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Master Thesis

Life cycle assessment as a decision-making tool in the design choices of buildings

La valutazione del ciclo di vita come strumento decisionale nelle scelte progettuali degli edifici

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Abstract

This thesis goes under the topic "Rethink Sustainability Towards a Regenerative Economy". As the goal is to approach and achieve the desired results for the regenerative built environment. It aims to increase building sustainability by investigating the integration of One Click LCA 2015 tool in building design as a decision-making tool. Moreover, to test the ability of Building Information Modelling (BIM) as it can be used to enhance sustainability with positive impacts on the three pillars of sustainability (economic, social, and environmental quality).

The scope of this study is to investigate Life-Cycle Assessment (LCA) and BIM integration and to provide a framework for the employment of LCA as a decision-making tool in the early design phases, built upon a BIM-based LCA tool. This thesis focuses on building industry environmental impact. Furthermore, specifically, it intends to explore how we can assist practitioners in striving for sustainable buildings since the early stages. The thesis presents case studies that applied One Click LCA to test the environmental impact of two buildings in the early stages of the design. The technological aspect of this research is fascinating and creates an excellent opportunity to develop a decision making or evaluation tool which can be used based on the data available. This will enhance the adaptability among the stakeholders, applying LCA as a decision-making tool.

This study was a first attempt to show at the experimental level that LCA could be successfully integrated into the BIM design process as a decision-making tool leading to more sustainable construction. It has been founded that the application of this tool is straightforward and useful and studied how to improve One Click LCA and make it more readable by BIM designs.

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Chapter 1: Introduction

Extreme environmental, economic, and social impacts of climate change are exponentially emerging when compared to the spent mitigation and adaptation efforts. This impact has proven that sustainability, which mostly focuses on limiting the damage, might not be enough. This required experts to adopt new approaches, and the second step was the restorative approach, which still mainly emphasizes repairing the caused damage.

The most recent human behaviour approach towards their surroundings is the regenerative approach, which is built on helping the system to remain healthy, independently preventing the damage. The aim is not just to limit or repair the damage, but to create long-life healthy systems based on a harmonious relationship between humans and nature. Moving humans' behavior towards their surroundings from an ego-centered dominant position over nature to an eco-friendly action towards nature, and finally to SEVA approach "social and economic value-added" to nature.

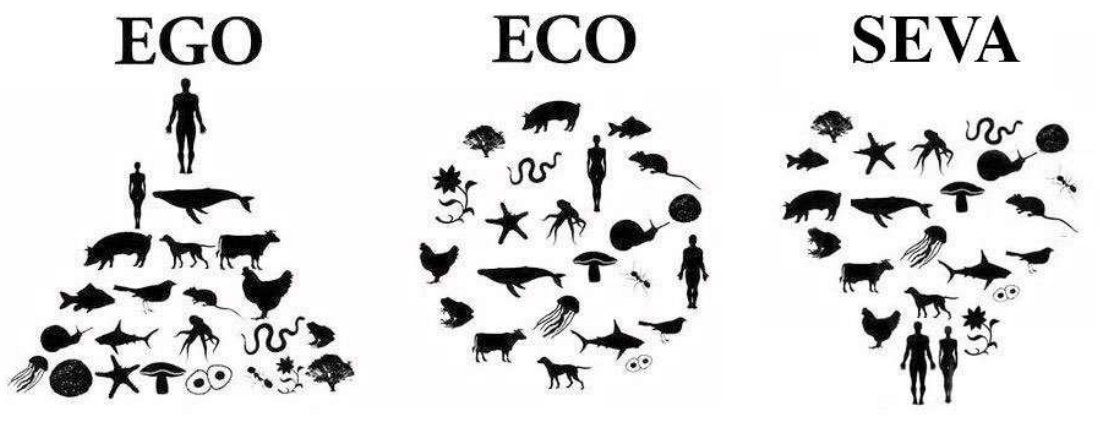

Figure 1: Development of human behavior towards their surroundings over time. Source: (Brown et al., n.d.).

According to the "Roadmap to a Resource Efficient Europe," (RREM, 2011) (European Commission, 2011) better construction and use of buildings could help to make an essential resource savings: it could influence 42% of the final energy consumption and about 35% of the total GHG emissions, 50% of the extracted materials, and it can save up to 30% of water in some regions. Moreover, humans spend over 90% of our time within buildings. This makes the regenerative built environment a massive and very influencer part of any proposed solution.

Introduction

Accomplishing a regenerative built environment requires a set of innovative approaches, new methods, and rethinking the used technologies. By running an extensive literature review on the different tools and methods adopted and experimentally test this LCA tools, this thesis aims to explore sustainability assessment and impacts, both at the local and global levels of the solution sets and related technologies implemented during the entire lifecycle of achieving a restorative/regenerative built environment. A second qualitative step is a comparison between the score of a building as a case study using different building certification methods.

The outcome of daily energy use for a property is called operation emissions, while the result of manufacturing, acquiring, and fixing the materials and components that structure a building is called the embodied emissions. Moreover, it also contains lifetime emissions from reparation, restoration, maintenance, replacement, and eventually, the destruction, demolition, and removal of the building or the material (RICS, 2017).

The construction industry has up to date addressed mostly operational emissions using construction protocols fulfilling specific reduction targets, planning requirements by local government institutes and building sustainability assessment schemes (BREEAM, LEED, etcetera), while barely addressing the embodied emissions. Toward obtaining a holistic understanding of construction projects total carbon effect, it is essential to measure mutually, the project operational and embodied emissions over the whole life of the product.

A whole life carbon method recognizes the total ultimate mutual opportunities aimed at decreasing the lifetime emissions as well as helping to avoid any unintentional costs of directing only operational emissions. For instance, the embodied carbon weight of using triple glazing instead of double-glazing windows could exceed the operational advantage resulting from the added windowpane. Accordingly, in order to have a future with fewer carbon emissions, active integration of whole life carbon must be considered in the sustainability agenda.

The central aim of whole life carbon assessment is the mitigation of carbon influence in the built environment. Improved understanding and constant assessment of the whole life carbon emissions of construction projects will empower the comparability of outcomes, benchmarking, and goal setting to accomplish carbon reduction.

1.1 Background and aims

Building Life Cycle Assessment is considered as a comprehensive method to evaluate the sustainability of a building over its life cycle; and has increasing importance in the scientific community (Soust-Verdaguer, Llatas, & García-Martínez, 2017). It provides a holistic framework for environmental assessment considering all phases of a building from the production of raw materials to the manufacture, use, and final disposal/recycling. Whole-building life-cycle assessment (LCA) and the reduction of embodied energy presents an opportunity to integrate optimal sustainability initiatives into the building design process (Schultz, Ku, Gindlesparger, & Doerfler, 2016). However, performing an LCA on whole buildings is an exhaustive task.

Compared to other products, it is more challenging to evaluate buildings environmentally because they are large in scale and involved in materials modeling. Furthermore, building manufacturing processes are less standardized than most consumer products due to the uniqueness of each building. Moreover, the limitation of available data on the environmental impacts of the manufacturing of construction materials or construction and demolition constitutes the analysis even more challenging (Ragheb, n.d.). As a result, in Europe, many LCA assessments are developed for certification purposes only at the end of the design process. However, the design phase offers the best opportunity to influence cost and sustainability impacts considering the whole life cycle stages of a structure (Ding, 2008).

Various studies have emphasized the importance of early informed decision making before and during the design process (Schlueter & Thesseling, 2009) (Azhar, Carlton, Olsen, & Ahmad, 2011). In the early design phases, project planning is more flexible, providing the potential for studying different alternatives, reducing costs, implementing changes, and improving performances. On the other hand, when the project evolves, the chance of making changes is smaller and involves higher costs. Consequently, the early design phase is considered a critical phase in achieving sustainability (Antón & Díaz, 2014).

The emerging building information modeling (BIM) technology is considered to be one way to address the deep-rooted fragmentation problem in the AEC industry, by providing a computer intelligible approach to exchange building information in design between disciplines (Zanni, Soetanto, & Ruikar, n.d.). Through the integration of BIM and LCA, the data required for performing an LCA during the design phase could be obtained directly from the BIM software (Eastman, Teicholz, Sacks, & Liston, 2011). The automatic extraction of the building data directly from the BIM model could support the performance of LCA. Therefore, the results of the assessment could be used for comparing alternatives in the early design phases. In this way, LCA could be rendered as a decision-making tool. Consequently, it can be claimed that BIM has enormous potential for achieving sustainability in the construction industry. Nevertheless, it is currently underused mainly because of the lack of interoperability and standardized guidelines.

The scope of this study is to investigate LCA and BIM integration and to provide a framework for the employment of LCA as a decision-making tool in the early design phases, built upon a BIM-based LCA tool. Towards this purpose, initially, the existing programs that achieve the integration between LCA and BIM must be identified and examined. The investigation should be carried out at both a theoretical and practical level to enable the author to distinguish the tool with the highest potential. Subsequently, founded on the selected tool, a practical methodology should be developed that allows the design team to use LCA as a consequence-based tool. In this way, it should be possible for the designers to highlight the most influential variables in a building's environmental impact and select the most sustainable solution. The framework is intended for application specifically during the early design stages, when the design problem is typically not well defined, the number of design alternatives is excellent, and the potential to reduce environmental impacts higher.

This thesis focuses on building industry environmental impact. Furthermore, specifically, it intends to explore how we can assist practitioners in striving for sustainable buildings since the early stages. This thesis presents case studies that applied One Click LCA to test the environmental impact of two buildings in the early stages of the design.

The objective of this thesis is to reflect on how these tools could become more user-friendly and more diffused among practitioners. Moreover, it will give an insight into how to apply more developments to these tools by including economic and social aspects and how to strengthen the integration of Building Information Modelling (BIM) software and LCA tools.

1.2 Research question

The main research question of this thesis is:

<u>How can we increase building sustainability by integrating LCA in the early design stages?</u>

1.3 Thesis structure

The section presents the overall structure for this thesis as follows:

- **Chapter 1 (Introduction):** This chapter introduces the whole thesis going through the research background and aims, the research question, and the thesis structure.
- **Chapter 2 (Methodology):** This chapter will go through the research methodology, which was used in this thesis. It will discuss the type of conducted research and the criteria used for collecting and filtering data. Moreover, it highlights the tools and materials studied and the rationality for choosing these tools and methods.
- **Chapter 3 (Literature review):** Presents the systematic, intensive literature review that has been done and all the information that is currently available about the topic considering scholarly writings that fulfill the thesis merit selection criteria.
- **Chapter 4 (Case study):** Presents the analyzed case studies going step by step using One Click LCA performing a complete life cycle assessment. Each case study will be discussed in a different section highlighting each step and concluding with the resulting report for each studied building, then the findings and results will be presented and highlighted clearly and objectively.
- **Chapter 5 (Discussion):** The obtained results will be discussed, and an explanation of how the research and its findings help to reach the objectives will be provided.
- **Chapter 6 (Conclusion and Future works):** Finally, the thesis is entirely summarized, providing an active call to action. Possible recommendations for further work are also reflected and shared in this chapter.

Chapter 2: Research Methodology

2.1 Overview

This chapter will go through the research methodology, which was used in this thesis. It will discuss the type of conducted research and the criteria used for collecting and filtering data. Moreover, it highlights the tools and materials studied and the rationality for choosing these tools and methods.

2.2 Overall process

This section discusses the overall process and journey for this research. As there are many strategies, technologies, and methodologies to evaluate the social, environmental, and economic aspects of the technologies in the regenerative built environment. At the first beginning following the research question and the aim of this research, an intensive systematic literature review was carried out to highlight the indicators of building environmental, economic, and social impacts.

By going through this literature review, it was observed that literature focused more on overall schemes for building sustainability assessment more than a list of individual indicators. Among these building sustainability assessment systems, the most frequently occurring in literature as BREEAM and LEED. At the same time, the literature mostly focused on assessing the environmental impact of buildings using LCA assessment methods and tools.

The oriented this research focus on how to reduce the overall impact of buildings by integrating LCA assessment methods in the early stages of design, and this, of course, brought BIM to the seen as being the umbrella for the most used design and visualization tool in the construction industry sector.

The next step was to find integration between BIM and LCA, resulting in a final complete building sustainability assessment covering all three billers of sustainability. These characteristics were present found in One Click LCA plugin, and from here, the research focused on examining in detail One Click LCA. Nevertheless, to examine this tool, this thesis included real-life case studies for newly constructed buildings. Moreover, to get a complete vision, the research compared the methodologies and results of one of the case studies to its result using the BRE Green Guide assessment tool.

The comparison of these assessment tools and the results of the case studies permitted knowledge of the benefits and limitations of the tool in each case generating suggestions and recommendations for the improvement of an assessment tool that integrates whole life building assessment in the early stages of design.

2.2.1 Research approach

This study uses two sample buildings for which the embodied carbon of over 300 available materials and assembly components have been calculated using the Global Warming Potential (GWP) figures from Environmental Product Declarations (EPDs) or Life Cycle Assessments (LCAs). Multiple options for each major element of the building's enclosure, insulation, and primary finishes have been considered, and between one and three EPDs/LCAs were considered for each material selection.

This thesis will answer the research question through:

1/ The first step was conducting an extensive quantitative literature review to understand all the dimensions of the topic and related topics. The literature review also has given a chance to understand and highlight the main guidelines and standers guiding building sustainability assessment. It also made it possible to understand what is needed exactly leading to a selection of a unique tool that integrates BIM and LCA giving a result

2/After deciding a tool to investigate, case studies were provided by Prof. Lilian Martins representing MLM Group, one of the most significant privately-owned engineering, environmental, and building control consultancies in the UK and across the globe.

3/The selection of case studies was based on different criteria; for example, the first case study had a good result summary by the Green Guide rating system. A second case study was selected to examine how will One Click LCA plugin will perform when we have a Revit model.

4/The next step was quantitative research analyzing these cases, highlighting which methods, tools, and indicators are used, producing a final report for each case using One Click LCA.

5/ In the first case, data regarding materials specifications and quantity were inputted manually to One Click LCA. However, materials specifications in the first case study

Material Breakdown were not very detailed and precise to meet very accurate and detailed martial specifications available within One Click LCA database.

Consequently, many assumptions and substitutions were done for the original building's materials.

6/ Average material quantities in typical structures were respected in the absence of specific materials quantities. Referring to the table below for average material quantities in typical structures. These estimations are recommended to use if:

The BIM model includes composite elements that consist of more than one material, with the absence of additional info of specific material quantities in the element, or the in case of availability of construction element, but not a specific quantity of the materials.

Material	**Constituents of the entire structure**	**Share of the material of total structure %**	**Kg of material per m2**	**m3/m2**	**liters/m2**	**m2/l**
Mortar in 130 mm thick brick wall	Brick, mortar	40	X			
Brick and mortar in brick wall	Brick, mortar	89.35% / 10.65%	90.44 / 10.78			
Steel studs in a light wall, 100 mm	studs		1,73			
Steel studs in a light wall, 80 mm	studs		1,44			
Wood studs in a light wall, 100 mm			6,37			
Wood studs in external wall			10,25			
Steel studs in an external wall	studs		8,3			
Roof trusses of wood	per m2 area of a truss (2.2psf)		10,74			
Roof trusses of steel	per m2 area of a truss (1.3 psf)		6,3			
External plastering & plaster net	glassfiber mesh/plasters	1.25% / 98.75	0.14 / 11.71			
Paint per m2 of wall	paint	100%			0,1015	9,85
Wooden windows	wood/glass	27% / 61%	9.5 / 21			
Metal windows	metal / glass	26% / 53%	12.3 / 27.5			
PVC windows	PVC / glass	26% / 58%	8.7 / 18.7			

Table 1: One Click LCA average material quantities in typical structures Source: ("Average material quantities," n.d.).

7/ In many cases One Click LCA database did not include the specific building material the following this preferences order was considered to substitute it:

- The local generic data - Used when products not chosen, or manufacturer has no specific data
- Regional generic data - Used when no suitable local data available or manufacturer has no specific data
- Other generic data - Used when no suitable local data available or manufacturer has no specific data
- Other manufacturers specific data - Used when buying a specific product or no local data available

8/ A qualitative approach using the evaluated results and methods helped in analyzing the efficiency and limitations of One Click LCA in reducing the environmental, economic, and social impact of the construction industry.

2.3 Research limitations

1. The One Click LCA license provided to the student did not contain all the features available in the program, such as the calculation of the score for the BREEAM assessment. Moreover, customer support technical aspects are only accessible for the business license.
2. The BIM software used in the research was Revit, so it was not possible to investigate the interoperability of One Click LCA with other programs such as ArchiCAD, Tekla, and Integrated Environmental Solutions Virtual Environment (IES-VE).
3. The main limitation of this research is the compatibility of building materials specifications with One Click LCA database. This forced many assumptions in terms of materials specifications, which is a very time-consuming process, and it reduces the accuracy of the results.
4. One Click LCA database includes very detailed materials specifications that were not applicable in both studied buildings. The variety of the same material name makes the search in the software very time-consuming. For example, to look for Vynil floor covering, assessors should also consider the word Vinyl with a different spelling. Moreover, as One Click LCA database includes

different countries, martial names assessors should consider the search in different languages.

5. The absence of a detailed Revit model in the first case study and the lake of essential data in the Revit model of the second building.
6. The assessment is performed in an early design stage of both buildings, which forced the absence of essential data for the assessment, for example, energy consumption accurate data.

Chapter 3: Literature review

3.1 Overview

The literature review refers to the collection of scholarly writings on this topic. This will include all peer-reviewed articles, books, dissertations, and conference papers. This chapter presents the information that is currently available about the topic considering scholarly writings that fulfill the thesis merit selection criteria.

The provided guidance and requirements can be merged into carbon assessment software tools and Building Information Modelling software, establishing the frame for carbon scheming systems.

For the collection, this thesis will consider scholarly writings with a minimum of 5 annual citations in order to strengthen research grounds. It is considering more focused and specialized research publications in this topic, e.g., The International Journal of Life Cycle Assessment, the Journal of Sustainability, and the Journal of Cleaner Production. While writings in this field usually considered the other two aspects of sustainability, the environmental and economic aspects.

3.2 Green/sustainable buildings

This section highlights which methods, tools, and indicators are used for conducting a whole building life assessment.

So far, there is not one recognized description or definition of a sustainable building be present. However, several guiding principles and standards have been established to assess (and verify) how buildings achieve specific environmental and ecological standards, for example, BREEAM and LEED (Ellison & Brown, 2011)[1]. This section labels the different definitions that are frequently used in this research field.

(Kibert, 2008)[2] introduced the following description of green buildings: “healthy facilities designed and built in a resource-efficient manner, using ecologically-based principles“ This description mostly focuses on the ecological effect of the construction

[1] Ellison, L., Brown, P., 2011. Sustainability metrics for commercial real estate assets – establishing a common approach. J. Eur. Real Estate Res. 4, 113 – 130. doi:http://dx.doi.org/10.1108/17539261111157299

[2] Kibert, C.J., 2008. Sustainable Construction: Green Building Design and Delivery, 2nd ed. John Wiley & Sons, Inc., Hoboken, New Jersey, Canada, P.8.

and does not include how the building influences and interrelates with its surroundings and its occupants.

(RICS, 2009)[3] describes sustainable buildings as follows: "Sustainable buildings should optimize value for their landlords and inhabitants and the wider public, while minimizing the usage of natural resources and giving low environmental influence, including their influence on biodiversity." This description has a broader limit since it includes end-users perceptions and the construction's interaction with its surroundings. The previous definition is consistent with (Berardi, 2013)[4], who claims that a green building should not just mind the environmental characteristics, but similarly, be "designed and operated to match the suitable fitness for the use with least environmental influence.".

(Cole, 1999)[5] argues for the resulting difference among green and sustainable building assessment: that a green building assessment emphasis the local environmental characteristics, with conventional building, applies as a point of departure, though a sustainable building is evaluated using pre-defined international sustainable (economic, environmental, and social) goals. However, some argue that the sustainability standards are impossible to achieve (Cooper, 1999)[6], (Goodland & Daly, 1996)[7], (Pearce, 2006)[8] and (Williams & Millington, 2004)[9].

Names "green" or "sustainable" are frequently used to indicate that construction is built in harmony with a third-party environmental assessment system, such as that of LEED

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[3] RICS, 2009. Sustainability and commercial property valuation (Valuation Information Paper No. 13, Page 6). Columns Design Ltd, Reading, Great Britain.
[4] Berardi, U., 2013. Clarifying the new interpretations of the concept of sustainable building 8, 72–78. doi:10.1016/j.scs.2013.01.008
[5] Cole, R.J., 1999. Building environmental assessment methods: clarifying intentions. Build. Res. Inf. 27, 230–246. doi:10.1080/096132199369354
[6] Cooper, I., 1999. Which focus for building assessment methods – environmental performance or sustainability. Build. Res. Inf. 27, 321–331. doi: http://dx.doi.org/10.1080/096132199369435
[7] Goodland, R., Daly, H., 1996. Environmental Sustainability: Universal and Non-Negotiable. Ecol. Appl. 6, 1002–1017.
[8] Pearce, D., 2006. Is the construction sector sustainable? Definitions and reflections. Build. Res. Inf. 34, 201–207. doi:10.1080/09613210600589910
[9] Williams, C.C., Millington, A.C., 2004. The diverse and contested meanings of sustainable development. Geogr. J. 170, 99–104. doi:10.1111/j.0016-7398.2004.00111.x

or BREEAM (Zalejska-Jonsson, 2013)[10], and this is the definition which was used in this thesis.

3.2.1 Buildings assessment schemes

With the advent of sustainable material selection and sustainable housing, numerous resources and tools have been created to aid informed decisions (Cole, 2005)[11] (Ding, 2008)[12] (USDOE, 2010)[13]. This section explores what information designers require to make sustainable material selection decisions when formulating decisions regarding the selection of low-cost green building materials and components at the critical stages of the design process, and analyses what support resources exist to enable this. In this section, some of the very few but popular assessment methods and expert tools used are examined in detail.

Figure 2: Popular assessment methods and expert tools by region. Source:(Martins, 2019)[14]

[10] Zalejska-Jonsson, A., 2013. In the business of building green: The value of low-energy residential buildings from customer and developer perspectives (Doctoral Thesis). KTH Royal Institute of Technology, Stockholm.
[11] Cole, Raymond J. "Building Environmental Assessment Methods: Redefining Intentions and Roles." In Building Research and Information, 2005. https://doi.org/10.1080/09613210500219063.
[12] Ding, G. K. C., (2008). Sustainable construction: The role of environmental assessment tools. Journal of Environmental Management. 86 (3), 451-64.
[13] United States Department of Energy, (2010). About the Weatherization Assistance Program. Washington, DC: Author. Available from: http://www.eere.energy. gov/wip/wap.html
[14] Martins, Lilian. "Sustainability and Building Certification Process - PowerPoint Presentation," 2019. (Martins, 2019)(Martins, 2019)(Martins, 2019)(Martins, 2019)

3.2.1.1 BREEAM and LEED

BREEAM (Building Research Establishment's Environmental Assessment Method) was developed in the United Kingdom in 1990 and is the building environmental assessment method with the longest track record (Peter & Somervell, 2004)[15], which was created by the UK government's Building Research Establishment (BRE 1997). BRE justly deserves the credit as the first, most significant (in terms of project numbers) and perhaps the world's most influential green building institute; its BREEAM (BRE Environmental Assessment Method) rating system influenced many other significant green buildings rating systems, including LEED, Green Star, and Green Globes.

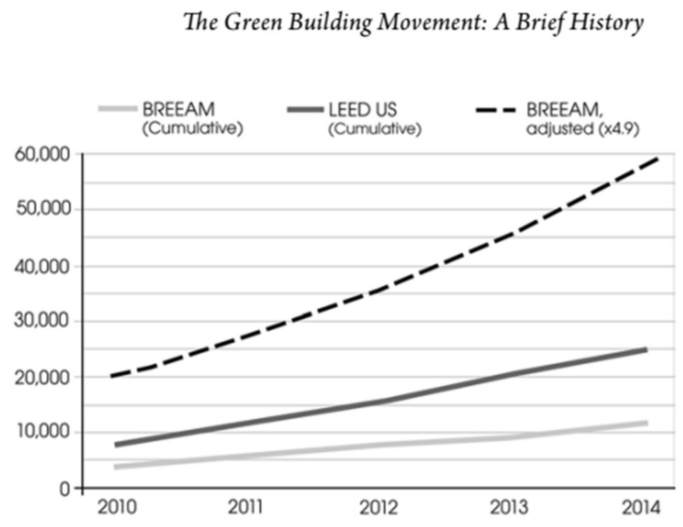

Figure 3: BREEAM VS LEED number of project certifications by 2015 (Yudelson, 2016)[16].

The non-profit US Green Building Council (USGBC) formed in 1993 established LEED (Leadership in Energy and Environmental Design), primarily as a model program in 1998 (LEED 1.0). First LEED Platinum building, certified in 2001 using version 1.0, was the Philip Merrill Environmental Centre in Annapolis, Maryland. The first technical USGBC staff-member came from BRE; he assisted in creating an updated and expanded standard (LEED 2.0), which was launched in June 2001,

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[15] James, Peter, and D. Somervell. April 29, 2004. Assessing the Environmental Performance of Buildings in Higher Education. Summary of a HEEPI workshop, University of Leicester. http://www.heepi.org.uk/documents/Assessing%20the%20environmental%20performance%20of%20Buildings%20in%20HE.doc

[16] Yudelson, J. Reinventing Green Building: Why Certification Systems Aren't Working and What We Can Do about It, 2016. https://books.google.com/books?hl=en&lr=&id=VYi0CwAAQBAJ&oi=fnd&pg=PP1&dq=Reinventing+Green+Building+Jerry+Yudelson&ots=cOG3gNu6cY&sig=gK3uZGL1_PKH31H_1qCvwwSxyvE.

establishing the elementary assessment categories, point totals, and database structure still in use today (Yudelson, 2016). The third major iteration, LEED 2009, will expire by June 2021. The last LEED version 4 (LEEDv4), introduced toward the end of 2013, and become mandatory for all new projects after October 2016. This decision permits projects that were registered before October 2016 under the LEED 2009 system to be certified, if they finish documentation by mid-2021.

In 2001, USGBC started training individuals in the LEED scheme and shaped a professional certification program, the LEED Accredited Professional (LEED AP), to train more people in ho to use the rating system.

