TEC3.1	Mobilitätsinfrastruktur	1	2,0%
Prozessqualität (PRO)	Qualität der Planung (PRO10)	PRO1.1	Projektvorbereitung und Planung	3	1,4%
		PRO1.3	Konzeptionierung und Optimierung in der Planung	3	1,4%
		PRO1.4	Sicherung der Nachhaltigkeitsaspekte in Ausschreibung und Vergabe	2	1,0%
		PRO1.5	Voraussetzungen für eine optimale Nutzung und Bewirtschaftung	2	1,0%
		PRO1.6	Verfahren zur städtebaulichen und gestalterischen Konzeption	3	1,4%
	Qualität der Bauausführung (PRO20)	PRO2.1	Baustelle / Bauprozess	2	1,0%
		PRO2.2	Qualitätssicherung der Bauausführung	3	1,4%
		PRO2.3	Geordnete Inbetriebnahme	3	1,4%
Standortqualität (SITE)	Standortqualität (SITE10)	SITE1.1	Mikrostandort	2	0,0%
		SITE1.2	Image und Zustand von Standort und Quartier	2	0,0%
		SITE1.3	Verkehrsanbindung	3	0,0%
		SITE1.4	Nähe zu nutzungsrelevanten Objekten und Einrichtungen	2	0,0%

Table A-3: ÖGNI Bewertungskategorien Und Kriterien Gewichtung (für Neubau Büro- und Verwaltungsgebäude, Version 2017) (German Language)

Source: office@ogni.at

Themenfeld	Kriteriengruppe	Kriterien-nummer	Kriterienbezeichnung	Bedeutungsfaktor	Anteil an der Gesamtbewertung
Ökologische Qualität (ENV)	Wirkungen auf globale und lokale Umwelt (ENV10)	ENV1.1	Ökobilanz - Emissionsbedingte Umweltwirkungen	7	7,9%
		ENV1.2	Risiken für die lokale Umwelt	3	3,4%
		ENV1.3	Umweltverträgliche Materialgewinnung	1	1,1%
	Ressourceninanspruchnahme und Abfallaufkommen (ENV20)	ENV2.1	Ökobilanz - Ressourcenverbrauch	5	5,6%
		ENV2.2	Trinkwasserbedarf und Abwasseraufkommen	2	2,3%
		ENV2.3	Flächeninanspruchnahme	2	2,3%
Ökonomische Qualität (ECO)	Lebenszykluskosten (ECO10)	ECO1.1	Gebäudebezogene Kosten im Lebenszyklus	3	9,6%
	Wertentwicklung (ECO20)	ECO2.1	Flexibilität und Umnutzungsfähigkeit	3	9,6%
		ECO2.2	Marktfähigkeit	1	3,2%
Soziokulturelle und funktionale Qualität (SOC)	Gesundheit, Behaglichkeit und Nutzerzufriedenheit (SOC10)	SOC1.1	Thermischer Komfort	5	5,1%
		SOC1.2	Innenraumluftqualität	3	3,1%
		SOC1.3	Akustischer Komfort	1	1,0%
		SOC1.4	Visueller Komfort	3	3,1%
		SOC1.5	Einflussnahme des Nutzers	2	2,0%
		SOC1.6	Aufenthaltsqualitäten Innen/Außen	2	2,0%
		SOC1.7	Sicherheit	1	1,0%
		SOC1.8	Mikroklima	1	1,0%
	Funktionalität (SOC20)	SOC2.1	Barrierefreiheit	3	3,1%
		SOC2.2	Nutzungsangebote an die Öffentlichkeit	1	1,0%
Technische Qualität (TEC)	Qualität der technischen Ausführung (TEC10)	TEC1.2	Schallschutz	2	4,1%
		TEC1.3	Wärme- und feuchteschutztechnische Qualität der Gebäudehülle	2	4,1%
		TEC1.4	Anpassungsfähigkeit der technischen Systeme	2	4,1%
		TEC1.5	Reinigungs- und Instandhaltungsfreundlichkeit des Baukörpers	2	4,1%
		TEC1.6	Rückbau- und Recyclingfreundlichkeit	2	4,1%
	Mobilität (TEC30)	TEC3.1	Mobilitätsinfrastruktur	1	2,0%
Prozessqualität (PRO)	Qualität der Planung (PRO10)	PRO1.1	Projektvorbereitung und Planung	3	1,4%
		PRO1.3	Konzeptionierung und Optimierung in der Planung	3	1,4%
		PRO1.4	Sicherung der Nachhaltigkeitsaspekte in Ausschreibung und Vergabe	2	1,0%
		PRO1.5	Voraussetzungen für eine optimale Nutzung und Bewirtschaftung	2	1,0%
		PRO1.6	Verfahren zur städtebaulichen und gestalterischen Konzeption	3	1,4%
	Qualität der Bauausführung (PRO20)	PRO2.1	Baustelle / Bauprozess	2	1,0%
		PRO2.2	Qualitätssicherung der Bauausführung	3	1,4%
		PRO2.3	Geordnete Inbetriebnahme	3	1,4%
Standortqualität (SITE)	Standortqualität (SITE10)	SITE1.1	Mikrostandort	2	0,0%
		SITE1.2	Image und Zustand von Standort und Quartier	2	0,0%
		SITE1.3	Verkehrsanbindung	3	0,0%
		SITE1.4	Nähe zu nutzungsrelevanten Objekten und Einrichtungen	2	0,0%