Country-oriented rating systems are now found in prevalent use in Germany, France, Singapore, China, India, Japan, Taiwan, Qatar, and the UAE. Nevertheless, BREEAM and LEED continue to dominate, certifying most projects, and having the most critical organizations in the field. Also, more than 100 country-specific green building councils now constitute the World Green Building Council, formed in 2002 (World Green Building Council). Let us look now at how the rating systems work to Understand better the challenges and opportunities they encounter in the marketplace. In this section, two significant systems shall be examined, BREEAM, LEED.

3.2.1.1.1 BREEAM

BREEAM is the world’s top sustainability assessment system for planning projects, infrastructure, and structures. BREEAM identifies and reproduces the value in advanced acting properties across the built environment lifecycle, beginning by new construction toward in-use and restoration[17].

BREEAM systematizes this using the third-party certification of the assessment of sustainability performance of a priority's considering environmental, social and economic impacts, using standards developed by The Building Research Establishment (BRE), which is a center of building science in the United Kingdom. BREEAM certified projects are more sustainable environments that improve the well-being of inhabitants and occupants, making better, more attractive assets investments and help

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[17] “BREEAM: The World’s Leading Sustainability Assessment Method for Masterplanning Projects, Infrastructure and Buildings - BREEAM.” Accessed January 6, 2020. https://www.breeam.com/.

to protect natural resources. Approaching a new construction building strategy comes first, followed by Assessment and certification, which can occur at several stages in the building lifecycle, from design and construction over to operation and refurbishment[18].

BREEAM is the world's leading environmental assessment method and building rating system: between 2010 and 2014, BREEAM certified 425,000 buildings, and two other million had registered for assessment since it initially launched in 1990 ("BREEAM," n.d.). Eight thousand seven hundred of these certified buildings were "nondomestic" (commercial) buildings; 73% were in the UK, and approximately 90% were new construction projects ("BRE Global | BRE Group," n.d.).

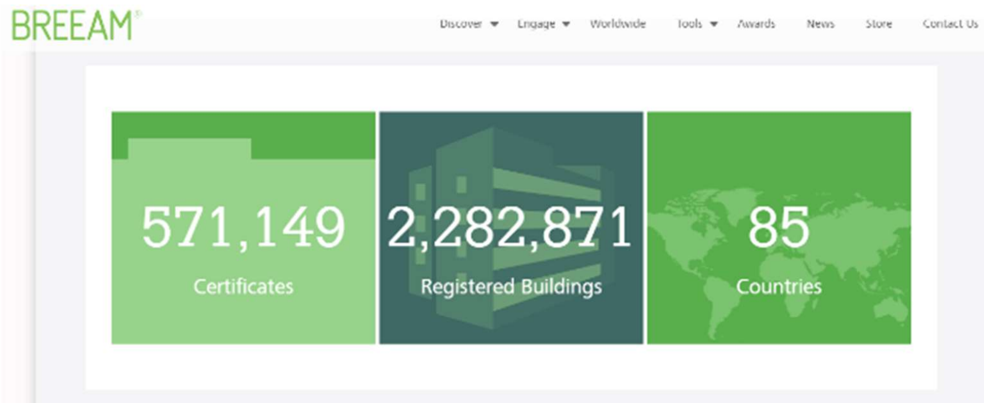


Figure 4: BREEAM statistics. Source: ("BREEAM," n.d.)[19]

BREEAM achieved more success in the UK (in certifying commercial buildings) when compared to LEED in the United States. BREEAM offers a complete and widely recognized method to evaluate a structure's environmental and social performance. BREEAM encourages engineers, designers, and clients to think about lower environmental effect design, minimalizing a building's energy weights before considering further advanced energy efficiency and low-carbon technologies. A BREEAM assessment is carried by an accredited organization, using BRE trained assessors, at several phases in a structure's life cycle. Similar to all other green building rating programs, the assessment is designed to provide building owners, managers, developers, designers, and others with:

[18] ("How BREEAM Certification Works - BREEAM," n.d.)("How BREEAM Certification Works - BREEAM," n.d.)
[19] "BREEAM." Accessed January 7, 2020.
https://www.breeam.com/.

• Market recognition for low environmental impact buildings.

• Assurance that verified environmental practices are combined in the building

• Stimulation to find state-of-the-art solutions that reduce a building's impact

• A standard that is advanced than present building regulation or building codes

• A scheme to support the reduction of operating costs and to improve living and working environments.

• Finally, it provides a standard that demonstrates progress toward corporate and organizational environmental objectives.

3.2.1.1.2 How BREEAM Works

Each of the assessments looks at the following impact groups for a building's construction or processes. BREEAM rewards performance directly above regulation or code that delivers environmental benefits, health benefits, and comfort. Points and credits are categorized into nine categories according to the environmental impact as follows:

• Management: commissioning, site management, and management policies,

• Health and Wellbeing: indoor and external matters (noise, light, air, quality, etcetera)

• Transport: transport associated CO2 and factors related to location

• Energy: operational energy and emissions CO2

• Water: consumption and efficiency

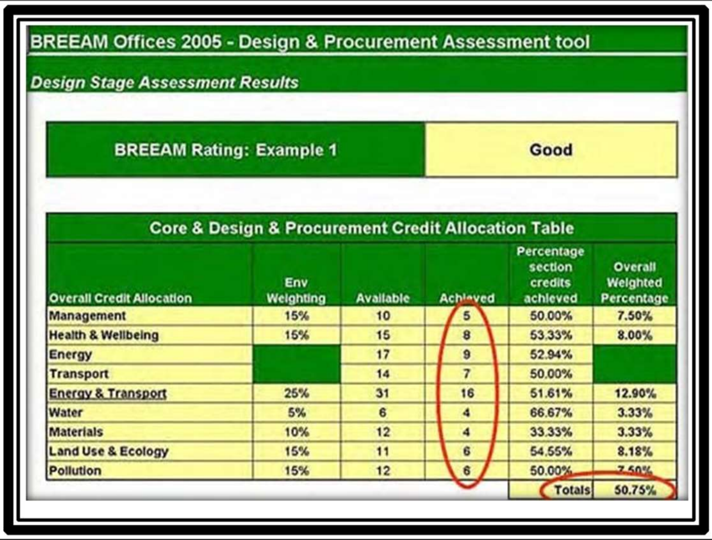
• Materials: embodied impacts of building materials, including lifecycle impacts

• Waste: building resource efficiency and operational waste management

• Pollution: external-air and water-pollution

• Land-Use & Ecology: site type and building footprint; a site's ecological value

The overall building performance is categorized as Unclassified (<30%), Pass (30%), Good (45%), Very Good (55%), Excellent (70%), and Outstanding (85%). **Figure 5** shows sample reporting and certification pages for a BREEAM. The results of the investigation are considered in the design development phase of structures, and changes can be made consequently to satisfy pre-designed criteria (Crawley and Aho, 1999)[20] (Kibert, 2008)[21].



BREEAM Offices 2005 - Design & Procurement Assessment tool

Design Stage Assessment Results

BREEAM Rating: Example 1	Good

Core & Design & Procurement Credit Allocation Table

Overall Credit Allocation	Env Weighting	Available	Achieved	Percentage section credits achieved	Overall Weighted Percentage
Management	15%	10	5	50.00%	7.50%
Health & Wellbeing	15%	15	8	53.33%	8.00%
Energy		17	9	52.94%	
Transport		14	7	50.00%	
Energy & Transport	25%	31	16	51.61%	12.90%
Water	5%	6	4	66.67%	3.33%
Materials	10%	12	4	33.33%	3.33%
Land Use & Ecology	15%	11	6	54.55%	8.18%
Pollution	15%	12	6	50.00%	7.50%
				Totals	50.75%

Figure 5: Sample reporting and certification for BREEAM. Source: (Peter & Somervell, 2004)[22]

Total points or credits which are gained in each section are multiplied by an environmental weighting that considers the section's relative importance. Each section score is then composed together to establish a single overall score. Once this overall score for a building is calculated, it is translated into a rating level. Minimum standards (prerequisites) exist for specific categories, depending on the certification level desired. The BREEAM system comprises specific rating systems to evaluate new construction, building operations, building renovations, communities, and infrastructure.

3.2.1.1.3 LEED

LEED is the second largest green building assessment scheme in the world. By 2015, there were more than 30,000 certified non-residential buildings and more than 50,000 certified residential units. LEED certifications are issued by the USGBC -affiliated

[20] Crawley, D., and Aho, I., (1999). Building environmental assessment methods: application and development trends. In Building Research and Information. 27 (4/5), 300-308
[21] Kibert, C.J. (2008). Sustainable construction: Green Building Design and Delivery. Second edition. New jersey, USA: John Wiley and Sons, Inc., Hoboken.
[22] James, Peter, and D. Somervell. April 29, 2004. Assessing the Environmental Performance of Buildings in Higher Education. Summary of a HEEPI workshop, University of Leicester. http://www.heepi.org.uk/documents/Assessing%20the%20environmental%20performance%20of%20Buildings%20in%20HE.doc

Green Business Certification Inc. (GBCI), created in 2008 (initially as the Green Building Certification Institute) to separate building certification and professional training from rating system development, which remained with US Green Building Council (USGBC). LEED is a performance-based tool for determining the environmental impact of building products and facilities from the whole-building perspective (Kibert, 2008)[23].

3.2.1.1.4 How LEED Works

When a project requests a LEED certification, it first registers that intention with the GBCI, pays a fee, and opens a project account. On various times during the project, project team members upload project data to LEED Online (Introducing the new LEED Online). GBCI offers an end-of- construction documents certification review for new projects and a concluding review for all projects upon completion. When a project-team finish uploading all relevant data, GBCI allocates a review-team to assess the information; once the review is done, GBCI rewards specific points received and certifies the project at a level.

LEED projects are evaluated in seven different categories, mainly reflecting the BREEAM rating system (not surprising since BREEAM heavily influenced LEED's developers). In LEED version 2.0 rating system for new construction and continuing through LEED 2009 (version 3), seven prerequisites must be accomplished for each project to succeed for certification. While in LEEDv4, prerequisites total from 11 to 14, dependent on the rating system used, adding considerable cost for a project to qualify for certification.

Initially, a single system for assessing new-construction, when introduced in 2001 as LEED version 2.0, the LEED rating system family now includes 22 variations, counting in LEEDv4:

• Building Design and Construction (New-Construction and Major Renovations) with eight versions.

• Interior Design and Construction with three versions.

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[23] Kibert, C. J. (2008). Sustainable construction : green building design and delivery / Charles J. Kibert (2nd ed). Hoboken: Hoboken : Wiley.

• Building Operations and Maintenance with six versions.

• LEED Homes with three versions.

• LEED for Neighbourhood Development with two versions.

It is a green building rating system for commercial, institutional and high-rise residential new construction and major renovation in five areas of sustainability: sustainable sites, water efficiency, energy and atmosphere, innovation and design process, materials and resources, and indoor environmental quality (Zhou et al., 2010)[24]. When a GBCI review team rewards all points accomplished, they are summed; finally, the project is certified in one of four levels: Certified, Silver, Gold, and Platinum.

[24] Zhou, P., Ang, B.W., and Zhou, D.Q., (2010). Weighting and Aggregation in Composite Indicator Construction: a Multiplicative Optimization Approach. Social Indicator Research. 96, (1), 169-181.

LEED
LEADERSHIP IN ENERGY & ENVIRONMENTAL DESIGN

SSA Child Care Center, LEED Project # 0265
LEED Version 2.0 Certification Level: CERTIFIED
Feb. 27, 2003

28 Points Achieved — Possible Points: 69

Certified 26 to 32 points | Silver 33 to 38 points | Gold 39 to 51 points | Platinum 52 or more points

6	Sustainable Sites	Possible Points: 14
Y		
Y	Prereq 1 Erosion & Sedimentation Control	
1	Credit 1 Site Selection	1
	Credit 2 Urban Redevelopment	1
	Credit 3 Brownfield Redevelopment	1
1	Credit 4.1 Alternative Transportation, Public Transportation Access	1
	Credit 4.2 Alternative Transportation, Bicycle Storage & Changing Rooms	1
	Credit 4.3 Alternative Transportation, Alternative Fuel Refueling Stations	1
	Credit 4.4 Alternative Transportation, Parking Capacity	1
1	Credit 5.1 Reduced Site Disturbance, Protect or Restore Open Space	1
1	Credit 5.2 Reduced Site Disturbance, Development Footprint	1
1	Credit 6.1 Stormwater Management, Rate and Quantity	1
	Credit 6.2 Stormwater Management, Treatment	1
	Credit 7.1 Landscape & Exterior Design to Reduce Heat Islands, Non-Roof	1
	Credit 7.2 Landscape & Exterior Design to Reduce Heat Islands, Roof	1
1	Credit 8 Light Pollution Reduction	1

2	Water Efficiency	Possible Points: 5
Y		
1	Credit 1.1 Water Efficient Landscaping, Reduce by 50%	1
1	Credit 1.2 Water Efficient Landscaping, No Potable Use or No Irrigation	1
	Credit 2 Innovative Wastewater Technologies	1
	Credit 3.1 Water Use Reduction, 20% Reduction	1
	Credit 3.2 Water Use Reduction, 30% Reduction	1

5	Energy & Atmosphere	Possible Points: 17
Y		
Y	Prereq 1 Fundamental Building Systems Commissioning	
Y	Prereq 2 Minimum Energy Performance	
Y	Prereq 3 CFC Reduction in HVAC&R Equipment	
2	Credit 1.1 Optimize Energy Performance, 20% New / 10% Existing	2
2	Credit 1.2 Optimize Energy Performance, 30% New / 20% Existing	2
1	Credit 1.3 Optimize Energy Performance, 40% New / 30% Existing	2
	Credit 1.4 Optimize Energy Performance, 50% New / 40% Existing	2
	Credit 1.5 Optimize Energy Performance, 60% New / 50% Existing	2
	Credit 2.1 Renewable Energy, 5%	1
	Credit 2.2 Renewable Energy, 10%	1
	Credit 2.3 Renewable Energy, 20%	1
	Credit 3 Additional Commissioning	1
	Credit 4 Ozone Depletion	1
	Credit 5 Measurement & Verification	1
	Credit 6 Green Power	1

6	Materials & Resources	Possible Points: 13
Y		
Y	Prereq 1 Storage & Collection of Recyclables	
	Credit 1.1 Building Reuse, Maintain 75% of Existing Shell	1
	Credit 1.2 Building Reuse, Maintain 100% of Existing Shell	1
	Credit 1.3 Building Reuse, Maintain 100% Shell & 50% Non-Shell	1
1	Credit 2.1 Construction Waste Management, Divert 50%	1
1	Credit 2.2 Construction Waste Management, Divert 75%	1
	Credit 3.1 Resource Reuse, Specify 5%	1
	Credit 3.2 Resource Reuse, Specify 10%	1
1	Credit 4.1 Recycled Content, Specify 25%	1
1	Credit 4.2 Recycled Content, Specify 50%	1
1	Credit 5.1 Local/Regional Materials, 20% Manufactured Locally	1
1	Credit 5.2 Local/Regional Materials, of 20% Above, 50% Harvested Locally	1
	Credit 6 Rapidly Renewable Materials	1
	Credit 7 Certified Wood	1

7	Indoor Environmental Quality	Possible Points: 15
Y		
Y	Prereq 1 Minimum IAQ Performance	
Y	Prereq 2 Environmental Tobacco Smoke (ETS) Control	
	Credit 1 Carbon Dioxide (CO_2) Monitoring	1
	Credit 2 Increase Ventilation Effectiveness	1
	Credit 3.1 Construction IAQ Management Plan, During Construction	1
1	Credit 3.2 Construction IAQ Management Plan, Before Occupancy	1
1	Credit 4.1 Low-Emitting Materials, Adhesives & Sealants	1
	Credit 4.2 Low-Emitting Materials, Paints	1
1	Credit 4.3 Low-Emitting Materials, Carpet	1
	Credit 4.4 Low-Emitting Materials, Composite Wood	1
1	Credit 5 Indoor Chemical & Pollutant Source Control	1
	Credit 6.1 Controllability of Systems, Perimeter	1
	Credit 6.2 Controllability of Systems, Non-Perimeter	1
1	Credit 7.1 Thermal Comfort, Comply with ASHRAE 55-1992	1
1	Credit 7.2 Thermal Comfort, Permanent Monitoring System	1
	Credit 8.1 Daylight & Views, Daylight 75% of Spaces	1
1	Credit 8.2 Daylight & Views, Views for 90% of Spaces	1

2	Innovation & Design Process	Possible Points: 5
Y		
1	Credit 1.1 Innovation in Design: Exemplary Performance 38% Local Materials	1
	Credit 1.2 Innovation in Design:	1
	Credit 1.3 Innovation in Design:	1
	Credit 1.4 Innovation in Design:	1
1	Credit 2 LEED™ Accredited Professional	1

Figure 6: An example of LEED® Version 2.0 documentation found on-line. Source: (USDOE, 2006).[25]

3.2.1.2 GREEN-STAR

Green Star is the most followed voluntary building environmental assessment scheme developed in Australia to accommodate the need for buildings in hot climates where cooling systems and solar shading are of significant importance(Cole, 1999)[26]. It is similar to BREEAM in that it evaluates the environmental merits of building products using the credit rating system based on several points allocated to the credits in order to determine the total scoring and hence the level of certification (Crawley & Aho,

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[25] U.S. Green Building Council (USGBC). 2006. U.S. Green Building Council. http://www.usgbc.org/

[26] Cole, Raymond J. "Building Environmental Assessment Methods: Clarifying Intentions." Building Research and Information, 1999. https://doi.org/10.1080/096132199369354.

1999)[27] (Kibert, 2008)[28]. It has a set of environmental criteria related to management, indoor environmental quality, energy, transport, water, materials, land use & ecology, emissions, and innovation. The building certification is expressed as the number of stars: 1-3 Stars (10-44 points; not eligible for formal certification), 4 Stars (45-59 points; Best Practice), 5 Stars (60-74 points; Australian Excellence) and 6 Stars (_75 points; World Leadership).

The disadvantage of this tool is that its use is limited to the evaluation of lettable areas within office buildings, hence excludes areas that are not offices or supporting the office. Moreover, the assessment structure is delineated in Australian standards and perhaps may not apply to other regions with different socio-technical background-given the differing views on impact assessment. **Figure 7** below is a screenshot from the actual assessment tool.

[27] Crawley, D., and Aho, I., (1999). Building environmental assessment methods: application and development trends. In Building Research and Information. 27 (4/5), 300-308.
[28] Kibert, Charles J. Sustainable Construction : Green Building Design and Delivery / Charles J. Kibert. 2nd ed. Hoboken: Hoboken : Wiley, 2008.

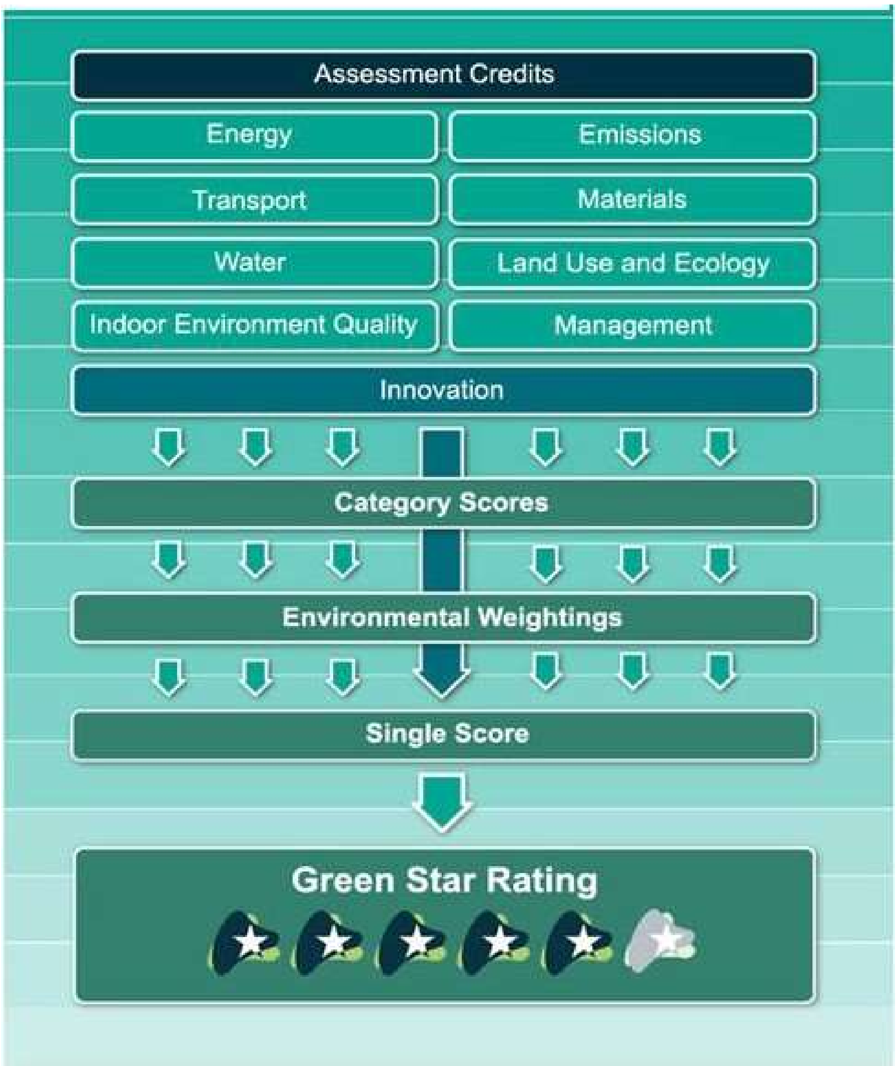

Figure 7: A Screenshot from GREEN-STAR actual assessment tool.

3.2.1.3 ATHENA

It is an LCA tool developed at the ATHENA Sustainable Materials Institute in Ontario, Canada (John, Clements-Croome, & Jeronimidis, 2005)[29]. This scheme ultimately aims to encourage the selection of material mixes of over 1200 building materials and assembly combinations(Carmody & Trusty, 2005)[30]. ATHENA impact estimator for buildings is the only software tool that evaluates whole buildings and combinations based on globally recognized life cycle assessment (LCA) methodology. The model

[29] John, Godfaurd, Derek Clements-Croome, and George Jeronimidis. "Sustainable Building Solutions: A Review of Lessons from the Natural World." Building and Environment, 2005. https://doi.org/10.1016/j.buildenv.2004.05.011.
[30] Carmody, John, and Wayne Trusty. "Life Cycle Assessment Tools." Informedesign Implications, 2005.

breaks down the selected assemblies comprising a design into their respective products to apply the model's life cycle inventory (LCI) databases that contain estimates of the environmental effects per unit of each building product (**Figure 8**).

A restriction of this tool is that it only allows the evaluation of assembly options, given that they also come with fixed dimensions (Joshi, 2010)[31]. Other significant drawbacks to this tool are the cost and required skills to use it and the limited options of designing high-performance assemblies.

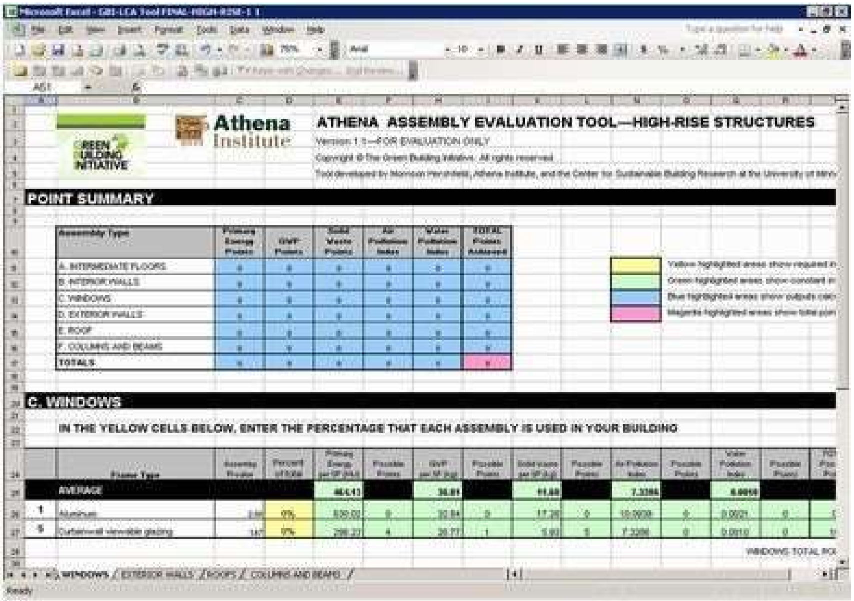

Figure 8: Sample of ATHENA reporting documentation[32]

3.2.1.4 GBTool

The International Framework Committee for the Green Building Challenge in Canada developed the GBTool in 1998 (Todd, Crawley, Geissler, & Lindsey, 2001)[33]. It is

[31] Joshi, Surabhi. "AIA Guide to Building Life Cycle Assessment in Practice Authorship and Acknowledgements A Guide to Life Cycle Assessment of Buildings 2," 2010.
[32] Adapted from HK Buildings Department, 2005.
[33] Todd, J. A., D. Crawley, S. Geissler, and G. Lindsey. "Comparative Assessment of Environmental Performance Tools and the Role of the Green Building Challenge." Building Research and Information 29, no. 5 (September 2001): 324–35. https://doi.org/10.1080/09613210110064268.

designed to reflect regional conditions and context (Crawley and Aho, 1999)[34] (Kibert, 2008)[35]. It includes criteria in categories such as Environmental Loadings, Site Selection, Project Planning, and Development, Energy and Resource Consumption, Indoor Environmental Quality, Functionality, Long-Term Performance, and Social and Economic Aspects. Criteria are assessed using scales that are based on local benchmarks of "typical" practice; buildings can score -1 if below typical practice or from +1 to +5, representing good to very high performance. The tool itself comprises two spreadsheets, one for data entry (to be completed by the project team) and one for establishing weights and benchmarks and completing the assessment (to be completed by third party sponsors or assessors).

However, since GBTool is not integrated with the life-cycle process of a project, it is difficult for the construction professionals to use the assessment indicators at the planning, design, and construction stages of the building process since it is limited to use in post-construction assessment. (**Figure 9** shows an example of CASBEE

[34] Crawley, Drury, and Ilari Aho. "Building Environmental Assessment Methods: Applications and Development Trends." Building Research and Information, 1999. https://doi.org/10.1080/096132199369417.

[35] Kibert, Charles J. Sustainable Construction : Green Building Design and Delivery / Charles J. Kibert. 2nd ed. Hoboken: Hoboken : Wiley, 2008.

reporting documentation).

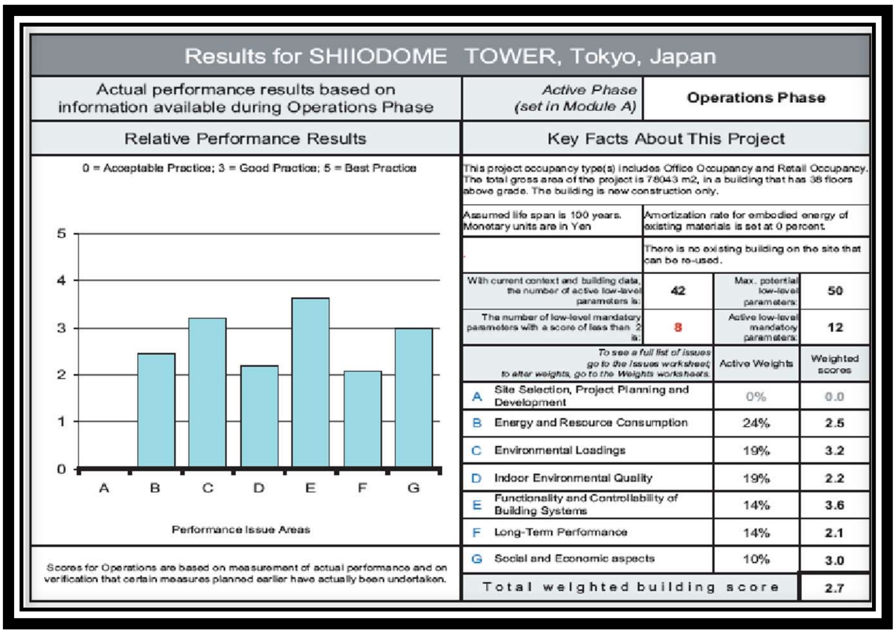

Figure 9: Sample reporting and certification for GBTool. Source: (Todd et al., 2001)

3.2.1.5 EPM

Environmental Preference Method (EPM) was developed by Wood /Energy in the Netherlands in 1991, within the program on Sustainable living at the Dutch Steering Committee on Experiments in Housing (Anderson, J. & Shiers D & Steele K BRE P, Shiers, n.d.)[36]. The primary aim of this model is to construct a ranking of building materials according to their environmental impacts by positively labeling or blacklisting a product using the matrices approach (Anderson, J. & Shiers D & Steele K BRE P, Shiers, n.d.)The principle of this method takes into account different factors, such as various damages of ecosystem, consumption/exhaustion of resources, energy consumption (in all phases of production, including transport), environmental pollution with different waste and hazardous materials, waste disposal problems, hazardous emissions into the atmosphere, global warming, impact on human beings, re-use and recycling possibilities, etcetera.

[36] Anderson, J. & Shiers D & Steele K BRE P, Shiers, David. “The Green Guide to Specification Book.” Accessed January 27, 2020. https://www.architecture.com/riba-books/books/sustainability/product/the-green-guide-to-specification.html.

The result is a list of excellent materials and products made based on the evaluation of the environmental impacts of each of them and adjusted to regular positions within a building (Anink, D., Boonstra, C. and Mak, n.d.)[37]. The matrices in EPM are, however, not published, and no detailed description is given of how a specific product is assessed. This model includes environmental aspects, but the second and third elements of sustainable materials (social and economic considerations) are not included, as shown in **Figure 10.**

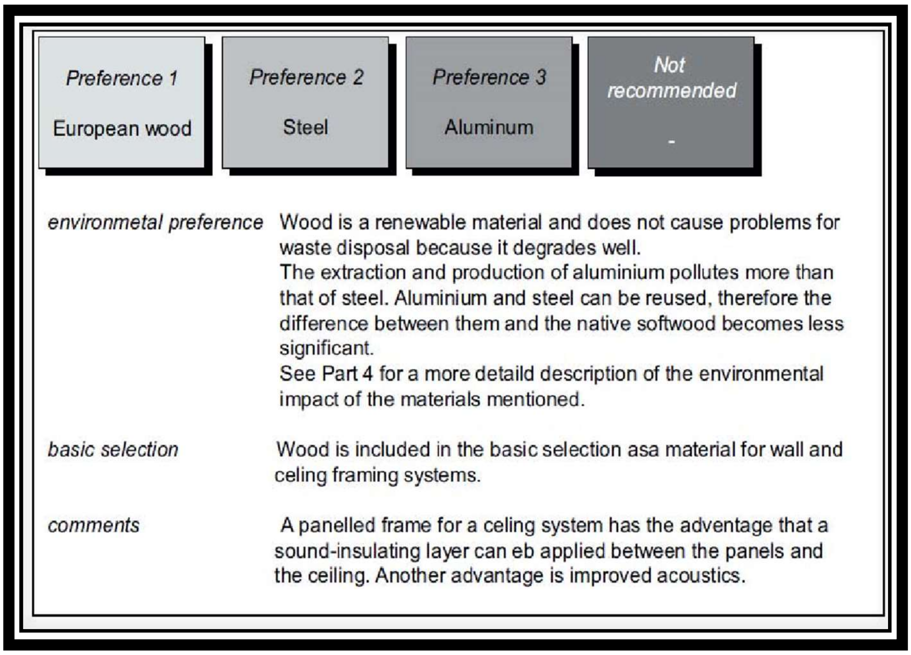

Figure 10: Relative ranking of wall and ceiling frame systems in the EPM method Source: (Link, et al., 2008).

3.2.1.6 Building for Environmental and Economic Sustainability (BEES)

It is a method for choosing environmentally preferable building materials (Lippiatt & Ahmad, n.d.)[38]. The BEES environmental performance assessment is based on the LCA standards, including categorizing in impact categories, normalizing by dividing by the

[37] Anink, D., Boonstra, C. and Mak, J. (1996). Handbook of Sustainable Building: An Environmental Performance Method for Selection of Materials for Use in Construction and Refurbishmment. London: James and James Publishers

[38] Lippiatt, Barbara C, and Shuaib Ahmad. "MEASURING THE LIFE-CYCLE ENVIRONMENTAL AND ECONOMIC PERFORMANCE OF CONCRETE: THE BEES APPROACH," n.d.

U.S. emission per year per capita and weighing by relative importance. The overall evaluation involves the environmental score and the economic score being weighted together to accomplish the most suitable balance between environmental and economic performances using relative importance decided by the decision maker's values. BEES Online, aimed at designers, builders, and product manufacturers, includes actual environmental and economic performance data for 230 building products (see the model in **Figure 11**.

The BEES system, however, is not capable of providing data for a full LCA of a complete building, as it only produces data for a limited amount of building products (Gloria, Lippiatt, & Cooper, 2007)[39] (Joshi, 2010)[40]. From those products, it only considers materials that are significant in weight, energy, or cost. It categorizes a minimal set of impact categories, hence limits the flexibility, accuracy, and performance of any building product in terms of maximizing its full potentials.

BEES 4.0

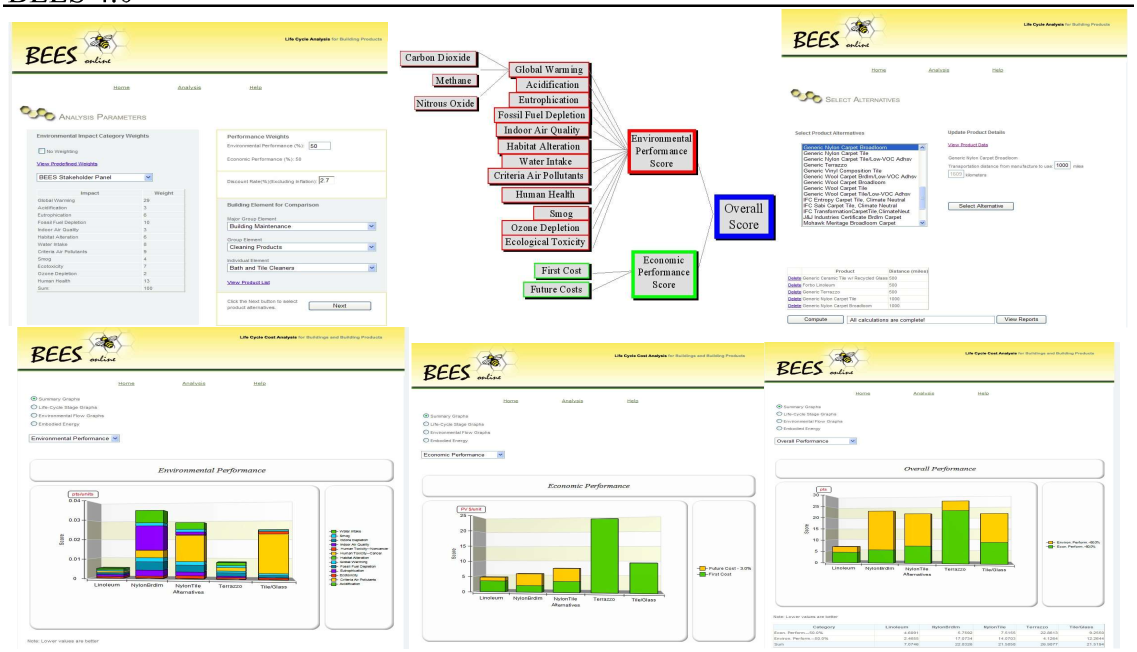

Figure 11: Sample of BEES model. Source: (NIST, 2011)[41].

[39] Gloria, Thomas P., Barbara C. Lippiatt, and Jennifer Cooper. "Life Cycle Impact Assessment Weights to Support Environmentally Preferable Purchasing in the United States." Environmental Science and Technology 41, no. 21 (2007): 7551–57. https://doi.org/10.1021/es070750+.
[40] Joshi, Surabhi. "AIA Guide to Building Life Cycle Assessment in Practice Authorship and Acknowledgements A Guide to Life Cycle Assessment of Buildings 2," 2010.
[41] The National Institute of Standards and Technology, 2011

3.2.1.7 CASBEE

Comprehensive Assessment System for Building Environmental Efficiency was developed in Japan, beginning in 2001. This family of assessment tools is based on the building's life cycle: pre-design, new construction, existing buildings, and renovation. It is a relatively new system developed for the Japanese market that is available in English but has not been tested in the U.S.

Results are plotted on a graph, with an environmental effect on one axis and benefit on the other axis – the best buildings will go under the section representing the lowest effect and the highest benefit. Each measure is scored from level 1 to level 5, with level 1 defined as meeting the least requirements, level 3 defined as meeting typical technical and social levels at the time of the assessment, and level 5 representing the highest level of achievement as shown in **Figure 12**.

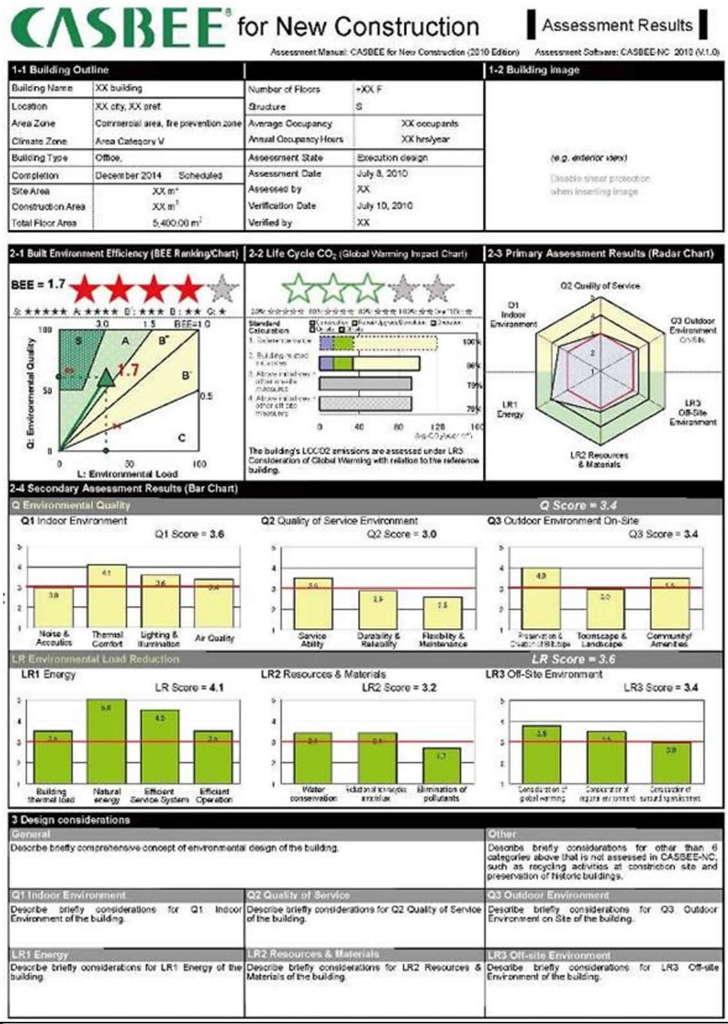

Figure 12: Sample of CASBEE reporting assessment result and documentation sheet[42].

This system, unfortunately, requires documentation of quantifiable sustainable design achievements, which are assessed by only trained, first-class architects, only those who passed the CASBEE assessors' examination.

3.2.1.8 CEPAS

The Comprehensive Environmental Performance Assessment Scheme (CEPAS) is a holistic assessment tool for several building types with clear differentiation of the entire building life cycle that covers the pre-design, design, construction, demolition, and operation stages. It employs an additive/weighting approach, which introduces and organizes performance criteria that make a clear distinction between "human" and "physical" performance issues as well as "building" and their "surroundings (Crawley

[42] Adopted from HK Buildings Department, 2005.

& Aho, 1999). This manifests as eight performance categories: Resource Use, Loadings, Site Impacts, Neighbourhood Impacts, Indoor Environmental Quality, Building Amenities, Site Amenities, and Neighbourhood Amenities (Cole, 1999). However, for the CEPAS assessment model, only single-ownership buildings are eligible for assessment. **Figure 13** shows an example of CEPAS Version

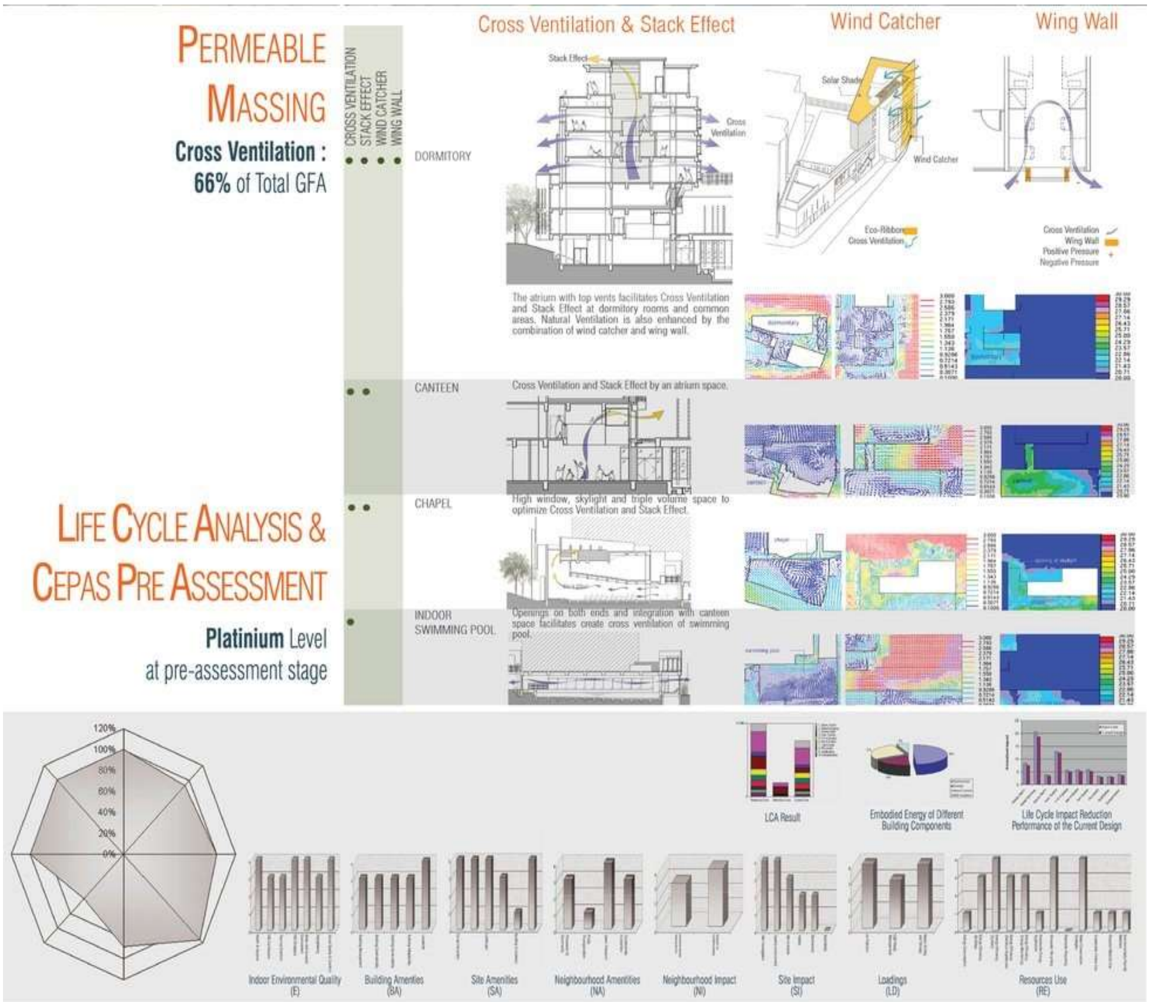

Figure 13: Sample of CEPAS reporting documentation[43].

3.2.1.9 SBAT

The Sustainable Building Assessment Tool (SBAT) was created in South Africa by the CSIR (Council of Scientific and Industrial Research) in 2001 (Gibbered, 2002)[44].

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[43] Adopted from Cole, 1999

[44] Gibberd, J., (2001). The Sustainable Building Assessment Tool – Assessing how buildings can support sustainability in Developing Countries. Continental Shift 2001- IFI International Conference, 11 – 14 September 2001, Johannesburg.

SBAT indicates the performance of a building or the design of a building in terms of sustainability and explicitly introduces performance criteria that acknowledge social and economic issues (Gibbered, 2003)[45]. A total of 15 performance areas are identified – equally divided within the overarching sustainability framework of environmental, social, and economical, as shown in **Figure 14**. These performance areas are each described through 5 performance criteria in three steps, namely: 1) Setting the Project Up, 2) Entering Measurements, and 3) Reading the Report. It also considers a nine-stage process based on the typical life cycle of a building: briefing, site analysis, target setting, design, design development, construction, handover, operation, reuse/recycle, is explicitly defined in this context.

The current tool, however, mainly assesses building performance with little recourse to material indicators. Since the tool is based on the overall performance of the building, any differences in the materials used do not affect the decisions with the result that the scheme is almost entirely unable to differentiate between choices of materials except for indirect consequences.

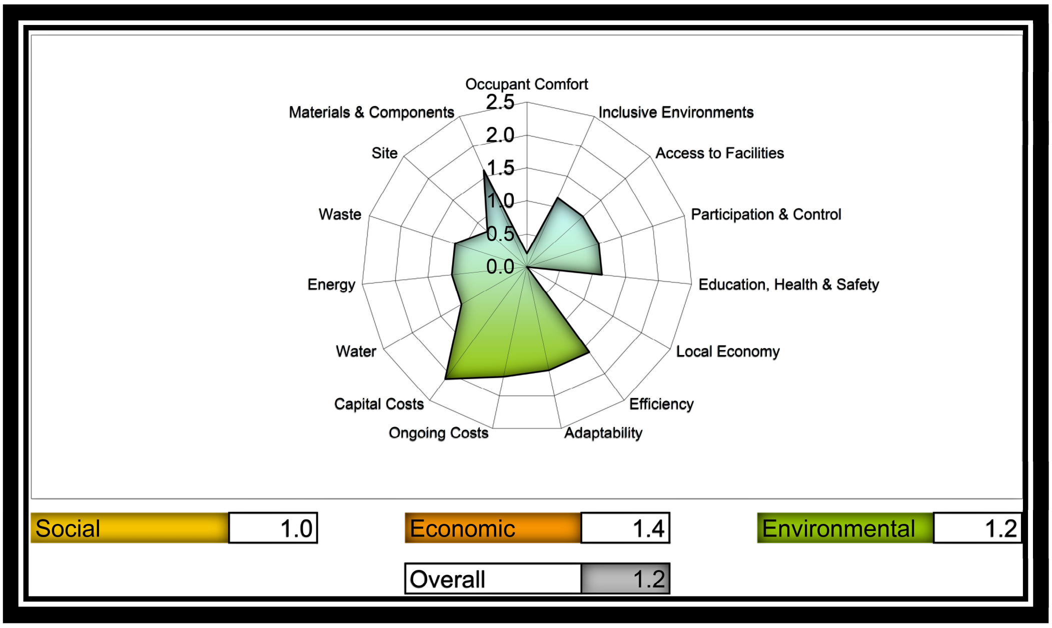

Figure 14: Sample of SBAT reporting documentation[46]

[45] Gibberd, J. T. (2003). Developing a Sustainable Development Approach for Building and ConstrucProcess. In J. Yang, & P. S. Brandon (Ed.), Proceedings of the CIB International Conference "Smart and Sustainable Built Environment (SASBE2003)". 19–21 November, Brisbane, Australia.
[46] Adopted from Gibbered, 2001.

Although the reviewed tools in both developed and emerging economies have an extended use in the built environment, various authors (Ding 2008; Zhou et al., 2008) have established strong credibility amongst expert/knowledge-based tools and emphasized their need in dealing with material selection problems using different assessment techniques. The following section examines some examples of existing expert/knowledge-based tools.

3.3 BIM and LCA

This section focuses on the significance of Life Cycle Analysis and Building Information Modelling integration, including the existing LCA applications that have been developed towards this purpose. Initially, the term BIM is defined, and the benefits it provides in the industry are briefly analyzed.

Contemporary technologies like building information modeling (BIM), and energy modeling have permitted architects and engineers to reflect upon the method buildings are designed and built in an innovative light. New approaches like energy performance modeling have transformed the technique of designers in projecting buildings. This change in the design progression has made constructions additionally efficient by permitting designers to take an additional holistic longstanding assessment of the buildings they project (Jennifer O'connor, 2014)[47]. Alternatively, evolving technology in this field allowed designers to inspect the embodied effects of the building design, expanding the understanding of the environmental impacts of buildings.

3.3.1.1 BIM

BIM is a model-centric business process characterized by design and documentation capabilities. It allows storing useful computable information, which can be coordinated and consistent for all the users of the project (Hunt, n.d.). Furthermore, it enables accurate, accessible, and actionable insight across the asset lifecycle. BIM was given the following definition "a digital representation of physical and functional characteristics" by the National BIM Standard (NBIMS).

It is the method of digitally representing and managing the assets of items. The rise of BIM as a design and visualization tool is an essential trend for the construction industry.

[47] Jennifer O'connor and Matt Bowick, "Advancing Sustainable Design with Life Cycle Assessment," SAB
Magazine, 2014, 27.

Its three-D modeling possibilities to deliver users and landlords with a far better representation of their projects, increasing the quality of both design and construction, and raising the speed of construction. Building information modeling allows the management of complex projects with massive information requirements far easier. BIM also supports the idea of integrated project delivery, a novel project delivery approach to integrating people, systems, practices, and business structures into a collaborative process. In this way, waste is reduced, and efficiency is optimized through all phases of the projects' life cycle (Azhar et al., 2011).

Building Information Modelling (BIM) is a methodology of design based on data-rich objects that form a model used in architecture, engineering, and construction. The main idea behind BIM is that all the objects used in the building process have their digital database that can be related to other objects and databases within the model (William, 2008).

One of the characteristics of high-performance green building projects is their dependence on significant additional modeling, additional specification requirements, and the necessity to track numerous features of the construction process, such as indoor air quality, construction waste management, safety during construction, and erosion and sedimentation control. Moreover, amounts of recycled materials, emissions from materials, and additional data should be collected for green building certification. BIM accepts plug-ins that can perform energy modeling and simulation and provide a platform for the data required by green building certification schemes.

3.3.1.2 LCSA, LCC, and SLCA

LCA is a system that measures the whole lifecycle of a product or process, including preproduction, production, and disposal, considering mostly environmental characteristics. Economic and social characteristics are measured by hiring Life Cycle Cost (LCC) and Social Life Cycle Assessment (SLCA) as additional tools to measure the economic and social features of a lifecycle for a process or a product. The considered LCA in this research measures a portion of the environmental impacts of building materials. For decision-makers, it is necessary to be familiar with all aspects of the environmental impacts of a product or process if so LCSA can be helpful (this can be used in the conclusion).

The National Risk Management Research Laboratory (NRMRL), being a part of the United States Environmental Protection Agency (EPA) describes life cycle assessment as "a cradle-to-grave approach for measuring industrial systems that assesses all phases of a product's life. It delivers a comprehensive view of the environmental characteristics of the product or process" (Mary Ann Curran, 2006)[48]. In the case of this research, the product is a building, and the study examines the environmental impacts related to the building materials from the preproduction stage to the end of life stage.

Although it is a mature concept, LCA is growing in importance because it allows the quantification of the environmental impacts of design choices that distance the entire life of the project. In the past, LCA was used to compare products and building sets, which provided some indication of how to progress decision making but did not provide data about the long-term impacts resulting from construction operation.

There is also a wide-ranging new method for LCA, which fairly considers all the environmental, economic, and social assessments called the Life Cycle Sustainability Assessment (LCSA). The LCSA is calculated following the formula below:

$$LCSA = LCA + SLCA + LCC$$

While LCA, SLCA, and LCC can be used independently. When applying the LCSA assessment for a product, the same system limitations must be used in all the three assessment tools to avoid re-calculation (M A Curran, 2015)[49] (Whitehead, Andrews, Shah, & Maidment, 2015)[50]. Clarification and translation of the results of the social impact for a product or a process into numerical values is not a simple job. Therefore, agreement on this subject is hard to fulfill, and proposed solutions are inadequate (Whitehead et al., 2015)[51].

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[48] Mary Ann. Curran, Life-cycle Assessment: Principles and Practice (Cincinnati, OH: National Risk Management Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, 2006).
[49] Curran, M. A. (2015) Life cycle assessment student handbook.
[50] Whitehead, B., Andrews, D., Shah, A. and Maidment, G. (2014) 'Assessing the environmental impact of data centres part 2: Building environmental assessment methods and life cycle assessment', Building and Environment. Elsevier Ltd, 93, pp. 395–405. doi: 10.1016/j.buildenv.2014.08.015.
[51] Whitehead, B., Andrews, D., Shah, A. and Maidment, G. (2014) 'Assessing the environmental impact of data centres part 2: Building environmental assessment methods and life cycle assessment', Building and Environment. Elsevier Ltd, 93, pp. 395–405. doi: 10.1016/j.buildenv.2014.08.015.