Table A- 4: BREEAM Assessment Categories and Weighting of the Criteria

(BREEAM UK New Construction (Non- domestic Buildings), Version2018) (English Language)

Issue ID	Criteria applicability to Simple Buildings			Credits available	Exemplary credits available
	No change	Simplified	N/A		
Management					
Man 01		✓		2	2
Man 02		✓		1	0
Man 03		✓		4	2
Man 04		✓		2	0
Man 05	✓			3	0
Health and Wellbeing					
Hea 01	✓			(3 to 5) building type dependent	1
Hea 02		✓		(2 to 3) building type dependent	2
Hea 04	✓			3	0
Hea 05	✓			(up to 4) building type dependent	N/A
Hea 06	✓			1	1
Hea 07	✓			2	0
Energy					
Ene 01	✓			9	7
Ene 02	✓			(1 to 2) building type dependent	0
Ene 03	✓			1	0
Ene 04	✓			3	0
Ene 05			✓	N/A	N/A
Ene 06	✓			2	0
Ene 07			✓	N/A	N/A
Ene 08	✓			2	0
Transport					
Tra 01	✓				0
Tra 02	✓				0
Water					
Wat 01	✓			5	1
Wat 02		✓		1	0
Wat 03		✓		2	0
Wat 04			✓	N/A	N/A
Materials					
Mat 01	✓			(Up to 7) building type dependent	3
Mat 02	✓			1	0
Mat 03	✓			4	1
Mat 05	✓			1	0
Mat 06	✓			1	0
Waste					
Wst 01		✓		5	1
Wst 02	✓			1	1

Issue ID	Criteria applicability to Simple Buildings			Credits available	Exemplary credits available
	No change	Simplified	N/A		
Wst 03	✓			1	0
Wst 04	✓			1 (offices only)	0
Wst 05	✓			1	1
Wst 06	✓			2	0
Land Use and Ecology					
LE01	✓			2	0
LE02	✓			Up to 2	1
LE03	✓			Up to 3	0
LE04	✓			Up to 4	1
LE05	✓			Up to 2	0
Pollution					
Pol01			✓	N/A	N/A
Pol02	✓			Up to 2	0
Pol03		✓		5	1
Pol04	✓			1	0
Pol05			✓	N/A	N/A

Table A- 5: LEED Assessment categories and Weighting of the criteria (Rating system LEED for New Construction and Major Renovation, Version 4) (English Language)

Source: https://www.usgbc.org/resources/leed-v4-building-design-and-construction-checklist

LEED v4 for BD+C: New Construction and Major Renovation
Project Checklist

Project Name:
Date:

Y	?	N			
			Credit	Integrative Process	1
0	0	0		**Location and Transportation**	**16**
			Credit	LEED for Neighborhood Development Location	16
			Credit	Sensitive Land Protection	1
			Credit	High Priority Site	2
			Credit	Surrounding Density and Diverse Uses	5
			Credit	Access to Quality Transit	5
			Credit	Bicycle Facilities	1
			Credit	Reduced Parking Footprint	1
			Credit	Green Vehicles	1
0	0	0		**Sustainable Sites**	**10**
Y			Prereq	Construction Activity Pollution Prevention	Required
			Credit	Site Assessment	1
			Credit	Site Development - Protect or Restore Habitat	2
			Credit	Open Space	1
			Credit	Rainwater Management	3
			Credit	Heat Island Reduction	2
			Credit	Light Pollution Reduction	1
0	0	0		**Water Efficiency**	**11**
Y			Prereq	Outdoor Water Use Reduction	Required
Y			Prereq	Indoor Water Use Reduction	Required
Y			Prereq	Building-Level Water Metering	Required
			Credit	Outdoor Water Use Reduction	2
			Credit	Indoor Water Use Reduction	6
			Credit	Cooling Tower Water Use	2
			Credit	Water Metering	1
0	0	0		**Energy and Atmosphere**	**33**
Y			Prereq	Fundamental Commissioning and Verification	Required
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Building-Level Energy Metering	Required
Y			Prereq	Fundamental Refrigerant Management	Required
			Credit	Enhanced Commissioning	6
			Credit	Optimize Energy Performance	18
			Credit	Advanced Energy Metering	1
			Credit	Demand Response	2
			Credit	Renewable Energy Production	3
			Credit	Enhanced Refrigerant Management	1
			Credit	Green Power and Carbon Offsets	2
0	0	0		**Materials and Resources**	**13**
Y			Prereq	Storage and Collection of Recyclables	Required
Y			Prereq	Construction and Demolition Waste Management Planning	Required
			Credit	Building Life-Cycle Impact Reduction	5
			Credit	Building Product Disclosure and Optimization - Environmental Product Declarations	2
			Credit	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2
			Credit	Building Product Disclosure and Optimization - Material Ingredients	2
			Credit	Construction and Demolition Waste Management	2
0	0	0		**Indoor Environmental Quality**	**16**
Y			Prereq	Minimum Indoor Air Quality Performance	Required
Y			Prereq	Environmental Tobacco Smoke Control	Required
			Credit	Enhanced Indoor Air Quality Strategies	2
			Credit	Low-Emitting Materials	3
			Credit	Construction Indoor Air Quality Management Plan	1
			Credit	Indoor Air Quality Assessment	2
			Credit	Thermal Comfort	1
			Credit	Interior Lighting	2
			Credit	Daylight	3
			Credit	Quality Views	1
			Credit	Acoustic Performance	1
0	0	0		**Innovation**	**6**
			Credit	Innovation	5
			Credit	LEED Accredited Professional	1
0	0	0		**Regional Priority**	**4**
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
0	0	0		**TOTALS**	**Possible Points: 110**

Certified: 40 to 49 points, **Silver**: 50 to 59 points, **Gold**: 60 to 79 points, **Platinum**: 80 to 110

Table A- 6: DGNB Assessment categories and Weighting of the criteria

(DGNB System- New buildings criteria set (INTERNATIONAL), Version 2018)

(English Language)

Source: DGNB System brochure, 2018, P. 26 and P.27.

TOPIC	CRITERIA GROUP	CRITERIA NAME
ENVIRONMENTAL QUALITY (ENV)	EFFECTS ON THE GLOBAL AND LOCAL ENVIRONMENT (ENV1)	**ENV1.1** Building life cycle assessment
		ENV1.2 Local environmental impact
		ENV1.3 Sustainable resource extraction
	RESOURCE CONSUMPTION AND WASTE GENERATION (ENV2)	**ENV2.2** Potable water demand and waste water volume
		ENV2.3 Land use
		ENV2.4 Biodiversity at the site
ECONOMIC QUALITY (ECO)	LIFE CYCLE COSTS (ECO1)	**ECO1.1** Life cycle cost
	ECONOMIC DEVELOPMENT (ECO2)	**ECO2.1** Flexibility and adaptability
		ECO2.2 Commercial viability
SOCIOCULTURAL AND FUNCTIONAL QUALITY (SOC)	HEALTH, COMFORT AND USER SATISFACTION (SOC1)	**SOC1.1** Thermal comfort
		SOC1.2 Indoor air quality
		SOC1.3 Acoustic comfort
		SOC1.4 Visual comfort
		SOC1.5 User control
		SOC1.6 Quality of indoor and outdoor spaces
		SOC1.7 Safety and security
	FUNCTIONALITY (SOC2)	**SOC2.1** Design for all
TECHNICAL QUALITY (TEC)	TECHNICAL QUALITY (TEC1)	**TEC1.2** Sound insulation
		TEC1.3 Quality of the building envelope
		TEC1.4 Use and integration of building technology
		TEC1.5 Ease of cleaning building components
		TEC1.6 Ease of recovery and recycling
		TEC1.7 Immissions control
		TEC3.1 Mobility infrastructure

TOPIC	CRITERIA GROUP	CRITERIA NAME
PROCESS QUALITY (PRO)	PLANNING QUALITY (PRO1)	**PRO1.1** Comprehensive project brief
		PRO1.4 Sustainability aspects in tender phase
		PRO1.5 Documentation for sustainable management
		PRO1.6 Urban planning and design procedure
	CONSTRUCTION QUALITY ASSURANCE (PRO2)	**PRO2.1** Construction site/construction process
		PRO2.2 Quality assurance of the construction
		PRO2.3 Systematic commissioning
		PRO2.4 User communication
		PRO2.5 FM-compliant planning
SITE QUALITY (SITE)	SITE QUALITY (SITE1)	**SITE1.1** Local environment
		SITE1.2 Influence on the district
		SITE1.3 Transport access
		SITE1.4 Access to amenities