3.4 Whole Building Life-Cycle Assessment

A WBLCA has proven to be a complex exercise practiced by experts (Giesekam et al., 2016), and although it has been incorporated into Green Building Rating Systems (GBRS), only in recent years have standardized methodologies become accessible for building designers. The methodologies available are diverse and use a variety of international standards as the primary reference. This variation causes differences in goals and scope, particularly in the description of the functional or reference units and system boundaries.

The diverse approaches to WBLCA available in different GBRS to evaluate embodied carbon pose a barrier for precise comparisons among buildings assessed with different tools, and therefore for the development of baselines to drive reductions in environmental impact (Bowick, O 'Connor, and Meil 2014). In order to continue the advancement of holistic environmental assessment in buildings, including more robust databases and a large body of knowledge, a standardized WBLCA methodology must be established for the building industry using simplified tools.

A life cycle assessment (LCA) tool is used by industry professionals to select environmentally preferable products, assemblies, or entire functional areas, with a reference service life of 60 years. Typically, only one method of analysis or tool may be utilized for a given building project. Results of an LCA is reported in terms of the environmental impacts listed in this practice and state whether operating energy was included in the LCA (ASHRAE 2016b). In recent years, simplified LCA methods have been developed for industry practitioners (i.e., Tally plug-in for REVIT).

A recent review indicates that BIM models for organizing building information are currently being used to estimate environmental and energy consumption impacts based on LCA, using templates and plug-ins for BIM software and automated processes for combining different data and software (Soust-Verdaguer, Llatas, and García-Martínez 2017).

BIM can help simplify the estimation of carbon emissions over a building's life cycle because it provides a majority of the information and calculation tools necessary for performing a life cycle assessment (LCA), which may lessen the problem of insufficient information when executing an LCA of a building (Peng 2016). BIM-enabled environmental impact feedback processes can assist designers in making decisions with significant impact during the early design stages while deferring decisions with a marginal impact on later design stages (Basbagill et al. 2013b).

WBLCA shows promise for evaluating and motivating lower impact buildings; however, better LCA data – i.e., guidelines for conducting whole building LCAs and databases with a large number of reference buildings – will be needed in order to assess the actual improvement of a specific accurately building (Simonen, 2015). Previous reviews have looked at WBLCA case studies of residential and nonresidential buildings and also the tools used to carry out the assessment (Cabeza, et al., 2014; Ortiz, Castells, & Sonnerman, 2009) and have also found gaps regarding environmental indicators, easily understandable presentation of LCA results to users, and adaptation of LCA to various purposes (Bribian, Uson, & Scarpellini, 2009).

A significant amount of carbon emissions arising from the built environment are the result of not only the use of built assets, operational emissions (phases 1: Direct GHG emissions arising from energy use (combustion) on-site and phase 2: Indirect GHG emissions arising from the use of purchased electricity, heat, or steam) – but also to their construction, embodied emissions (phase 3: Other indirect (embodied) GHG emissions, according to the GHG Protocol). Operational emissions are a consequence of energy consumption in the day-to-day use of a building, while embodied emissions arise from manufacturing, acquiring, and installing the materials and components included in the building. These as well contain the lifetime emissions from maintenance, repair, replacement, and ultimately demolition and disposal. More detail on the terminology concerning embodied, operational, and whole life carbon is given in the following overview.

The construction industry has up to now been mostly addressing operational emissions using in building regulations setting emissions reduction targets (Part L), planning requirements by local authorities and sustainability assessment rating systems (BREEAM, LEED, etcetera.) ("Part L of the Building Regulations | isurv," n.d.) with the embodied aspect of carbon emissions not being adequately taken into consideration. To obtain an entire understanding of a construction project's whole carbon impact, appears a necessitate to measure equally the projected operational and embodied emissions over the whole life of the product or the process. Considering operational, and embodied emissions together, concluded in a project's expected life cycle, launches the whole life carbon approach.

A whole life carbon approach recognizes the complete best-combined opportunities for reducing lifetime emissions and aids to avoid any unintentional consequences of concentrating on only operational emissions. For instance, the embodied carbon burden of installing triple glazing rather than double can be higher when compared to the operational advantage resulting from the extra windowpane. So, whole life carbon needs to be effectively integrated into the sustainability agenda in order to achieve a lower-carbon future.

The central goal of whole life carbon assessment is the mitigation of carbon impacts in the built environment. Improved understanding and reliable assessment of the whole life carbon emissions of a built project will, in turn, permit the comparability of results, benchmarking, and target setting to accomplish carbon reduction.

Clear and measurable whole life carbon targets will support the hunt for emissions reductions. The adoption of such targets into the built environment sustainable development strategies, building sustainability assessment schemes and planning requirements, etcetera., predetermined obligations, and building regulations and legalizations establishes a future objective to steer the construction industry.

Lifelong thinking: an early reflection of possible upcoming climate change effects and the advancing of suitable adaptation plans, strategies, and polices will promote the resilience of built assets. The advancements in the quality, analysis, and availability of carbon data, as well as their integration with BIM, must further advance the accessibility, precision, and comfort of conducting whole-life carbon assessment(RICS, 2017).

The reference study periods RSPs that must be used for whole life carbon assessment are defined like this for different constructions:

• Domestic projects: 60 years (for both LEED v.4; BREEAM 2014 New Construction – Mat 01 Life cycle impacts)

The propose RSPs are fixed to allow comparability between the whole life carbon results among diverse projects.

They are projected to:

• Be widely representative of typically required service lives of the different building types.

• Allow for enough period for the assets to experience wear, tear, and the replacement cycles of main building components and systems.

• Stretch across a period in the future that is reasonably predictable.

3.4.1 Life cycle stages – overview

Whole-life thinking includes considering all life cycle stages of a process or a project, from raw material mining, product manufacturing, transport, and installation on-site over to the operation, maintenance, and final material disposal.

The following section refers to EN 15978; 7.4 (BSI EN 15978, 2011). It also reflects the potential aimed at recovery, reuse, and recycling. EN 15978 presents a sectional approach to a built property's life cycle, dividing it into different stages, as shown in **Figure 15**.

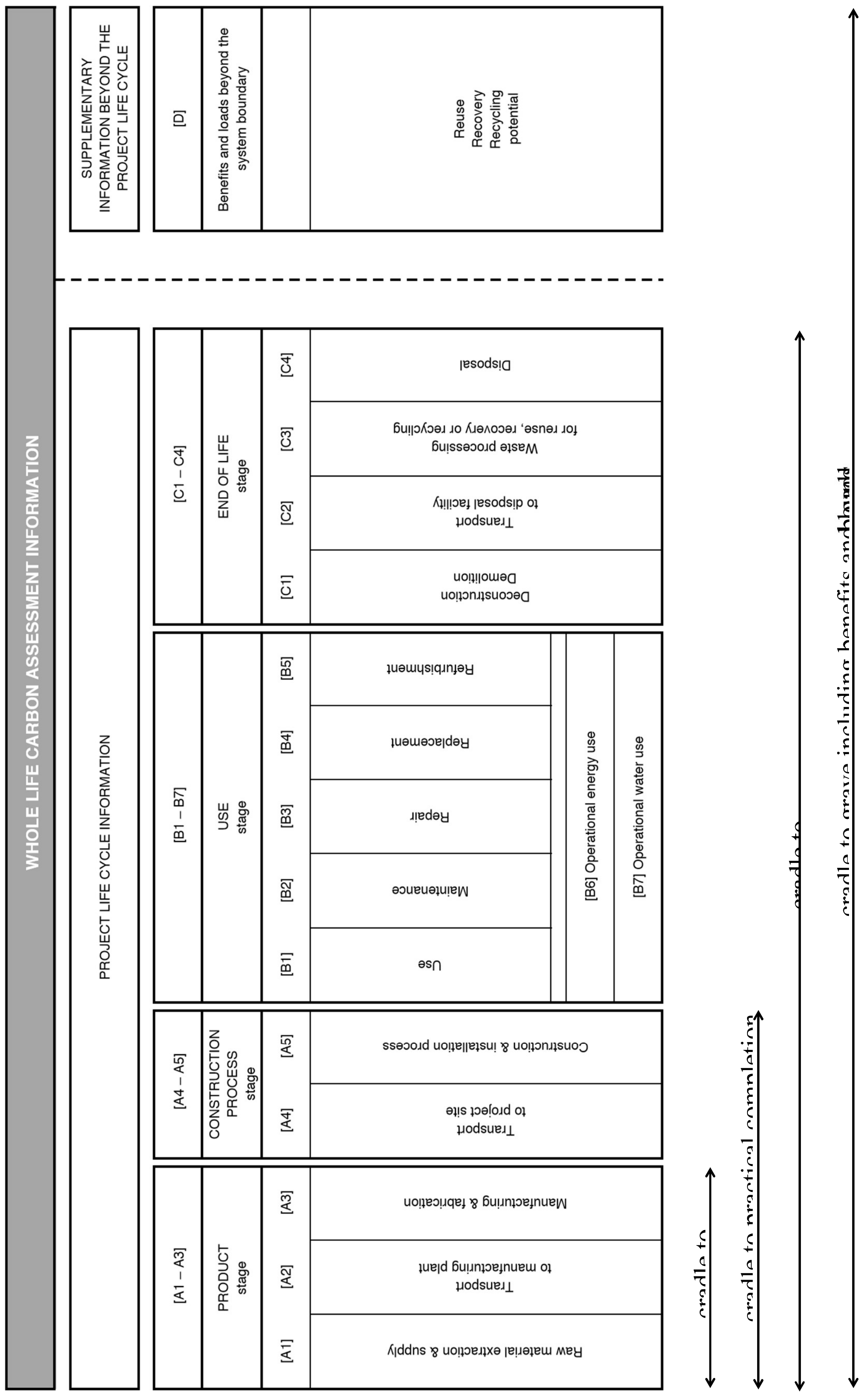

Figure 15:Modular info for the assessment according to EN 15978 counting representative system limitations.

The life cycle stage sections allow transparency and flexibility in the valuation. They also deliver a standardized structure for complete besides coherent reporting, with group sections that might be seen individually along with a combination with one another. A comprehensive whole-life carbon assessment must account for entirely all emissions arising over the whole life of a product or a process. It must as well account for all future reusability and recyclability of its different essential elements sections [A] to [D]: cradle to grave counting impacts outside the system boundary – as appropriate to each project.

The limitations of whole life carbon assessment and the life cycle stage sections enclosed should be specified and justified in the report. Clear limitations are critical for transparency, subsequent consistency, and credibility of carbon results. However, wherever more restricted scopes are instructed, fitting the needs of specific projects must be identified, declaring all the life cycle stages included in the assessment.

All life cycle stages, following the above **Figure 15**, are applicable for new constructions. For standing buildings that are to undergo refurbishment, all life cycle stages are applicable for only new elements installed to the building. For current objects being taken, only use emissions [B], [C] and beyond [D] must be measured over the life cycle. Emissions from the production and construction stages [A] group with the existing building and therefore considered as outside of the scope of the studied project.

3.4.1.1 Product stage [A1-A3]:

Referring to EN 15978; 7.4.2 and 8.4, and EN 15804; 6.3.4.2. The product stage addresses the carbon emissions attributable to the cradle to gate processes; raw material supply, transport, and manufacturing. The procedures covered by [A1– A3] regularly arise in several stages, where components are manufactured and after transported to another fabrication plant for assembly into a system. All these interim steps need to be considered.

The carbon emissions arising in the product stage [A1–A3] of the objects comprised in the whole-life carbon assessment must be measured by assigning suitable embodied carbon aspects to the given fundamental material quantities. Consequently:

[A1–A3] = Material amount (a) × Material embodied carbon factor (b)

Assessors need to confirm that (a) and (b) are measured against the equivalent metric, for example, per kg, and accustomed accordingly using, e.g., material densities wherever necessary. Density data must be obtained from the related EPD used or from technical documentation available by the product supplier. When detailed density data is absent, the average information representative of the category of an item should be used with their source stated. Project team members, such as the structural engineers, cost consultants, etcetra., should be consulted for clarification on material assumptions if necessary. Where a comprehensive specification for products and materials is existing, the equivalent carbon statistics should be used. Nevertheless, at initial design phases, the technical specification is probable indicative and the cost plan or BoQ not yet including detailed information on building materials and product categories.

Material choices made primary in the design process due to an absence of detailed information on technical specifications can severely impact the product stage carbon emissions [A1–A3], leading to particular inconsistencies between results for similar projects. Consequently, in such cases, generic data illustrative of standard, market average specifications must be used in the assessment. These statistics should be refined at later project stages as product-specific information becomes available.

3.4.1.2 Construction process stage [A4 and A5]:

Referring to EN 15978; 7.4.3 and 8.5, and EN 15804; 6.3.4.3. Units [A4] and [A5] respectively address the emissions related to the transportation of the materials and products from the factory gate to the project site and their assembly into a building.

3.4.1.2.1 Transport emissions [A4]

Transport emissions must contain all phases of the journey of the products following their leaving from the final industrial plant to the project site, considering any temporary stops at storage depots and distribution centers(BSI EN 15978, 2011)(British Standard Institution, 2014).

Material or system mass (a):

It should be obtained from acceptable sources, as shown in section 3.4.3, and account for all material losses during transport wherever possible.

Transport distance (b):

It should be measured based on the distance between the industrial manufacturing location and the project site and the anticipated supply chain route of each element. When detailed sourcing data is unobtainable, the transport scenarios in the following table should be used in whole-life carbon assessments for UK-based projects. Similar defaulting scenarios must be established for diverse countries. Assessors, in consultation with the design team, should practically assign the predicted products and components into each of the groups: locally, nationally, European, and globally manufactured, to inform the transport scenario.

The transportation of individuals and traveling of workforces is excluded from the calculations as the emissions related to these events are not attributable to the project but to the individual employees.

Transport scenario	Km by road[52]	Km by sea[53]
Locally manufactured e.g., concrete, aggregate, earth	50 [54]	-
Nationally manufactured e.g., plasterboard, blockwork, insulation	300	-
European manufactured e.g. CLT, façade modules, carpet	1,500 [55]	-
Globally manufactured , e.g. specialist stone cladding	200 [56]	10,000

Table 2: Default transport scenarios for UK projects (RICS, 2017).

3.4.1.2.2 Construction – installation process emissions [A5]

Referring to EN 15978; 7.4.3.3 and 8.5, EN 15804; 6.2.3.

The carbon emissions rising from any onsite or offsite construction-associated actions must be measured in [A5]. This comprises any energy consumption for onsite

[52] Means of transport assumed as average rigid HGV with average laden – average laden as per BEIS carbon conversion factors.
[53] Means of transport assumed as average container ship.
[54] EeB Guidance Document, Part B: Buildings – Operational guidance for life cycle assessment studies of the Energy-Efficient Buildings Initiative, p.199.
[55] Generic distance for items assumed to be sourced from continental Europe, e.g. Austria.
[56] Generic distance for items assumed to be sourced fromEastern Asia.

accommodation, plant-use, and the effects associated with any waste produced through the building process, its treatment, and disposal.

The carbon emissions allied with any waste produced during the construction process must be accounted for in line with the principles drawn for the product and transport stage [A1–A3] and [A4] – see 3.4.1.1 and 3.4.1.2.1 – and EoL stages [C2–C4] – see 3.4.1.4. Site waste disposal scenarios as follows:

- Disposal to landfill/incineration [A1–A3] + [A4] + [C2] + [C4]
- Reuse or recycling on-site [A1–A3] + [A4] + [C3]
- Reuse or recycling off-site [A1–A3] + [A4] + [C2] + [C3]

3.4.1.3 Use stage [B1–B7]

Referring to EN 15978; 7.4.4.1 and 8.6.1, EN 15804; 6.3.4.4.1.

The use stage must seizure the carbon emissions associated with the process of the built environment over its whole life cycle, from practical completion to the end of its service life as determined in 3.4.

This includes all emissions related to operational energy and water use, along with all embodied carbon effects related to maintenance, repair, replacement, and refurbishment of construction components. Rational scenarios should be established for the maintenance, repair, replacement, refurbishment, and process of the construction based on projects, specific data, and discussion with the project team.

3.4.1.3.1 In-use emissions {B1]

Referring to EN 15978; 7.4.4.2 and 8.6.2, and EN 15804; 6.3.4.4.2. The in-use unit [B1] seizures the emissions ascending through the life of construction from its components, e.g., GHG released from HFC[57] insulation.

Any carbon released from construction components during the life of the construction should be reported in [B1].

Carbon emissions emitted by building elements, and the impact of potential carbon absorption should be accounted for. Specific consideration should be paid to any emissions arising from refrigerants, insulation blowing agents, paints, etcetera.

[57] Hydrofluorocarbons.

3.4.1.3.2 Maintenance emissions [B2]

Referring to EN 15978; 7.4.4.3 and 8.6.3, and EN 15804; 6.3.4.4.2.

Buildings assets with sophisticated cladding and MEP installations require regular maintenance to ensure continued efficiency, good appearance, and validity of warranties. All these repetitive activities involve the use of energy and products. These should be accounted for in part [B2].

Unit [B2] must address the carbon emissions arising from any actions related to maintenance processes, plus cleaning, and any products used. Furthermore, it should include any emissions from the energy and water use allied with these actions.

3.4.1.3.3 Repair emissions [B3]

Referring to EN 15978; 7.4.4.4 and 8.6.3.

This unit [B3] is intended to give a reasonable permit for refurbishing unpredictable damage by and above the maintenance regime. Consequently, It applies to the same structure element categories as maintenance emissions. If none of these sources is available, repair emissions should be assumed as equivalent to 25% of maintenance emissions [B2].

Module [B3] must consider the carbon emissions arising from all activities that relate to repair processes and any products used.

3.4.1.3.4 Replacement emissions [B4]

Referring to EN 15978; 7.4.4.5 and 8.6.3.

During the service life of a structure, there will be carbon emissions arising from the replacement of objects, such as building services equipment, windows, and cladding, roof surfaces, interior finishes, etcetera. These will happen at different cycles depending on the original specification and corresponding life expectancy of the different elements. It should be assumed that objects are being replaced on a like-for-like basis, and full replacement (100%) of the items is assumed once the specified lifespan is reached. It must be assumed that objects are being substituted on a full similarity basis, and full replacement (100%) of the items is assumed once the specified lifespan is reached.

Module [B4] must consider any carbon emitted in associated with the predicted replacement of building elements, counting any emissions from the replacement procedure. All emissions arising from the manufacture, transportation to site, and installation of the replaced objects must be considered. This as well Includes any losses during these processes, as well as the carbon associated with component removal and EoL treatment.

Building part	Building elements/components	Expected lifespan
Roof	Roof coverings	30 years
Superstructure	Internal partitioning and dry lining	30 years
	Wall finishes: Render/Paint	30/10 years respectively
Finishes	Floor finishes Raised Access Floor (RAF)/Finish layers	30/10 years respectively
	Ceiling finishes Substrate/Paint	20/10 years respectively
FF&E	Loose furniture and fittings	10 years
Services/MEP	Heat source, e.g., boilers, calorifiers	20 years
	Space heating and air treatment	20 years
	Ductwork	20 years
	Electrical installations	30 years
	Lighting fittings	15 years
	Communications installations and controls	15 years
	Water and disposal installations	25 years
	Sanitaryware	20 years
	Lift and conveyor installations	20 years
Façade	Opaque modular cladding e.g., rain screens, timber panels	30 years
	Glazed cladding/Curtain walling	35 years
	Windows and external doors	30 years

Table 3: Indicative component lifespans (Royal Institution of Chartered Surveyors., 2006) (Scheuer, Keoleian, & Reppe, 2003).

3.4.1.3.5 Refurbishment emissions [B5]

Referring to EN 15978; 7.4.4.6 and 8.6.4, and EN 15804; 6.3.4.4.2. Refurbishment, as separate from replacement, is defined as a planned modification or improvement to the physical features of the building for it to cater to the dimed future function identified and quantified at the outset. This would typically involve a proposed change of use at a point throughout the service life of the project, along with a considerable amount of works to several parts of the building.

Phase [B5] must consider any carbon emissions associated with any building components used in refurbishment, counting any emissions from refurbishment events. All emissions ascending from the production, transport to site, and installation of the elements used must be comprised. This comprises any losses through these processes, in addition to the carbon associated with their elimination and EoL treatment.

The calculation of refurbishment emissions [B5] must account for any material add-ons and variations as per the new build – see 3.4.1.1, 3.4.1.2 – instead of like-for-like as in replacement – see 3.4.1.3.4.

3.4.1.3.6 Operational energy use [B6]

Referring to EN 15978; 7.4.4.7 and 8.6.5. This section covers any emissions rising from the energy-use of the operation of technical systems in the construction through the life of the project.

Operational carbon emissions arising by the energy use of structure integrated systems as projected and, or measured through the life cycle of the project, necessity to be reported below phase [B6].

Operational emissions must include all energy use measured as per (Part L of the Building Regulations), counting heating, domestic hot-water supply, lighting, air-cooling system, ventilation, and auxiliary systems. Life-cycle emissions connected with the operation of supplementary building-integrated systems (lifts, safety, security, and communication fittings) must also be comprised as part of the total operational emissions [B6] then reported separately where applicable.

Carbon emissions arising from non-building-related systems (e.g., ICT equipment, cooking uses, specialist equipment, etcetera) – nonregulated energy use – can signify a critical part of the total operational emissions. Consequently, these would be included in the assessment where possible to provide a broad picture of the project life cycle impacts. Such carbon emissions arising from unregulated energy use must be stated separately within the stage [B6]. Impacts from waste generated by operational energy use should also be measured by counting any treatment and transportation it might involve.

Wherever building operations need fuel to be transported to the site, e.g., gas bottles, oil supply, etcetera, the transport emissions allied with the delivered fuel must be contained within the calculation of operational emissions, as transportation emissions characterize upstream transmission and distribution effects for such fuels. The data provided by MEP, sustainability, and ICT consultants must be used in the operational emissions calculations, e.g., BRUKL submissions, energy calculations according to CIBSE TM54, energy modeling outcomes from SBEM and or dynamic thermal simulation, etcetera.

Operational carbon data are typically expressed as CO2, according to contemporary practice (Part L of Building Regulations). As stated by the government's Standard Assessment Procedure (SAP), CO2 is representing CO2e (BRE, 2014).

Wherever on-site renewables are fixed (PVs, solar thermal systems, etcetera), the whole-life carbon assessment report must state in what way the energy outputs are projected to be used for the specific project. If the information on the allocation of the on-site produced energy is absent, the assumption that energy generated on-site satisfies building needs should be adopted. That is, building-related (regulated energy added to lifts, security, and communications fittings) take priority over non-building-related systems (deregulated energy) being exported to the grid (BSI EN 15978, 2011).

Unregulated energy demand can be assumed to be equal to the regulated energy demand for this calculation, in case of the absence of project-specific estimates (*BREEAM UK new construction* , 2014). All benefits accruing from energy production onsite and exported to the grid must be captured within stage [D] – see 3.4.1.5, as recommended in EN 15978 7.4.4.7.

A complete assessment of the whole life of a project must advise decision making as precisely as possible. Consequently, considering the influence of climate change when calculating future operational emissions, for example, heating and cooling demand through the service life of the structure, is essential. It is recommended that in such scenarios, the figures used are modeled or adjusted utilizing future weather data.

3.4.1.3.7 Operational water use [B7]

Referring to (EN 15978; 7.4.4.8 and 8.6.6), this section goes through the carbon impacts associated with water-use during the operational processes of the building.

All carbon emissions associated with a water supply and waste-water treatment over the life cycle of the building must be reported under module [B7] (excluding water used throughout maintenance, repair, replacement and refurbishment which are reported elsewhere).

All emissions related to energy consumed from water-related systems, e.g., provision of domestic hot water, etcetera. Should be captured under module [B6]. Estimates on anticipated water consumption should be made based on the values provided in Guidelines for the building services, for the building type, in the absence of project-specific data at early design stages. Estimated water consumption must be substituted by figures provided by the public health and or MEP consultants and landscape architects as they are ready.

Carbon conversion factors for water-use and treatment, as issued by the local water supplier, must be used. If absent, the relevant generic carbon conversion factors from an allowable source should be used.

3.4.1.4 End of Life (EoL) stage [C1-C4]

Referring to EN 15978; 7.4.5.1 and 8.7.1, and EN 15804; 6.3.4.5. EoL stage begins when the building has reached the end of its life and will no longer be used. For the whole life carbon assessment, this is assumed to occur at the end of the reference study period of the building.

All emissions ascending from decommissioning, stripping out, disassembly, deconstruction and demolition activities along with transport, processing, and disposal of materials operations at the end of life of the project should be considered in phase [C].

When the site is clean and leveled to the ground level and is ready for further use, the EoL stage is considered complete within the scope of whole life carbon assessment. Assessors should develop a suitable project EoL scenarios at the building level along with separate machinery levels where applicable, built on future purposes provided by the project team, examples, and current EoL practices. The EoL scenarios should be detailed and clarified in the whole life carbon assessment report.

In the absence of precise data, scenarios on the amount of landfilling, reuse, and or recycling of each item at the EoL must be established according to the current standard practice. Most construction metals, such as steel, aluminum, and copper, are highly recyclable several times without a significant decrease in quality. Consequently, high recovery rates have been recognized across the industry because of their reuse and recycling potential, along with the high economic value of the scrap.

3.4.1.4.1 Deconstruction and demolition emissions [C1]

Referring to EN 15978; 7.4.5.2 and 8.7.2. Deconstruction must include all site-based events required to dismantle, deconstruct, and or demolish the assessed building.

The carbon emissions arising from any on or off-site deconstruction and demolition activities must be considered in [C1] and counting any energy consumption related to onsite accommodation and plant use.

3.4.1.4.2 Transport emissions [C2]

Referring to EN 15978; 7.4.5.3 and 8.7.3.

All carbon emissions related to the transportation of deconstruction and demolition to the disposal site, including any temporary stations, must be captured in stage [C2].

Transport emissions for these materials should be calculated following this formula:

$$[C2] = \text{Mass of transported waste (a)} \times \text{Transportation carbon factor (b)} \times \text{Distance to the disposal site (c)}$$

In the absence of project precise data, default distances to be used for the transportation of redundant items according to anticipated EoL scenarios.

An average heavy goods vehicle (HGV) should be assumed as the mode of transportation with 50% weight to account for the vehicles coming to the site empty and leaving with a 100% load.

3.4.1.4.3 Waste processing for recovery, reuse, or recycling emissions [C3]

Referring to (BSI EN 15978, 2011); 7.4.5.4 and 8.7.4.

Once materials and or machinery are recovered, reused, or recycled subsequently to the end of the life of the structure, all carbon emissions related to their treatment and processing before reaching the end-of-waste state should be considered in phase [C3].

Calculation of [C3] must follow the End of Life scenarios predicted by the assessor per each item. Information for [C3] from related EPDs must be used and appropriately accustomed to suit particular EoL scenario. In the absence of precise data regarding the waste processing for objects to be repurposed, the defaulting emissions for disposal to landfill must be applied, see 3.4.1.4.4.

3.4.1.4.4 Disposal emissions [C4]

Referring to EN 15978; 7.4.5.5 and 8.7.5. In case of items not being recovered for reuse and or recycling. Stage [C4] seizures the emissions resulting from all processing required before removal and from the degradation or burning of landfilled materials.

Items intended for final disposal either in landfill or incineration, a consideration for the emissions arising from these items disposal should be contained within [C4].

Moreover, the calculation of [C4] follows the EoL scenarios developed by the assessor per item, while using [C4] information from related EPDs, appropriately customized to suit the selected EoL scenario.

Where data for disposal is unobtainable or is specified as ‘0’, a general hypothesis should be used for the [C4] emissions of inorganic substances. New landfill sites regularly employ methods to capture the gases ascending from organic substance decomposition like carbon dioxide (CO_2) and methane (CH_4). This will influence the corresponding landfill emissions that should be accustomed based on the efficiency of landfill gas capture.

Potential energy recovery from organic waste burning or captured landfill gas burning should be reported within the stage [D] – see 3.4.1.5. Organic items contain natural feedstock energy, and their decomposition ascends CH_4 and CO_2 with sizeable related EoL emissions. Therefore, all EoL emissions must be inspected in conjunction with possible benefits from energy substitution when burnt to guarantee maximum benefit and environmentally friendly trade-off.

3.4.1.5 Benefits or burdens beyond the system boundary [D]

Referring to (BSI EN 15978, 2011); 7.4.6 and 8.8, and (British Standard Institution, 2014); 6.3.4.6 and 6.4.3. Stage [D] shelters any benefits or burdens accruing from the repurposing of elements discarded from building, or any energy recovered from it outside the project's life cycle.

Module [D] is proposed to deliver a more comprehensive view of the environmental impacts of a building project accounting for the future potential of its materials when reused, repurposed, recovered, or recycled. [D] seizures the emissions or possible loads from using repurposed objects to exchange primary materials. Stage [D] can be used as a measure for calculating circularity and evaluating future resource efficiency.

Module [D] contains the possible environmental benefits or burdens of materials and components outside the life of a building project. Stage [D] must be reported separately and not combined with cradle to grave stages [A–C].

Nevertheless, it is crucial to measure module [D] data along with cradle to- grave [A–C] data to obtain a complete understanding of the environmental effects of a building project.

Diverse scenarios can be established for the same project regarding the future recovery and repurposing of objects outside the EoL. Each scenario will consequently result in a different value for [D]. Each scenario must be presented evidently and clarified inside the whole-life carbon assessment report indicating its possibility. Moreover, depending on the degree of reuse or recycling expected, suitable limitations for the possible benefits or burdens must be determined according to what the point of substitution is anticipated to per each scenario. In the absence of any precise information connected to the future potential of objects, assessors can measure such benefits or burdens, where possible, corresponding to the subsequent guidance.

When an element is made-up of recovered materials as a secondary product, [D] measures the avoided or potentially supplementary emissions when comparing the secondary production with manufacturing a functionally comparable item from primary materials. Consequently, module [D] contains the benefit of replacing the original product and not manufacture it from scratch, along with any emissions from the processing of the secondary product, as follows:

[D] = – [A1–A3] [58] of replaced main product + [A1–A3] of secondary product

Energy recovered from materials beyond the end-of-waste state, e.g., wood incineration is considered in module [D] as per (British Standard Institution, 2014); 6.3.4.5. This is when the rate of energy recovery is higher than 60%. Energy recovery calculations are directed based on the net calorific value of the studied material. The type of energy offset must be determined according to rational assumptions relevant to the local practices enabling realistic estimations of the avoided carbon emissions.

The carbon sequestered in wood or other bio-based materials[59] being repurposed should be considered in module [D], wherever possible. For elements being substituted several times through the life cycle of the building project, module [D] should account for each time the item is being substituted, and the redundant element is intended to be repurposed.

3.4.2 Floor area measurement

The floor areas of the building are measured and must be determined from the following sources that must be used in the whole life carbon assessment in the subsequent order of preference: BIM model, Bill of quantities (BoQ) or cost plan, Consultants' drawings.

3.4.3 Quantities measurement

Referring to EN 15978; 9.1–9.3 (BSI EN 15978, 2011), this section specifies how to determine and include the quantities of the materials and products that form the building in the whole life carbon assessment. Material quantities must be determined; the following sources should be used and specified in the whole life carbon assessment, following an order of preference: Materials delivery records, BIM model, Bill of quantities (BoQ) or cost plan, Approximations from consultants' drawings. When assessing existing buildings, actual quantities should be obtained from 'as-built' drawings and contractor records; If not possible, site surveys might be essential.

The assessment must account for gross material quantities permitting for any losses during transportation and on-site construction processes as appropriate in modules [A4–A5] see section 3.4.1 - *Life cycle stages*.

[58] [A1–A5] where applicable, as per explanation above, e.g. where components being reused 'as is'.
[59] Biogenic carbon

3.4.4 Units of measurement

The whole life carbon assessment outcomes must be reported with the following units: kgCO2 equivalent (kgCO2e), or any specified metric multiples thereof as appropriate, e.g., tCO2e.

3.5 The Green Guide

This section delivers an overview of the Green Guide to Specification. The Green Guide considers typical UK construction specifications and compares their environmental impact on a scale of A+ (lowest environmental impact) to E (highest environmental impact). Assessments are made using specifications that accomplish similar levels of performance, and the environmental effect is for a complete lifecycle (from manufacture to end of life disposal).

The specifications are divided into component types, such as external walls and windows. The building types enclosed by the Green Guide are those within BREEAM and the Code for Sustainable Homes.

3.5.1 Outline of the Green Guide rating system

The first version of the Green Guide in 1996 intended to deliver a simple 'Green Guide' to the environmental effects of building materials that would be easy to use and well based on numerical data (“The Green Guide Explained : BRE Group,” n.d.).

The Green Guide is now part of the Building Research Establishment Environmental Assessment Method (BREEAM). The Green Guide includes more than 1,500 specifications used in various types of buildings. Over the various editions, data on the relative environmental performance of some materials and components has changed, reflecting changes in manufacturing practices mutually, the way materials are used in buildings, and the developing environmental knowledge.

Green Guide uses Life Cycle Assessment (LCA) (Via BRE's Environmental Profiles Methodology 2008; available from the Green Guide online) to examine a broad range of environmental impacts for different construction approaches meeting the same performance criteria. It considers six main building types:

• Commercial buildings, such as offices

• Educational

• Healthcare

• Retail

• Domestic

• Industrial

Across those building, element groups, the Green Guide offers a broad but not comprehensive catalog of building specifications covering the most common building materials.

By evaluating the relative environmental performance using rating bands of A+ to E (for the overall ecopoints[60] score or individual environmental impact categories), the user can select specifications based on personal or organizational preferences or priorities.

3.5.2 How the Green Guide works

This section goes through the way that the Green Guide works, providing diverse levels of detail on the assessment of the life cycle, the underlying Life Cycle Assessment (LCA) methodology, and how the rating bands were formed.

The Green Guide splits the building parts into basic categories to permit the direct comparison of the environmental performance allied with different systems accomplishing a set level of performance called the "functional unit." The Green Guide online platform was arranged to present similar specifications together; still, specifications from diverse sections of the same elemental category could be compared with each other since they perform the same function.

The different possible specifications typically employed to attain the set functional unit are identified before any assessment of their environmental impact is performed. Once the specifications are identified, they are measured over a 60-year study period following these life cycle stages: production, installation, usage (including maintenance and repair), lastly, disposal and demolition.

The performance of the specifications inside an elemental category is compared to create the lowest environmental impact and the highest environmental impact. These standards set the range of the A+ to E rating scale: the rating bands are built by

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[60] Ecopoints: the normalised profile values are multiplied by weighting factors developed for each impact category and the results summed to give a single figure.

separating the range into six equal sections. This procedure is done for the ecopoints range and the range for each environmental impact category. **Figure 16** presents the different sections of the external wall elemental category to show the relationship between each sub-category and the main category.

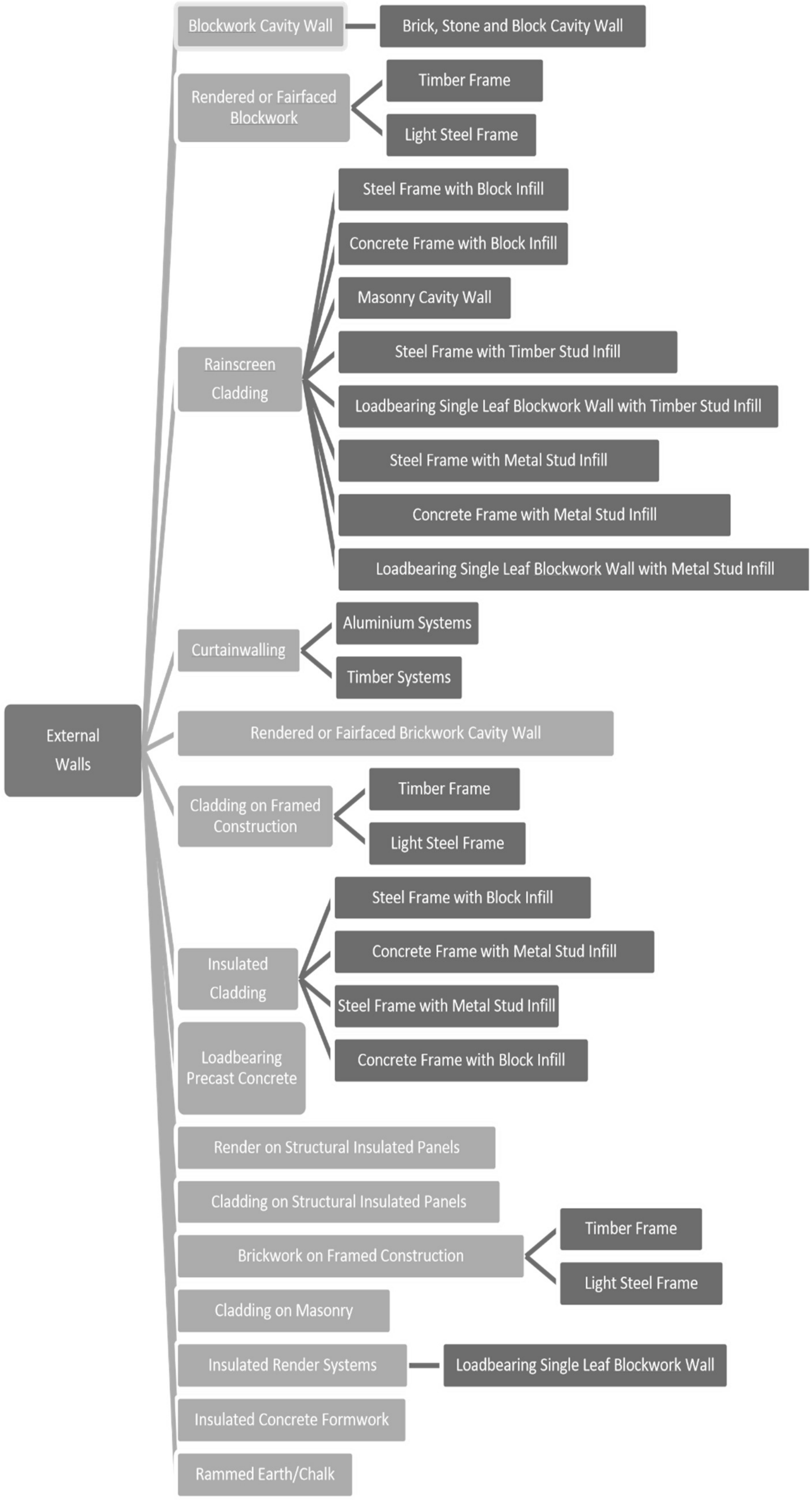

Figure 16: Different sections of the external wall elemental category. Source: ("The Green Guide Explained : BRE Group," n.d.)

3.5.2.1 The Green Guide Structure

The Green Guide assesses six building types:

- Commercial buildings
- Educational
- Healthcare
- Retail
- Domestic
- Industrial

The elements that have the most significant influence on the environmental impact of the building are assessed individually, differing between building types.

The following elements are covered:

- External walls
- Internal walls and partitions
- Windows
- Roofs
- Ground floors
- Upper floors
- Insulation
- Landscaping
- Floor finishes

The elemental categories assessed vary according to building type:

Building Type	Elemental category					
	External walls	Windows	Roof	Upper floor slab	Internal walls	Floor finishes/ coverings
Office	✓	✓	✓	✓	-	✓
Retail	✓	✓	✓	✓	-	✓
Industrial	✓	-	✓	-	-	-
Education	✓	✓	✓	✓	✓	✓
Healthcare	✓	✓	✓	✓	✓	✓
Prisons	✓	-	✓	✓	-	✓
Courts	✓	✓	✓	✓	✓	✓
Multi-residential	✓	✓	✓	✓	✓	✓
Other buildings	✓	✓	✓	✓	✓	✓

Table 4: The elemental categories assessed.

Inside each primary category, the specifications related to the building type are presented. All specifications required to attain the same technical performance, which is labeled by the functional unit. The functional unit defines what is being assessed and what levels of performance are essential. For instance, the functional unit for external walls is:

1m² of external wall structure, to satisfy present Building Regulations, and a U-value of 0.3 W/m²K. Anywhere applicable, the specification will also contain an internal-wall finish.

Variation for retail/industrial: 1m² of external-wall structure, to satisfy present Building Regulations, and a U-value of 0.3 W/m²K.

3.5.2.1.1 Life cycle stages from the perspective of the Green Guide

Any specifications are measured over a 60-year study period using the following life cycle stages:

• manufacture;

• installation;

• use, maintenance, and repair

• Final disposal (even if accrued beyond the 60 years) at demolition.

Consequently, it is essential to recognize how much waste typically arises at installation and where it goes. It is necessary as well to know where material removed during the use goes. BRE has obtained data on typical waste rates and disposal at installation, replacement, and demolition.

All wastage rates used in the Green Guide are taken from those in the pricing document Laxton's[61]. Laxton's construction pricing tool includes figures of on-site waste for building materials. Data on disposal routes were obtained from a variety of sources, including the Waste & Resources Action Programme (WRAP) and BRE expert knowledge. Effects from the use stage arise from any replacement needed during the 60-year study period and any maintenance required, and any required maintenance.

Replacement Factor is calculated as follows:

Replacement Factor = (the study period/the reference service life[62]) – 1

Seven factors are defined in ISO 15686 service life planning that influence element durability, which needs to be considered when determining the element service life(British Standard, 2017). These seven factors are listed below:

1. Material and component quality.

2. Design.

3. Workmanship.

[61] V B Johnson LLP Laxton's Building Price Book 2006
[62] The reference service life determines the number of replacements during the 60-year study period.

4. Indoor environment.

5. Outdoor environment.

6. Maintenance.

7. Use Specifications accustomed to the building sector

The Green Guide uses the following data sources for the calculation of reference service lives:

• The Component life manual (1992)

• The Building fabric component life manual (1999)

• The Building services component life manual (2000)

• The Guide to ownership, operation, and maintenance of building services (CIBSE, 2000)

• The life expectancy of building components (BCIS, 2001)

• Costs-in-use tables (1991).

- BRE also considered service life information provided by trade associations.

3.5.2.1.2 The Green Guide rating bands

The information goes with a specific sequence to produce the Green Guide ratings for each elemental category. Starting by the element type to determine the functional unit to which the specifications are calculated. Specifications are then modeled using the appropriate materials' LCA data groups.

The ratings bands for each category were calculated following this approach:

$$Range = Ecopoint_{maximum} - Ecopoint_{minimum}$$

$$Band\ width = \frac{Range}{6}$$

$$A^{+}Band = Ecopoint_{minimum}\ to\ \left(Ecopoint_{minimum} + \frac{Range}{6}\right)$$

$$A\ Band = A^{+}{}_{maximum}\ to\ \left(A^{+}{}_{maximum} + \frac{Range}{6}\right)$$

$$B\ Band = A_{maximum}\ to\ \left(A_{maximum} + \frac{Range}{6}\right)$$

$$C\ Band = B_{maximum}\ to\ \left(B_{maximum} + \frac{Range}{6}\right)$$

$$D\ Band = C_{maximum}\ to\ \left(C_{maximum} + \frac{Range}{6}\right)$$

$$E\ Band \geq D_{maximum}$$

Figure 17 below shows how the Ecopoints for a group of specifications for an elemental category happens over the 60-year study period leading to the Green Guide rating.

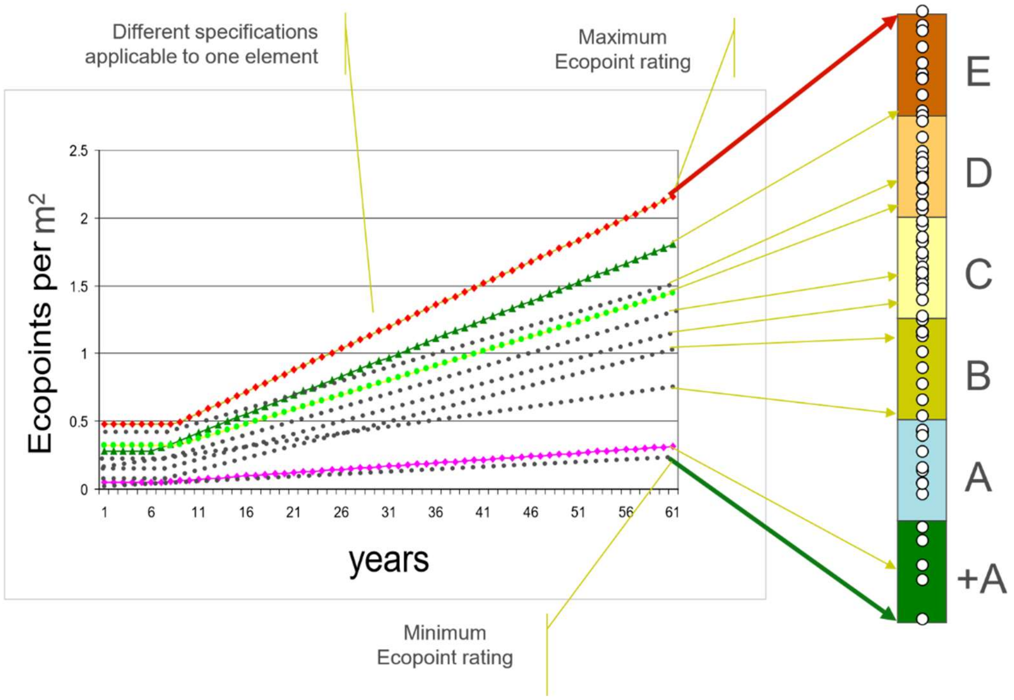

Figure 17: Ecopoints, according to the Green Guide. Source: ("The Green Guide Explained : BRE Group," n.d.)

Specifications with A+ ratings produce the lowest total environmental impact after that A, B, C, D, and E. E is the worst general performance. Otherwise, users may compare the diverse specifications for a specific impact and can, therefore, efficiently choose their weighting.

When reviewing ratings, it is essential to memory:

1. The A+ to E ratings are only applicable inside a specific element group. An A+ rating in a specific group is not equal to an A+ rating in another group.

2. The Summary Ratings for some element groups span a much broader range of values than for other element groups.

3. The number of band ratings is not equivalent to each environmental effect or element.

4. For different environmental issues, it is indicated where each specification lies inside the series of values found per each group.

5. Furthermost, structures will last longer than the expected 60 year study period, and hence the value of low maintenance and design for stretched permanency are possibly under-estimated in the ratings.

6. The ratings are allocated at the time of writing, employing the finest available data.

3.5.2.2 Green Guide approach to Life Cycle Assessment (LCA)

This section will introduce the method of Life Cycle Assessment (LCA) adopted by BRE's Environmental Profiles Methodology for measuring the environmental effects related to building materials through their life cycle is based.

Environmental Profiles permit designers to request reliable and comparable environmental data about building materials and suppliers the chance to present credible environmental data about their products.

Life cycle assessments are usually considered using a 3-stage approach:

Stage 1 Goal and Scope:

- The assessment is being done within the company to improve products, processes, or policy decision making. It is used outside the company to conduct comparisons among services, products, or processes.

Stage 2 Inventory Analysis:

- Includes mapping of the processes for each life cycle stage producing the functional units to be studied to give a Process Flow Diagram.
- Gather information on inputs (quantities of energy and materials used) and outputs (products and measured emissions to air, land, and water) for all that processes on the Process Flow Diagram.
- After that data is converted into environmental effects (electricity use becomes fossil fuel consumption and emissions to air, NOx, and SO2), water (e.g., NOx) and land (e.g., fuel ash), caused by electricity generation, the impacts are summed for the whole life cycle producing an Inventory Table.
- In this stage, the Process Flow Diagram is produced to show all procedures involved in the diverse life cycle stages, combined with an Inventory Table showing the summed environmental impacts over the whole life.

Stage 3 Impact Assessment: In this stage, there are three steps to assess the impact:

- Classification: The results from the Inventory Table are positioned through environmental impact categories everywhere they produce an impact.
- Characterization and Normalisation: The quantity of each material in an impact category is converted to the quantity of that group's reference material required to cause the same effect.
- Valuation: The normalized profile is weighted to display the relative importance of each group in its consequence on the environment. The outcomes can be summed to give a single score.

Over consultation with a cross-section of involved parties, BRE Global has produced weighting factors shown in **Table 5** below. These weighting factors are used with the normalized environmental profile to produce a UK Ecopoints score.

Classification: Category	**Characterization and Normalisation: Per European Citizen Unit**	**Valuation: Weighting (%)**
Climate Change	12.3 tonne CO_2 eq. (100 yr)	21.6
Water Extraction	377 m^3 water extracted	11.7
Mineral Resource Extraction	24.4 tonnes minerals extracted	9.8
Stratospheric Ozone Depletion	0.217 kg CFC-11 eq.	9.1
Human Toxicity	19.7 tonnes 1,4-DB eq.	8.6
Ecotoxicity to Freshwater	1.32 tonnes 1,4-DB eq.	8.6
Higher Level Nuclear Waste	23,700 mm^3 high-level waste	8.2
Ecotoxicity to Land	123 kg 1,4-DB eq.	8.0
Waste Disposal	3.75 tonnes solid waste	7.7
Fossil Fuel Depletion	6.51 tonnes oil equivalent (toe) [63]	3.3
Eutrophication	32.5 kg PO_4 eq.	3.0
Photochemical Ozone Creation	21.5 kg C_2H_4 eq.	0.2
Acidification	71.2 kg SO_2 eq.	0.05

Table 5: BRE Global weighting factors.

3.5.2.2.1 Categories Environmental Impact

The Green Guide assesses thirteen different environmental impact categories. Many different emission substances can cause environmental effects in one category, and one material can contribute to different impact categories. The step of characterization measures all the diverse materials that are contributing to an impact category, relatively producing an overall measure of the level of environmental impact in that category.

This is assumed by using reference material or unit, wherever the input of each assessed emission is calculated, converting the quantity of emission into the equivalent amount of the reference material or unit.

The Environmental Profiles Methodology uses characterization factors to cover a complete range of emissions and environmental impacts produced by the manufacturer, use, and disposal of construction materials.

1. Climate Change refers to the modification in global temperature produced by the release of "greenhouse gases" effect, for example, carbon dioxide produced by human action. A higher global temperature is likely to cause a climatic disturbance, desertification, rising sea levels, and the spread of diseases.

[63] Fossil fuel depletion is reported as MJ based on the Lower Heating Value for any fossil fuel used. The Lower Heating Value (also termed LHV, net calorific value or net CV) assumes that there is no recovery of the latent heat of vaporization of water in the fuel and the reaction products. One toe is around 42 GJ LHV.

2. Water Extraction: this factor is meant to recognize the value of water as a resource, and the damage caused by over-extraction from rivers and aquifers, this category contains all water withdrawal, except seawater; rainwater collected on-site, water extracted for power generation or cooling and then returned to the same source with no modification in water quality, water kept in holding lakes on-site for recirculation.

3. Mineral Resource Extraction: This category is associated with the consumption of any virgin mineral material, e.g., the mining of aggregates, metal ores, and minerals. This indicator is proposed to relate to resource use, with no coverage of other environmental impacts that might be associated with mining or quarrying or the relative scarcity of resources.

4. Stratospheric Ozone Depletion: Ozone reducing gases cause harm to the ozone layer. There is significant doubt about the joint impacts of different gases in the stratosphere, damage to the ozone layer decreases its capability to prevent ultraviolet (UV) light entering earth atmosphere, increasing the amount of carcinogenic UVB light striking the earth’s surface

5. Human Toxicity: The emission arising by some materials can have effects on human health. Valuations of toxicity are based on acceptable concentrations in air, water; air quality guidelines; acceptable daily consumption for human toxicity. Influences on air and water have been joint. This factor describes providence, exposure, and effects of toxic materials for an infinite time prospect.

6. Ecotoxicity to Freshwater Land: emission of some materials can have effects on fresh-water ecosystems. The assessment of toxicity is based on maximum acceptable concentrations for ecosystems. The factor describes fate, exposure, and the impacts of toxic substances on the environment.

7. Ecotoxicity to Land: emission of some substances can have effects on the terrestrial ecosystems. The assessment of toxicity is based on maximum acceptable concentrations for ecosystems.

8. Nuclear Waste: Radioactivity can cause severe harm to human health. At present, no treatment or lastingly secure storing solution exists for higher-level radioactive waste, for example, those produced by nuclear power manufacturing and from withdrawing

nuclear power stations. It to be stored for periods of 10,000 years or more for their radioactivity reaches safe levels.

9. Waste Disposal: This category factor characterizes the environmental problems related to the loss of resources implied by the final disposal of waste. BRE customs a total measure based on the mass of all waste that is disposed of in a landfill or burnt. It does not contain any other effects related to landfill or burning.

10. Fossil Fuel Depletion: This category factor is associated with the use of fossil fuels. Fossil fuels are a limited resource offering a valued source of energy and feedstock for materials such as plastics. Though there are alternatives, these are only able to replace a small proportion of our current use.

11. Eutrophication: Nitrates and phosphates are crucial for life, nonetheless increased concentrations in water can boost the extreme growth of algae and reduce the oxygen inside the water. Eutrophication can consequently be classified as the over-enrichment of watercourses. Its existence leads to damage to ecosystems, increasing mortality of marine fauna and flora, and to the loss of species that are reliant on low-nutrient environments.

12. Photochemical Ozone Creation: In atmospheres encompassing nitrogen oxides (NOx) and volatile organic compounds (VOCs), ozone can be formed in the existence of sunlight. Though known as ‘summer smog’ ozone in the high atmosphere has a protecting effect counter to ultraviolet (UV) light, low-level ozone is concerned with diverse effects, for example, crop damage and increased rate of asthma.

13. Acidification: Acid gases react with water in the atmosphere forming “acid rain,” a process recognized as acid deposition. Once this rain falls, frequently a significant distance from the source of the gas, it damages the ecosystem to variable degrees, dependent upon the nature of the ecosystem.

3.5.3 How the Green Guide is used

The Green Guide is used within BRE's BREEAM systems and the Code for Sustainable Homes. BREEAM aims to encourage the use of ingredients that have a lower influence on the environment, considering the whole life cycle of the materials in question. Credits are given for selecting high-performance specifications for main building elements using the Green Guide to Specification; several BREEAM schemes take a little different method to what elemental categories of the Green Guide will be used.

The Code for Sustainable Homes was published at the end of 2006 by the UK Department for Communities and Local Government ("Buildings: Specified Code for Sustainable Homes or BREEAM Standard | Brighton & Hove City Council," n.d.). The Code presented a single national standard used in the design and building of new homes in England and is based on the former BRE EcoHomes scheme. Inside the Code, credits are given for the use of materials with a low environmental effect. This is assessed using the Green Guide ratings, and five key elements are assessed under the code:

• Roof

• External wall

• Internal walls

• Upper and ground

• Windows

3.5.3.1 How to use the Green Guide online

The Green Guide online offers designers and assessors with easy-to-use guidance on how to make the best environmental selections when choosing building materials and components.

In the Green Guide online, construction materials and components are measured in terms of their environmental effect across their whole life cycle from the cradle to the grave, inside comparable specifications. This accessible and reliable data will be of great support to all those involved in the design, building, and management of constructions as they work to decrease the environmental impact of their built assets. Specifications revealed through the Green Guide would not be used as a base for on-site construction. They are generic to illustrate a range of typical materials, although each effort was made to ensure that the data specified here is accurate.

3.5.3.2 Element section

Each building component included in the Green Guide has its section. Some of the elements have been divided into types of specifications to become more user-friendly.

For example, the section on the component "Non-Loadbearing Internal Walls" has been subdivided into three subsections:

- Framed Partitions
- Masonry Partitions
- Proprietary and Demountable Partitions

Each section on a building component includes:

- A description of the functional unit
- Further description, where relevant
- Table showing applicability to BREEAM, Ecohomes, and Code for Sustainable Homes, if appropriate
- Element sub-categories linked to rating tables

3.5.3.3 Functional unit

At the start of each elemental building section, info is available on the functional unit. It provides critical data about the overall characteristics of each specification, counting the unit of comparison and its performance characteristics. For example, Functional unit insulation: $1m^2$ of insulation with thickness to offer a thermal resistance value of 3 m^2K/W, correspondent to around 100mm of insulation with a conductivity (k value) of 0.033 W/mK.

Functional units were established by BRE and placed out to consultation to guarantee they covered all relevant aspects and typical situations for each component.

3.5.3.4 Rating Tables

For each element, the Green Guide ratings are shown alphabetically in tables. Reliant on the number of specifications, the element set may have been divided into sub-categories. The ratings are based on the range for the entire element set, not the sub-categories.

The Green Guide rating tables are displayed as follows:

Green Guide 2008 ratings

Building type >	Domestic
Category >	Landscaping
Sub-category >	Boundary Protection

	Element number	Summary rating
Brickwork wall, 1 brick thick	827020001	E
Brickwork wall, 1/2 brick thick	827020002	B
Concrete post and gravel board close boarded fencing	827020020	A
Galvanised steel palisade fencing	827020018	C
Galvanised steel post and wire strung at 1 ft intervals	827020003	A+
Galvanised steel railings	827020004	B
Galvanised weld mesh fencing with metal posts	827020029	A
Galvanised wire chain link fence with metal posts	827020005	A
Hedging or any living barrier	827020006	A+
Perforated concrete blockwork wall	827020008	A+
Plastic coated chain link fencing with metal posts	827020009	A
Plastic coated steel palisade fencing	827020017	C
Plastic coated weld mesh fencing with metal posts	827020016	A+
Pre-treated timber close boarded fencing	827020010	A+
Pre-treated timber palisade or picket fencing	827020011	A+
Pre-treated timber post and panel fencing	827020012	A+
Pre-treated timber post and rail fencing	827020013	A+

Table 6: Green Guide rating table by element.

Choosing a separate element will show the comprehensive info for that element, plus the breakdown of ratings through the 13 environmental factors; as revealed below:

Green Guide 2008 ratings

Building type >	Domestic
Category >	Landscaping
Sub-category >	Boundary Protection

Element	Brickwork wall, 1/2 brick thick
Element Number	827020002
Summary Rating	B
Global Warming	D
Water Extraction	A
Minerals Extraction	A
Ozone Depletion	B
Human Toxicity	B
Freshwater Aquatic Toxicity	A
Nuclear Waste	B
Terrestrial Ecotoxicity	A
Waste Disposal	B
Fossil Fuel Depletion	B
Eutrophication	B
Photochemical Oxidation	A+
Acid Deposition	B

Table 7: Green Guide rating summary.

3.6 One Click LCA (2015)

This section will present One Click LCA (2015) in detail discussing its life cycle stages prospective, databases incorporated in it, and it supported standards.

3.6.1 Life cycle stages

They are also based on EN 15978. Life cycle stages for a structure are the different stages of a building's lifetime. For example, raw material collecting, manufacturing of products, use phase of the structure, end of life. European markets define the building life cycle stages by EN 15978 and EN 15804 standards, which can be included in LCAs. The following table lists all life cycle stages according to EN standards:

Product Stage			Construction Process Stage		Use Stage							End-of-Life Stage				Benefits and loads beyond the system boundary		
Raw material supply	Transport	Manufacturing	Transport to building site	Installation into building	Use/application	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction/demolition	Transport	Waste processing	Disposal	Reuse	Recovery	Recycling
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	D	D

Table 8: One Click LCA life cycle stages according to EN standards.Source: ("Life cycle stages," n.d.).

One Click LCA supports an assessment of a whole life cycle stages from Cradle to Grave as defined in EN 15978, as well as building products and processes in A1-A5, building use, energy, maintenance, water consumption in B1-B7, end-of-life impacts in C1-C4 and finally the external effects in module D.

One Click LCA tools target a whole building LCA for various certifications and assessment systems; the quantity of the life cycle phases existing is limited to match the requirement of each specific system. This is revealed in the table below.

	A1-A3	A4	A5	B1-B3	B4-B5	B6	B7	C1	C2	C3 - C4	D
Complete building LCA (EN 15978)	x	x	x	x	x	x	x	x	x	x	x
BREEAM –UK / -Intl	x	x	x	x	x	x	x	x	x	x	x
Building element LCA / BREEAM SE / NOR 1.0/11	x	x	x	x	x	x	x	x	x	x	x
LEED (CML, TRACI and Intl)	x	x		x	x			x	x	x	
HQE	x			x	x	x		x	x	x	x
DGNB-DE / -Intl / -DK	x				x	x				x	x
Bâtiment Bas Carbone	x	x	x	x	x					x	
Life cycle CO2	x	x	x	x	x	x	x	x	x	x	x
IMPACT-equivalent	x	x	x	x	x	x	x	x	x	x	x
IMPACT-compliant	x		x		x			x	x	x	
Embodied impacts of materials	x										

Table 9: Life-cycle stages supported by One Click LCA for each method. Source: ("Life cycle stages," n.d.)

3.6.1.1 End of life scenarios for building products

3.6.1.1.1 End of life scenario C1 - C2 emissions

One Click LCA's calculation method for End-of-life scenario C1 (Deconstruction, demolition) and C2 (Transport) is based on default values for demolition and transport. It must be noted that the C1/C2 emissions are not used in every certification tool as often C1/C2 emissions are outside of the scope. One of the reasons for this is that these emissions often cannot be influenced and are a significantly smaller portion of the total

C1-C4 emissions. C1 emissions only consider the fuel consumption of machinery; C2 emissions are based on the removed material mass.

3.6.1.1.2 End of life scenario C3 - C4 emissions

One Click LCA's calculation method for End-of-life scenario (C3-C4) and benefits and loads scenario (module D) follows EN 15 978 / EN 15804 and follows the categorization and end-of-life scenarios from DGNB International (2014) (p. 21) ("End of life scenarios for building products," n.d.). This does not apply to DGNB DE, DK, and International, in which C1-C2, C3-C4, and D information from the EPD is also taken into consideration.

3.6.1.1.3 Impact assessment categories

One Click LCA supports the 24 impact categories recorded in EN 15804 based on impact assessment method CML and 6 Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI) impact categories (Epa, of Research, & Technology Division, n.d.). Nevertheless, the impact categories existing for each calculation tool is dependent on its purpose. For example, BREEAM Mat 01 LCA tool only displays the six impact categories obligatory for this credit. Here below, a complete list of impact categories and which of them are revealed for each calculation tool.

Indicators	BNB	BREEAM UK/Intl	DGNB DE	DGNB Intl/DK	HQE	LEED CML/Intl	Building Element	LCA complete	life-cycle LCA	Life-cycle CO2
Global warming (Kg CO2 e)	X	x	x	x	x	x	x	x	x	x
Ozone depletion (Kg CFC-11 e)	X	x	x	x	x	x	x	x	x	
Acidification (Kg SO2 e)	X	x	x	x	x	x	x	x	x	
Eutrophication (Kg (PO4)3-e)	X	x	x	x	x	x	x	x	x	
Photochemical ozone depletion (Kg C4H4 e)	x	x	x	x	x	x	x	x	x	
Abiotic depletion (kg Sb e)			x					x		
Abiotic depletion (MJ net calorific value)								x		

Table 10: One Click LCA list of impact categories. Source: ("Impact assessment categories," n.d.)

Still included in One Click LCA other EN standard impact categories:

- The use of primary renewable and non-renewable energy and the use of primary renewable and non-renewable energy sources used as raw materials (MJ net calorific value)
- The use of secondary material (kg)
- The use of renewable and non-renewable secondary fuels (MJ net calorific value)
- The Net use of freshwater (m3)
- Hazardous and Non-hazardous of waste disposal (kg)

- Radioactive waste disposal (kg)
- Components and materials for re-use and recycling (kg)
- Materials for energy recovery (kg)
- Exported energy (MJ per energy carrier)
- Global warming potential (GWP): it is a comparative measure of how much heat is trapped in the atmosphere by greenhouse gas. The global warming potential is considered in carbon dioxide equivalents meaning that the greenhouse potential of emission is assumed to CO2. Subsequently, the time that gases stay in the atmosphere is combined within the calculation. A time-range for the assessment is defined as 100 years. For CML methodology, unit kgCO2-Eq and TRACI kgCO2-Eq/kg substance are used.
- Ozone depletion potential (ODP): it signifies a comparative value that specifies the potential of a material to extinguish ozone gas as associated with the potential of chlorofluorocarbon-11, which is given an orientation value of 1, resulting in a balanced state of entire ozone decrease. For CML methodology unit kg CFC-11-Eq and for TRACI kg CFC-11-Eq/kg substance is used.
- Acidification potential (AP): it occurs mainly through the change of air pollutants into acids, leading to a reduction in the pH-value of rainwater and fog. Acidification potential is defined as the capability of certain materials to shape and release H+ions and is given in sulfur dioxide equivalents (kgSO2-Eq/kg substance for TRACI and kgSO2-Eq for CML).
- Eutrophication potential (EP): it is the enhancement of nutrients in a space, it can be terrestrial or aquatic or. Any emissions of N and P to the soil, water, air, water, and biological material to water are combined into a single measure. The unit for TRACI is kg N-Eq/kg substance is used, and the CML methodology is kgPO4-Eq.
- Photochemical ozone creation potential (POCP) (Smog creation): Radiation from the sun generates aggressive reaction substances, for example, ozone, in the existence of nitrogen oxides and hydrocarbons. POCP for CML methodology is stated with the reference unit in ethylene-equivalents (kgC2H4-Eq), and for TRACI, the ozone formation is used as a reference (kgO3Eq/kg substance is used).
- Abiotic depletion potential (ADP) (Fossil fuel depletion): it defines the decrease of the total quantity of non-renewable raw resources in the globe and is determined per every abstraction of minerals and fossil fuels based on the remaining stock and

the rate of extraction. The results are calculated in MJ for TRACI methodology and CML methodology in reference case for Antimony kg Sb-eq or MJ.

- Human health cancer and noncancer; it focuses on covering those substances of concern within the US (e.g., TRI chemicals). It has then been known that the current global economy frequently requires the addition of suppliers who are outside of the US inside countries who may have their lists of reportable chemicals("Impact assessment / characterisation methodology in One Click LCA," n.d.). The USEtox extended set permits this extension into elements of concern globally. It is developed through two spatial scales: continental and global. The environmental compartments within the continental scale include rural air, urban air, industrial soil, agricultural soil, freshwater, and coastal marine water. The suggested units for the USEtox human health cancer, noncancer, and ecotoxicity are CTUcancer/kg, CTUnoncancer/kg, and CTUeco/kg, respectively.

3.6.1.1.4 The service life of materials

A product's service life is its period of use in service. Service life is necessary to calculate replacement impacts of the construction material within the calculation period. LCA and LCC usually use the service life of a building as a calculation period (BSI EN 16627, 2015). For some tools, the calculation period is pre-defined and cannot be modified by the user (Royal Institution of Chartered Surveyors., 2006).

Here is an example of building product impact with a service life of 12 years that is installed in a building with a service life of 60 years:

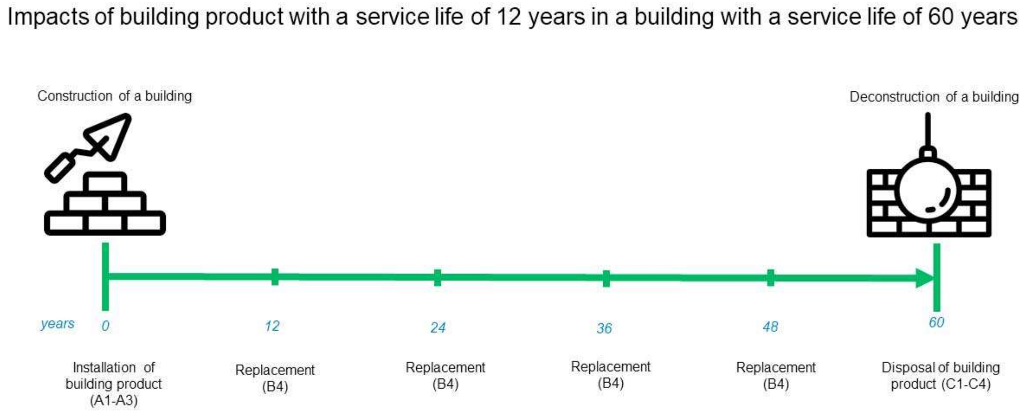

Table 11: An example of building product impact with a service life of 12 years. Source: ("Service life of materials," n.d.)

One Click LCA offers four options to determine the service life of building products:

Default service life declared in the product EPD is automatically included when adding a new resource.

Technical service life: This is the amount of time in which a product maintains its function.

Commercial service life: is the amount of time recommended for heavy use of a particular type of product. This is important for building products in buildings that require consistently high-quality standards, such as shopping spaces and hotels.

Table 12: Product service life based on the project-specific info. Source: ("Service life of materials," n.d.).

3.6.2 Databases incorporated in One Click LCA

For One Click LCA, most of the material's environmental effects are based on producer or product category EPDs, collected from different EPD databases, along with information from building material manufacturers. Moreover, it includes generic building material databases counting Oekobau.dat and IMPACT. Currently, One Click LCA database covers over 10.000 different building material resources ("Databases incorporated in One Click LCA," n.d.).

All the incoming building material info is checked for its validity, reasonability, and coverage before to be added to the database. It reviews, verify, curate, and integrate data from various public and private sources to the One Click LCA database for customer perusal. All data undergoes a rigorous ten-point verification using a process that has been reviewed by the Building Research Establishment (BRE). As the last step, the data is filtered according to the requirements of the calculation tool/scheme.

Region	European data coverage	Asia and Pacific	North American data coverage	Middle Eastern data coverage
	Environdec (The International EPD System)	One Click LCA generic construction materials database	One Click LCA generic construction materials database	One Click LCA generic construction materials database
	Spain: DAPconstrucción, GBC Espana, and AENOR	Australia: Building Products Innovation Council	ASTM	Environdec (International EPD Program)
	Germany: Ökobaudat, ift, Rosenheim, IBU, Kiwa BCS	EPD Australasia; ASTM; Environdec (International EPD Program)	CSAGroup	South American data coverage
	Netherlands: MRPI, NMD (Nationale Milieudatabase)	IBU	IERE Earthsure	BAU-EPD
	Switzerland: KBOB-Ökobilanzdaten	MRPI	FPInnovations	BRE
	France: INIES, PEP, Ecopassport	Ökobaudat	NREL	INIES
	United Kingdom: IMPACT, BRE	SCS Global	NRMCA	UL Environment
	Austria: BAU-EPD	UL Environment	NSF	EPD Americalatina
	Czech Republic: CENIA		SCS Global	GBC Brasil
	Portugal: DAP Habitat		UL Environment	
	Denmark: EPD Danmark		Quartz	
	Italy: EPD Italy			
	Poland: ITB			
	Slovenia: ZAG			
	Finland: RTS EPD			
	Ireland: EPD Ireland			
	Norway: EPD Norge			

Table 13: One Click LCA database.

3.6.3 Standards supported in One Click LCA

One Click LCA whole-life cycle assessment tool for the European market is based on the EN 15978 standard. The EN 15978 standard is according to the ISO 14040/44 standard, which means that any EN standard-based tools are also compliant with ISO 14040/44 ("Standards supported in One Click LCA," n.d.). Moreover, for the North American market, the tools are compliant with ISO (International Organization for

Standardization, 2006). The tool is also third-party verified for EN 15978, ISO 21931–1, ISO 21929–1, and input data for ISO 14040/44 and EN 15804 standards.

One Click LCA building product EPD tools are based on EN 15804 standard. This EN standard is also according to the ISO 14040/44 and compliant with ISO 14040/44. Moreover, the tool is also verified against EN 15804.

3.6.4 Functional/declared unit

The functional unit[64] describes the impact results for certain service levels the product provides. Such as, for insulation products, it could be 1 m2 of insulation which ensures a thermal resistance of 1.5 m2/WK for 50 years. It is usually used in the Environmental product declaration (EPD) calculations. When a product function in a building level is not known (e.g., if the product has different uses in the building) or once the study does not reflect all the life cycle stages, the declared unit is used instead of the functional unit. It represents the physical quantity of the product, such as 1 m2 of 50 mm thick insulation or 1 kg insulation ("Functional/declared unit," n.d.).

In One Click LCA product level calculations, the unit can be (without restrictions) selected based on the material, and the studied life cycle stage. For buildings, most of the LCA tools in One Click LCA provide results as an overall for the whole building and per 1 m2 of building area (different area definitions can be used). Furthermore, other units such as impacts per 1 m2 of building/year of building use or impacts per user amount might be offered for some tools.

3.6.5 Energy impacts

In One Click LCA database, the influences of electricity and district heat have been counted using the energy production fuel mixes for each country provided by the International Energy Agency (IEA).

The effects of the fuels have been modeled based on the Ecoinvent Centre database (Ecoinvent, 2016). IPCC Guidelines (Darío Gómez et al., n.d.) and Emission Inventory Guidebook (Trozzi, n.d.) have also been used to complement the exhaust emission data("Energy impacts," n.d.).

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[64] Functional unit is the unit used to declare the result in the EPD and the building life cycle assessment.

The impacts of the electricity are calculated using the obtained fuel mixes and the effects of the diverse fuels and using the production of energy as a denominator, accordingly, resulting in impacts per kWh of energy.

Chapter 4: Case studies

4.1 Overview

The chapter presents the analyzed case studies going step by step using One Click LCA performing a complete life cycle assessment. It will discuss each case in a different section highlighting each step and concluding with the resulting report for each studied building.

This chapter will present the findings and results clearly and objectively. It will not discuss what the findings mean.

4.2 Erith Quarry Primary School

Project Information

- Location: London
- Sector: Education, Schools

Partners

- Architect: SEW Architects, MLM Group

Located in South East London by the River Thames, this is a former quarry and landfill site. This unique circular, three-story 630 people primary school is part of the Quarry Hills development. The school is situated at the highest, most prominent point of Erith Quarry, and becomes the focal point of the emerging community.

Figure 18: Erith Quarry Primary School. Source: ("Places – Studio Egret West," n.d.)

Key Features

- Exceptional sun-lighting
- Primarily naturally ventilated
- Underfloor heating
- Green roof
- LED internal and external lighting
- Photovoltaic panels on the roof

The school's circular footprint is embedded into the landscape, elevated above terraced communal spaces. The circular shape maximizes natural daylight and ventilation and provides the flexibility of space that will allow a comprehensive curriculum of teaching areas, multipurpose halls, and a music and drama studio. It also provides space for a central, external courtyard, which creates a secure sanctuary for both play and outdoor learning ("Places – Studio Egret West," n.d.).

Figure 19: Circular frame of Erith Quarry Primary School. Source: ("Places – Studio Egret West," n.d.)

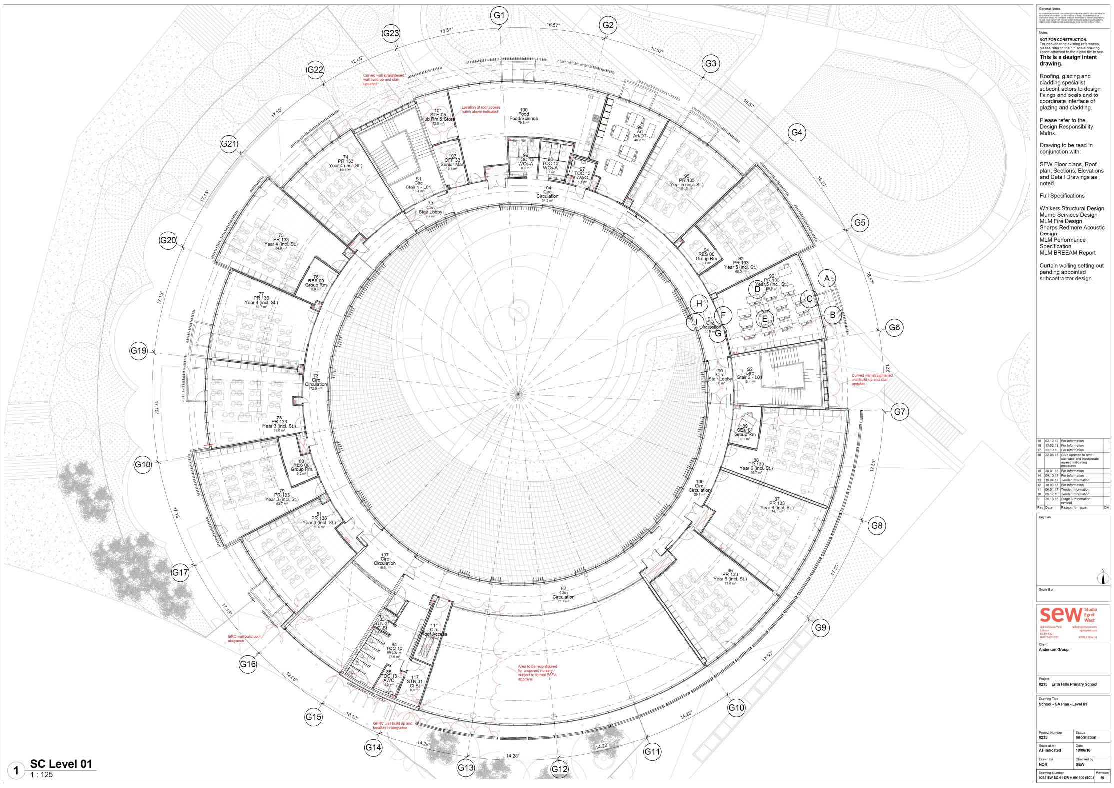


Figure 20: Circular frame structural drawing.

The school building is designed with concrete, glass, and timber as the primary materials. These have a strong relationship with the historical background of the quarry and the existing woodland, guaranteeing that it blends in comfortably with its setting.

Figure 21: Front view, Erith Quarry Primary School. Source: ("Places – Studio Egret West," n.d.)

Figure 22: Front view structural drawing

The glazing maximizes natural daylight and visual connections to the landscape with 360-degree views out across the landscape.

Figure 23: Natural lighting glazing. Source: ("Places – Studio Egret West," n.d.)

Figure 24: Glazing drawing details.

4.2.1 Step by step guidance

For the first case study, the Revit model of the building was not applicable, so all building data and materials specifications were inputted manually to One Click LCA and here are the steps:

1. The first step was to open One Click LCA website and to create a student account and to request student lenience that the tool offers.
2. Go to the home page to register the project and enter specifications.

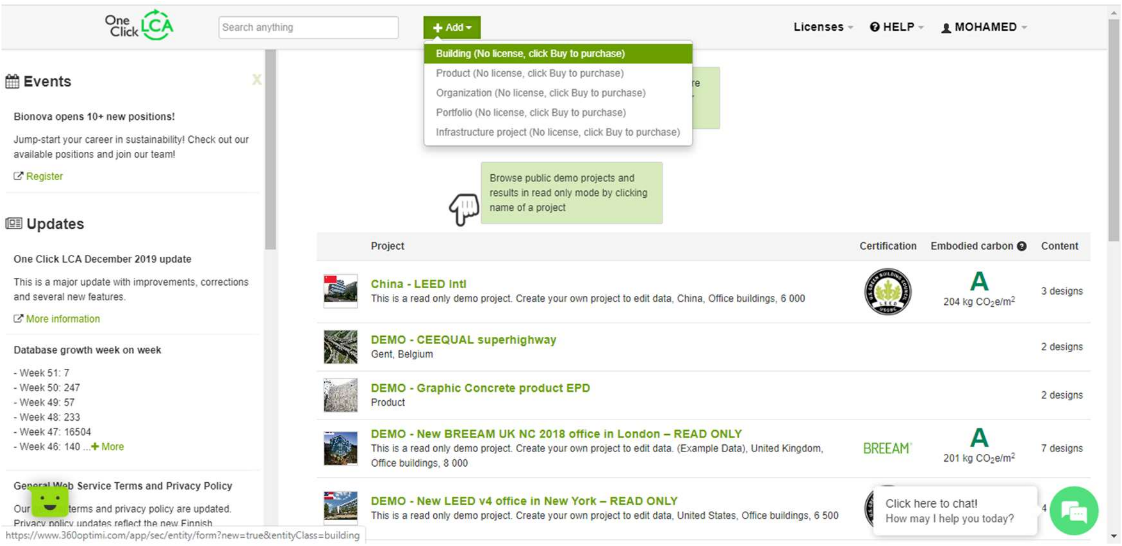


Figure 25: One Click LCA Home Page.

3. Input building details and set the calculation period and building area

- Enter here the service life of the building required by the client or through regulations; for LCA, this is also the reference study period/calculation period for the analysis.
- Enter the building area in the respective question form. Specify as a minimum gross internal floor area (GIFA). This will be used to provide results per 1 m2, in order to make the possible comparison between different projects.
- Enter the certification pursued and the intended assessment scheme (BREEAM, LEED, etcetera).

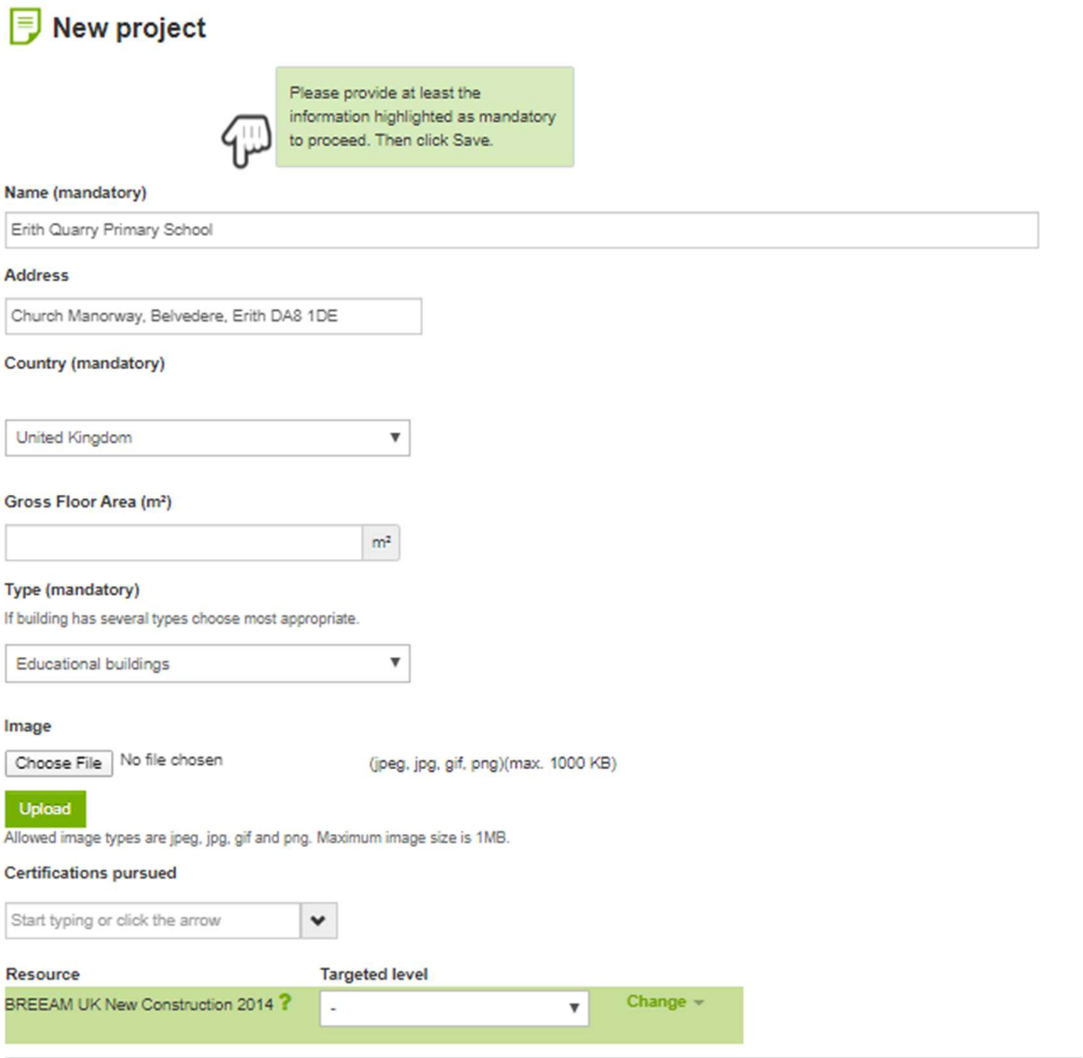


Figure 26: One Click LCA new project.

- Enter the license number provided upon request

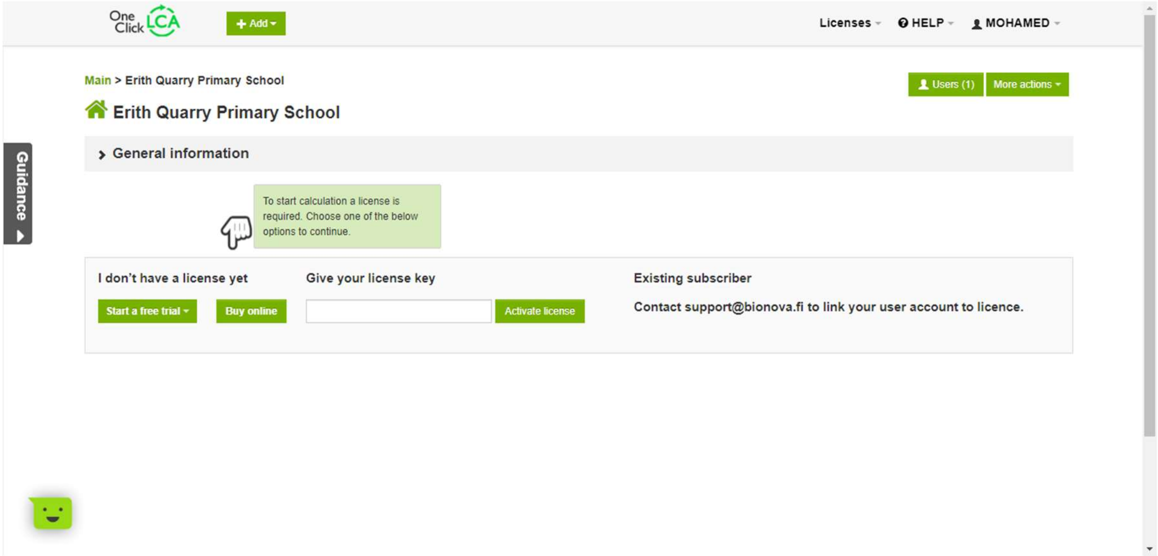


Figure 27: One Click LCA license input.

- Create a new design within the project specifying the design name, design stage (RIBA /AIA stages), calculation tools, scope, and type of analysis.

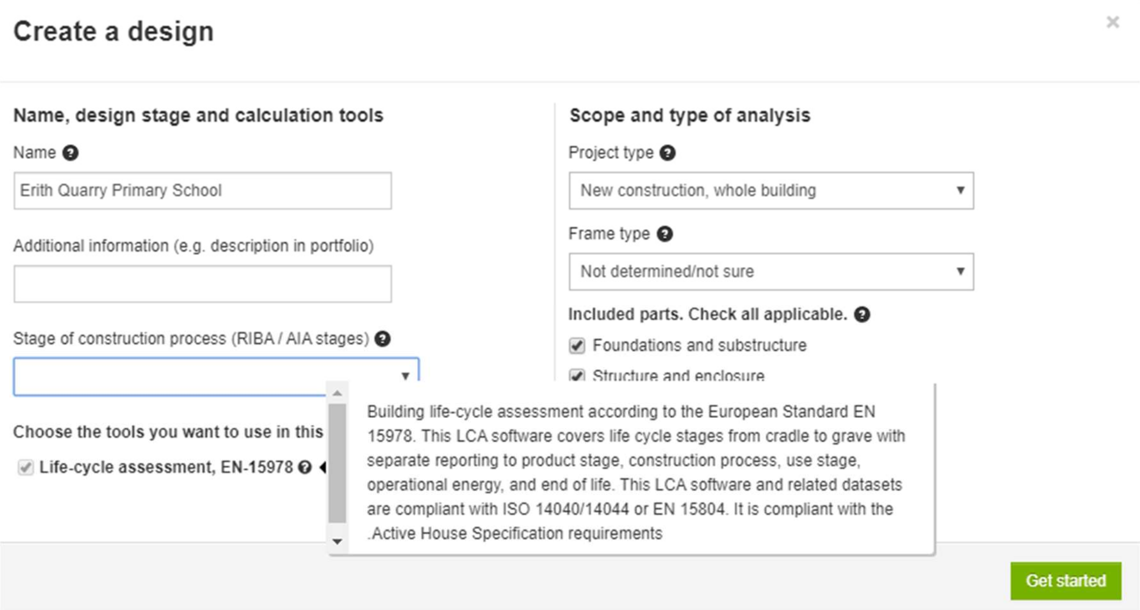


Figure 28: One Click LCA creates a design.

4. Set design's LCA parameters and LCA default values for materials calculation

- It is possible to fill in or modify the Parameters to ensure the correct default values. In the case of uncertainty of which settings could be used, it also possible to use the default values, which are based on the project location. These values can always be edited later.

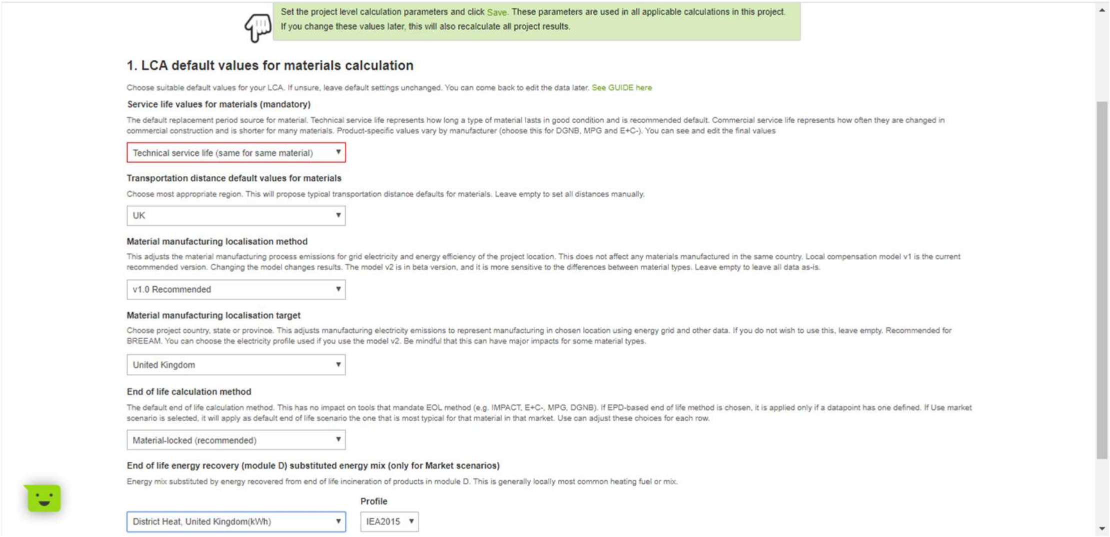


Figure 29: One Click LCA default parameter setting.

- Service life values: Each material row in the assessment will use a specific service life to calculate its impacts for replacement and disposal (B4-B5 category). At this point, it is possible to define the default service life that is automatically applied to every material in the calculation. The default value will be ignored if a change was made to the service life manually.

  Technical service life - In the technical service life, it is assumed that the same type of materials has the same service life setting. The technical service life represents how long materials last in the right conditions, and this service life setting is the recommended default.
- Commercial service life - The commercial service life setting should be selected when doing retail or hotel projects, in which the service life of the interior (and other materials) is shorter. E.g., flooring and finishes will be replaced more often with this service life setting.
- Product-specific service life - With this service life setting, the service life values vary per manufacturer, and the settings from the EPD will be used. Choose this service life setting for DGNB, E+C- and MPG calculations.

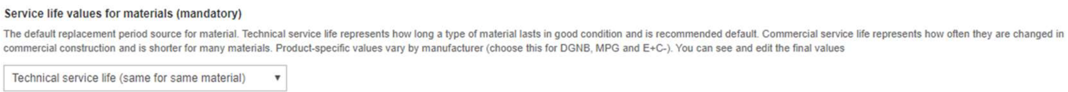


Figure 30: One Click LCA Choose the service life setting.

- Transportation distance - default values for materials: Each material row in the assessment will use a specific transportation mode and distance from the building material manufacturer to the building site to calculate its transportation impacts. Here it is possible to define the default transportation distances that are automatically applied to every material in the calculation. The default value will be ignored if any change was made to the input manually in the 'Building materials' question form.

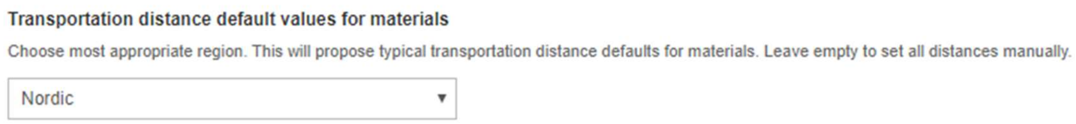


Figure 31: One Click LCA Choose the default transportation values.

- Material manufacturing localization method: Each material in the assessment has its manufacturing impacts primarily defined by the energy profile of its manufacturing country. Here it is possible to select the local compensation factor, which adjusts the impacts of material manufacturing in another country to represent manufacturing in the chosen location.
- The material manufacturing localization method (formerly called Local compensation) solves the lack of local environmental profiles for projects all over the world. It automatically adjusts manufacturing electricity to the local electricity mix so that it is possible always to get more representative results for the projects. It is important to note that this does not change the manufacturing process fuel mix (e.g., from coal or oil to natural gas). The process applies only to electricity as that invariably changes between locations of manufacturing, while the same process fuels may be used in plants making similar products across the globe.

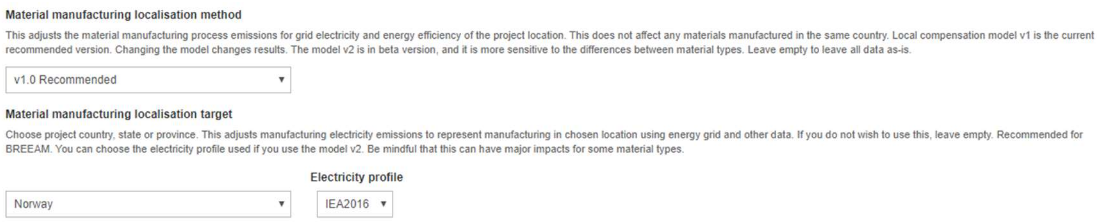


Figure 32: One Click LCA Choose the material manufacturing localization target.

5. Enter the construction materials, site operations, energy, and water demand.

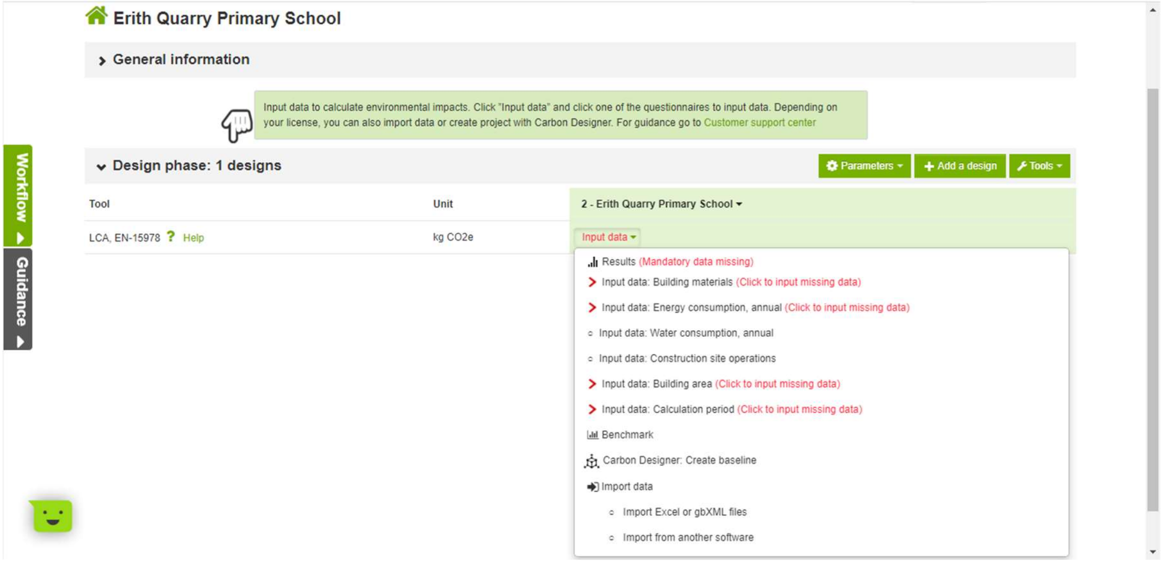


Figure 33: One Click LCA Data input.

- Use net quantities (amounts of material installed in the building), which shall be accurate to +/- 5 %. For each material, it is possible to adjust the service life based on the product, transportation distance and mode and use the Comment field for additional info (e.g., specify the construction element where the material belongs to). The resources are used for calculating A1-A3, B1-B5, C1-C4, and D modules.
- For construction site operations, specify the climate region and construction site area (question 1 in Construction site operations question form) OR input manually project-specific information in the questions 2-5.
- Materials specifications were taken from Materials Breakdown provided, and AutoCAD drawings see Appendix and Appendix
- Include project-specific data for annual energy (kWh/y) and water (m3/y) consumption.

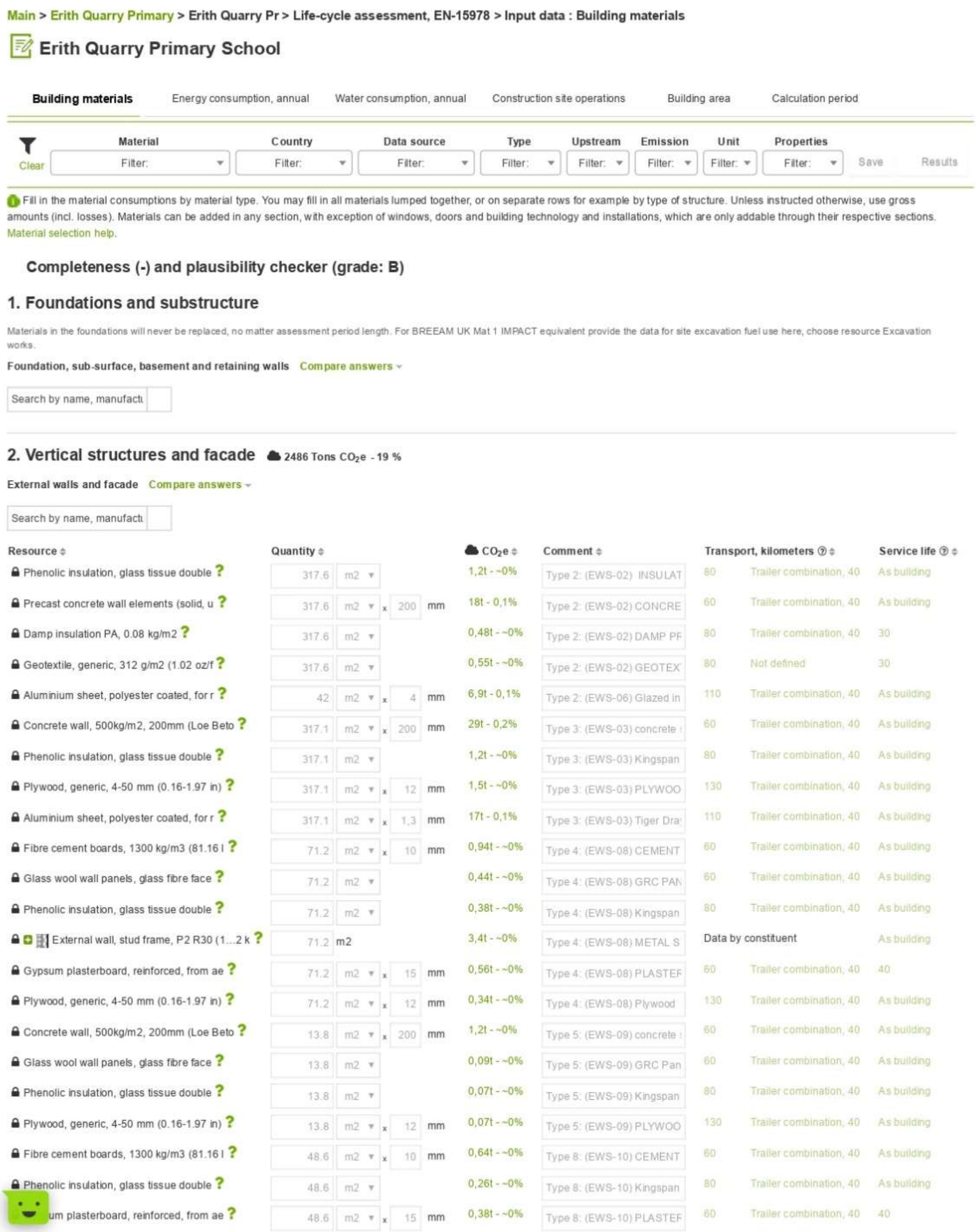


Figure 34: Manually input building materials (a screenshot from the tool online).

6. Click 'Results' to analyze the LCA

- The results will be reported as a generic overview of the impact categories and life cycle modules. It is possible to download a detailed report by clicking 'More actions'->'Detailed report,' which enables you to download an Excel file.
- Results are visualized for most contributing materials for each impact category, breakdown of Global Warming Potential for different life cycle modules, and graph of result accumulation over the service life of the building.

4.2.2 Resulting report

One Click LCA generates a comprehensive report as the result of the analysis. Here is the resulting report of Erith Quarry Primary School building analysis:

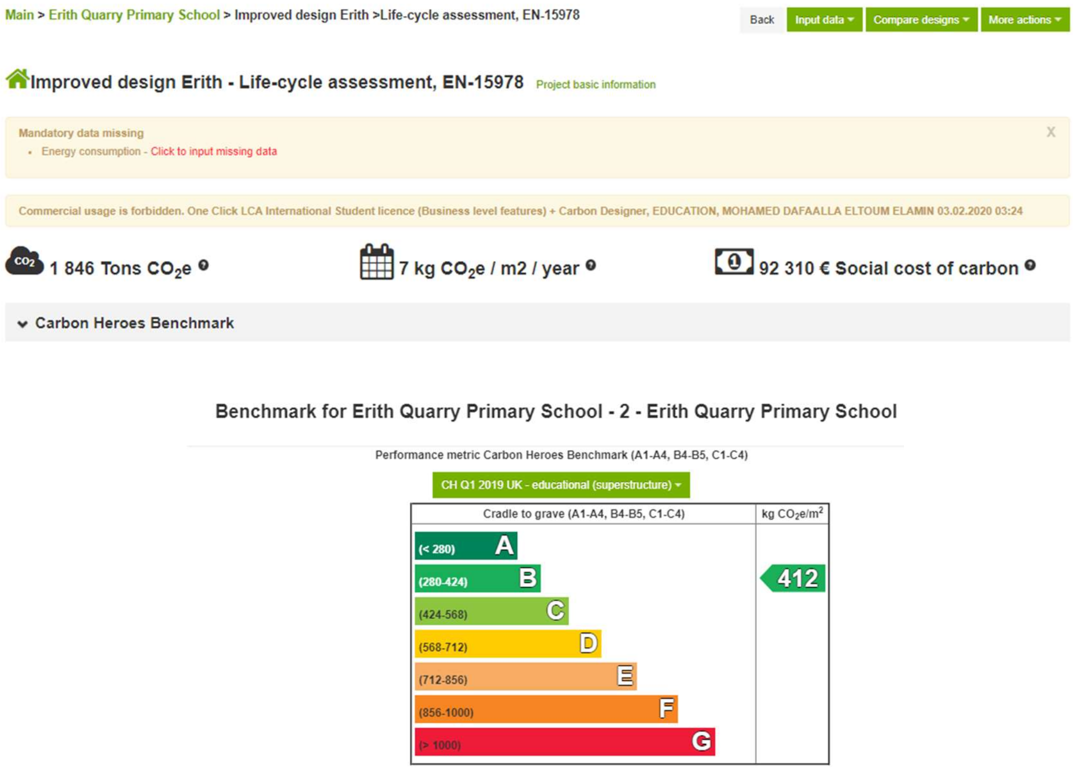


Figure 35: Erith Quarry Primary School Embodied carbon benchmark.

Results

Life-cycle assessment results

	Sector	Global warming kg CO2e	Acidification kg SO2e	Eutrophication kg PO4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ
A1-A3	Construction Materials	1 037 651,56	4 241,11	14 432,86	0,06	493,71	123 978 427,93
A4	Transportation to site	14 700,79	67,34	14,66	0	0,86	419 033,36
B1-B5	Maintenance and material replacement	639 457,15	3 688,91	28 284,77	0,04	264,99	13 724 574,85
B7	Water use	115,74	0,81	2,32	0	0,03	2 088,42
C1-C4	Deconstruction	154 274,68	319,09	55,46	0,01	7,96	1 198 012,58
D	External impacts (not included in totals)	-137 531,38	-285,04	-78,57	-0	-18,31	-1 173 425,22
	Total	**1 846 199,92**	**8 317,26**	**42 790,07**	**0,11**	**767,55**	**139 322 137,14**
	Results per denominator						
	Gross Internal Floor Area (IPMS/RICS) 4473.7 m2	412,68	1,86	9,56	0	0,17	31 142,49

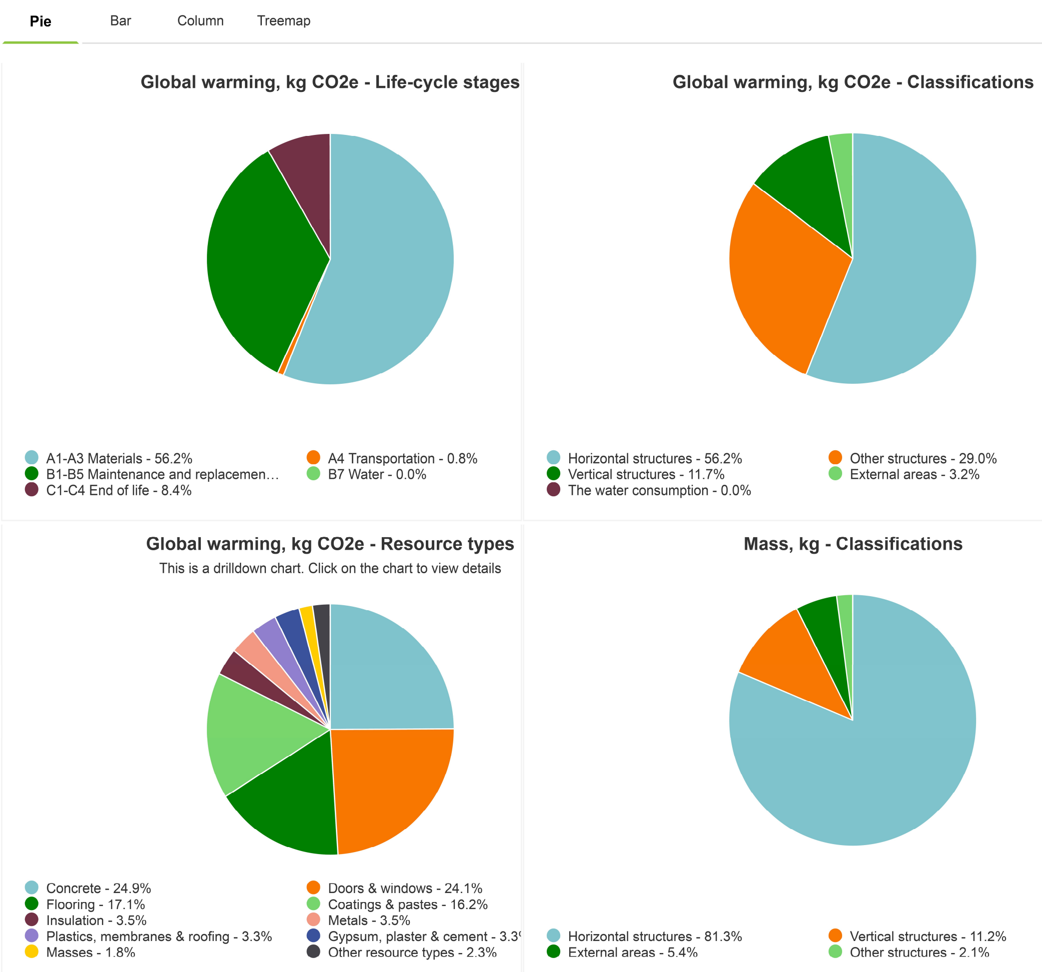
Table 14: Erith Quarry Primary School Life-cycle assessment results by stage.

Most contributing materials (Global warming)

No.	Resource	Cradle to gate impacts (A1-A3)	Of cradle to gate (A1-A3)	Sustainable alternatives
1.	Hollow core concrete slabs, generic	343 tons CO_2e	33.1 %	show sustainable alternatives
2.	Aluminium framed glazed doors, single glazed, per sq. meter	212 tons CO_2e	20.4 %	show sustainable alternatives
3.	Polyurethane waterproofing membrane	92 tons CO_2e	8.9 %	show sustainable alternatives
4.	XPS insulation board	58 tons CO_2e	5.6 %	show sustainable alternatives
5.	Sound and shock absorbent recycled rubber flooring	50 tons CO_2e	4.8 %	show sustainable alternatives
6.	Metal framing components for gypsum plasterboard	38 tons CO_2e	3.6 %	show sustainable alternatives
7.	Concrete wall	29 tons CO_2e	2.8 %	show sustainable alternatives
8.	Aluminium sheet, polyester coated, for roofing, cladding and facades panels, 1mm	26 tons CO_2e	2.6 %	show sustainable alternatives
9.	Facing bricks, clay pavers and brick slips	25 tons CO_2e	2.4 %	show sustainable alternatives
10.	Window, glass roof	21 tons CO_2e	2.0 %	show sustainable alternatives

Table 15: Erith Quarry Primary School's most contributing materials for global warming.

Life-cycle overview of Global warming



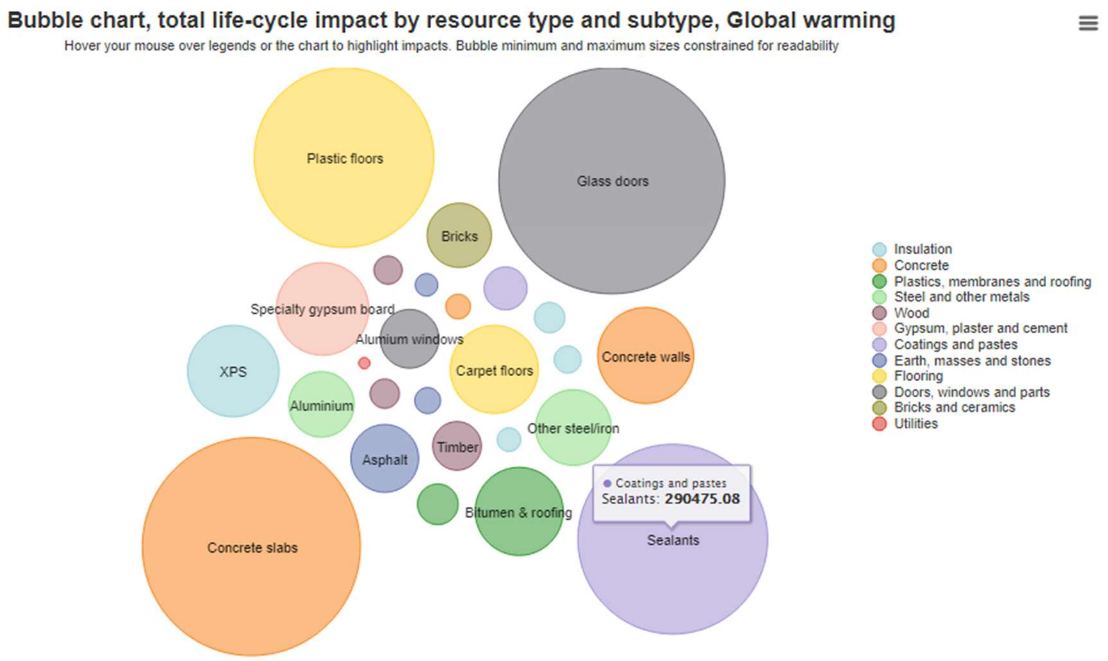


Figure 36: Total life-cycle impact by resource type and subtype.

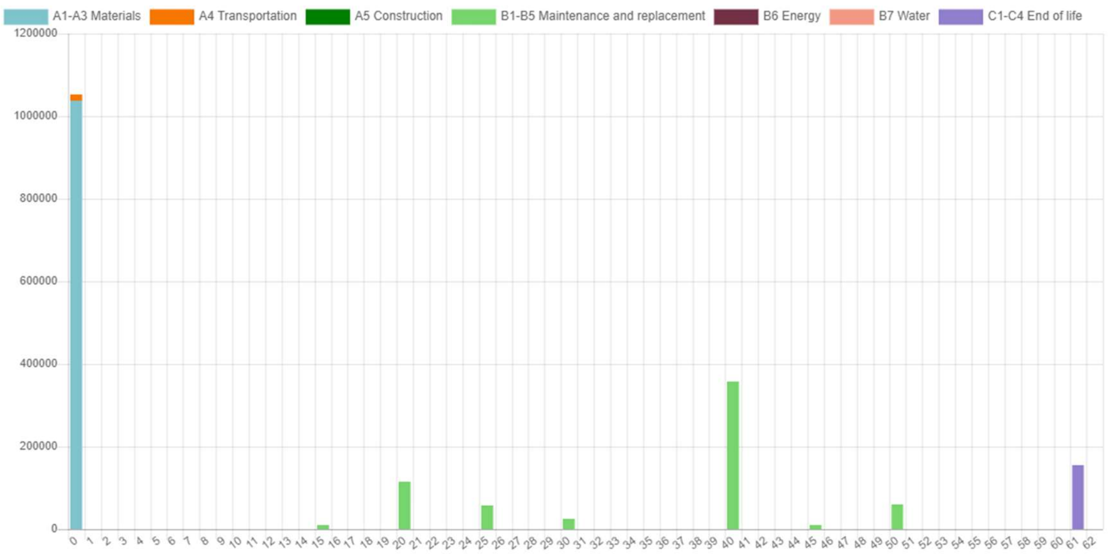


Figure 37: Visualisation of annual impacts.

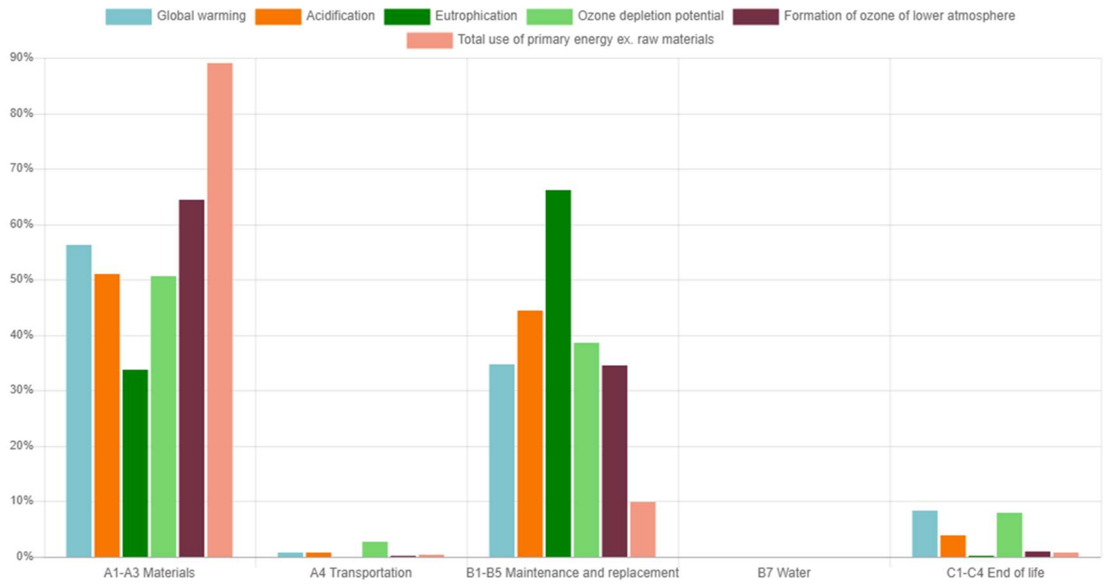


Figure 38: Results by life-cycle stage.

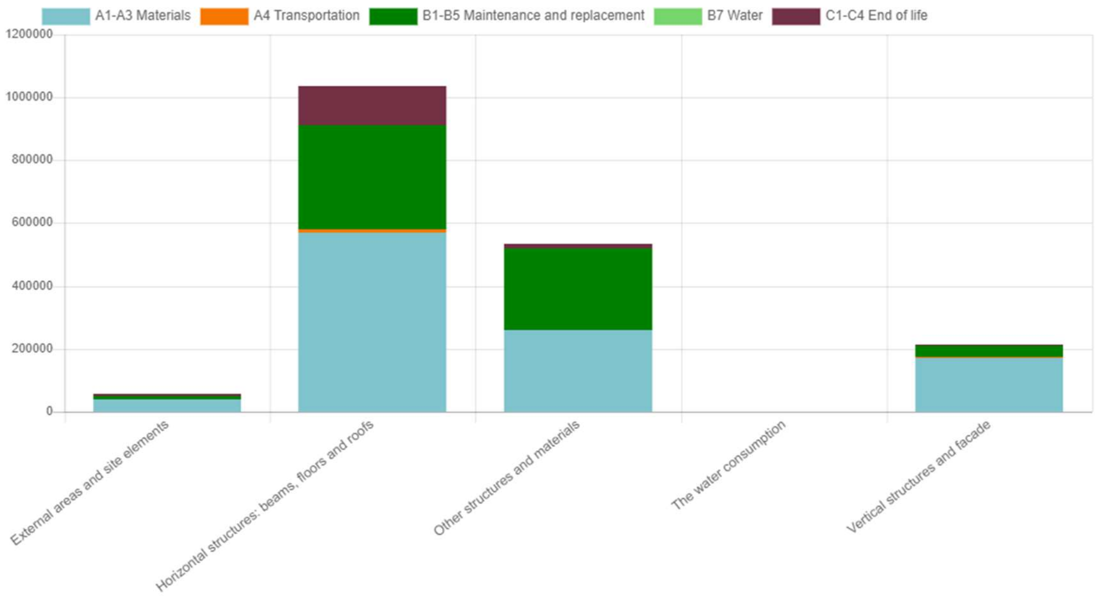


Figure 39: Global warming (GWP) breakdown.

4.3 Queen Mary School of Business and Management

Project Information

- Location: London
- Sector: Education, Schools

Partners

- Architect: SEW Architects, MLM Group, Nicholas Hare Architects,
- AECOM
- Gardiner and Theobald
- PLMR Snapdragon
- CBRE

Background & vision

Hatton House and the Arts Research Centre are located at the southeastern corner of the Mile End Campus, adjacent to the Regent's Canal. To maintain and enhance Queen Mary's reputation for academic excellence, and to continue to provide opportunities to students, the University is bringing forward its plans to redevelop the sites in order to provide a new building for the School of Business and Management (SBM).

The School of Business and Management is currently located within the Francis Bancroft Building. The space within the Building, when vacated, will be used to help grow other departments at Queen Mary.

Core purpose

To promote social justice, sustainability and good governance in the management of private, public and voluntary organizations through the School's research and education.

Figure 40: Queen Mary School of Business and Management location

Source:(*Queen Mary Univesity of London consultation displaying*, n.d.)

Qualitative Feedback

Based on the comment forms and feedback with students staff and the community, these were the main issues raised:

• Provide more study space for Queen Mary students and staff

• Support for improvements to the towpath

• Provide more space for the local community.

• Safeguard heritage

• Minimize disruption from the construction of the new building.

Focused on:

1. Creating better links and accessibility to the community

2. Ensuring that heritage is reflected in high-quality design

3. Providing new vibrant public spaces

4. Delivering effective education and study space

Proposals

Summary of proposals:

• 8255 sqm of educational floorspace

• Six stories of teaching and research space

• Social learning areas for all Queen Mary students

• Public access to the building at both upper and lower ground levels

• Working with the existing site levels to provide a ground floor entrance level and a lower ground level that connects with the canal side path

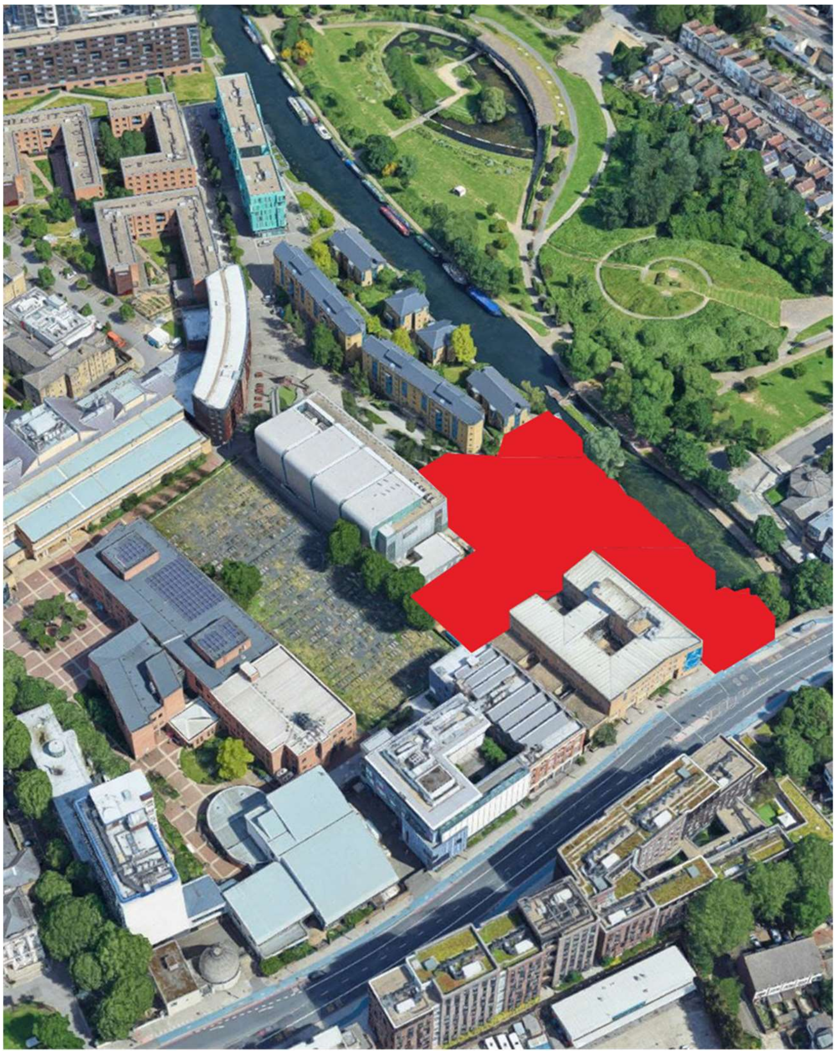


Figure 41: Queen Mary School of Business and Management location

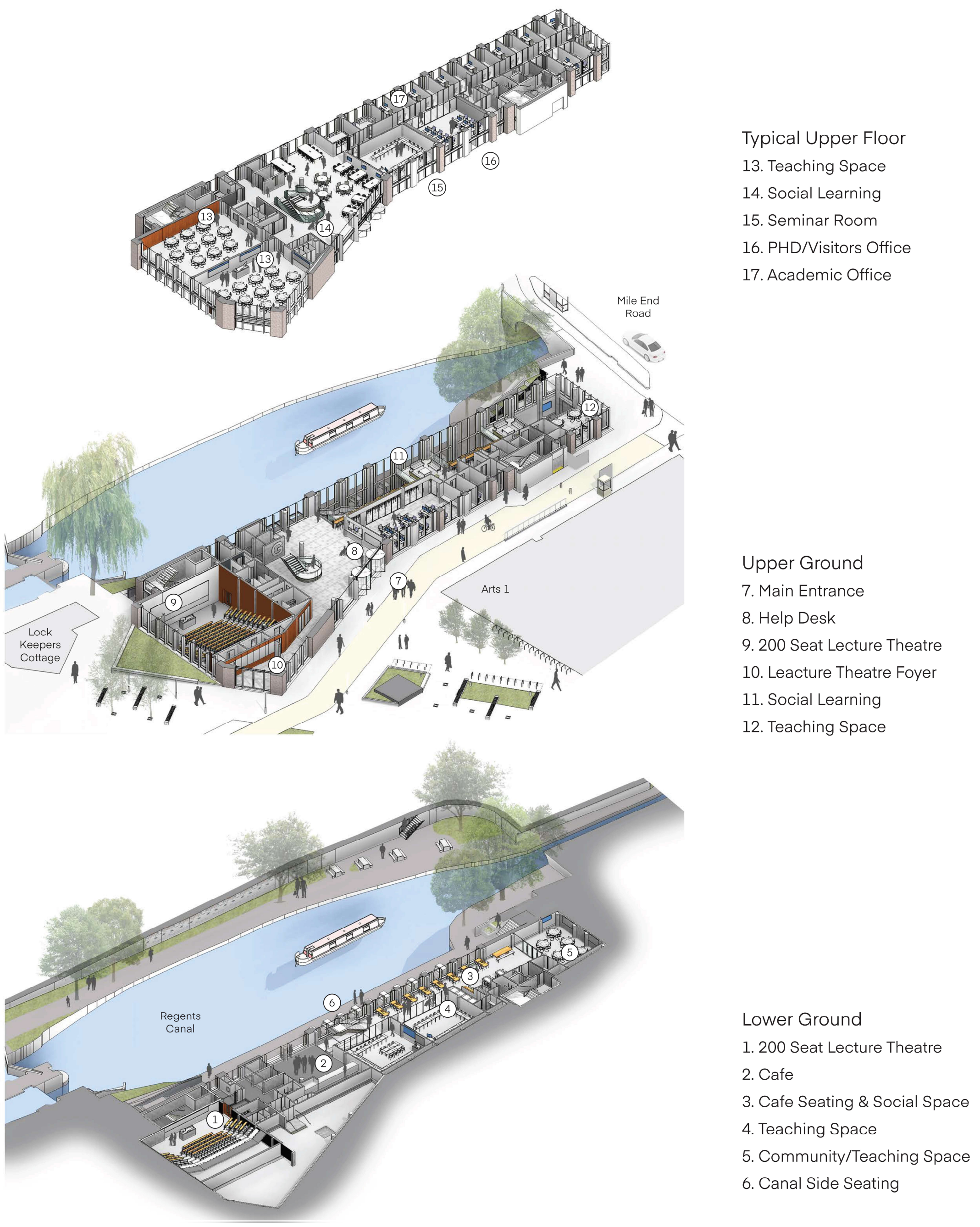


Figure 42: Queen Mary School of Business and Management floor plan.

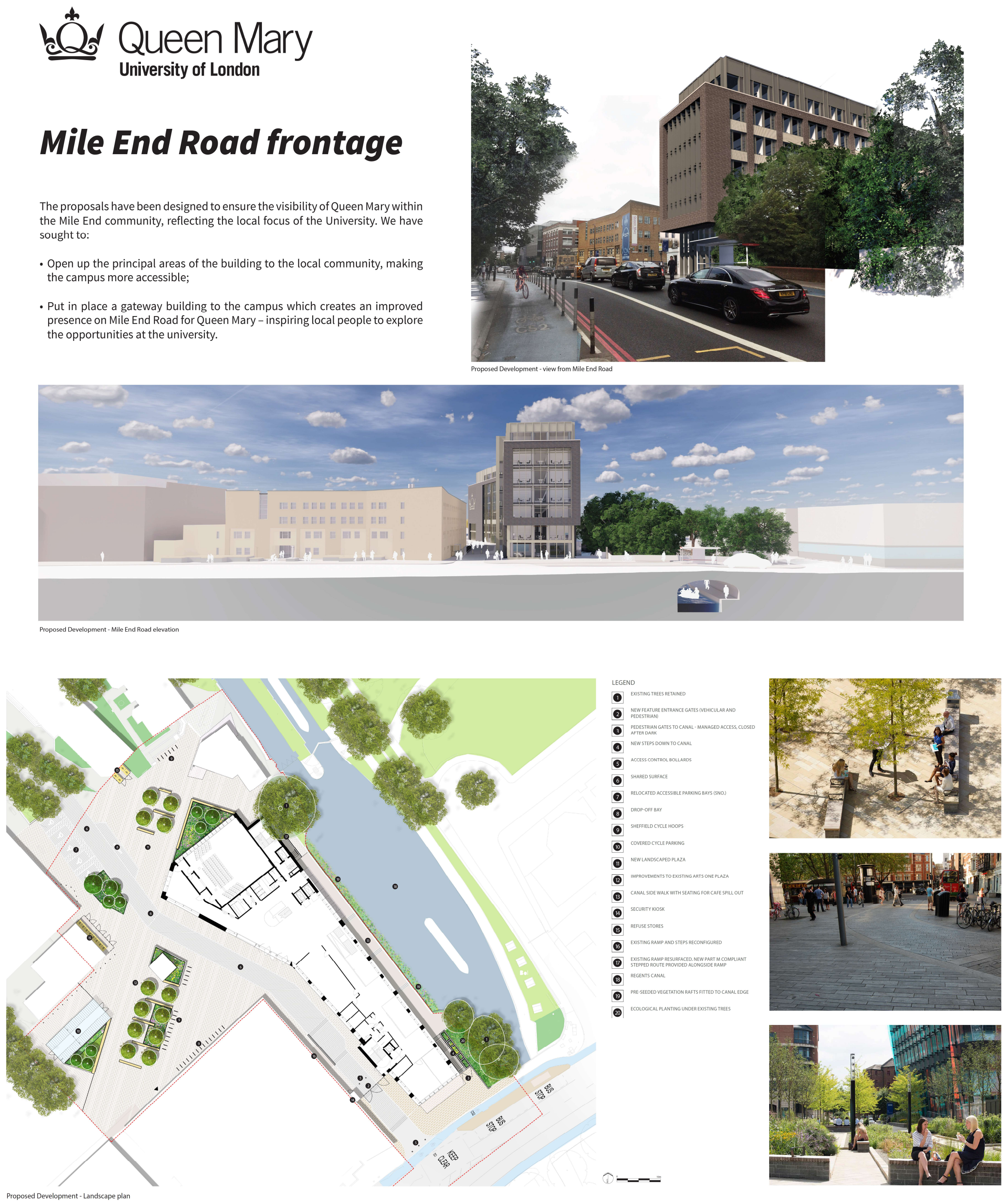
Source:(*Queen Mary Univesity of London consultation displaying*, n.d.)

• Great views from the new buildings and social learning spaces across the canal basin to the park.

• A vibrant cafe and social space at canal side level with direct access from Mile End Road.

• A building designed to the highest quality that can be appreciated from the campus and the Mile End Park.

• BREEAM excellent design to meet Tower Hamlet's energy and sustainability objectives in the new local plan.



Queen Mary
University of London

Improved access

The scheme will make access to the campus more pedestrian and cycle friendly. The provision of "shared space" will prioritise pedestrians.

Vehicular access will be strictly controlled by on-site security. Rising bollards will control access during the day with gates allowing the site to be secured at night.

The new access route will be a predominantly "car free" development with parking for only for designated Blue Badge holders. The existing designated parking spaces will be relocated so that they are more accessible for users of the new School of Business and Management as well as the other buildings nearby.

There will be new covered secure cycle parking and existing cycle hoops will be relocated so that they are more easily monitored.

The new shared space will encourage access to the whole campus increasing permeability for the local community as well as Queen Mary staff, students and visitors.

Proposed Development - View across main square

Access, parking and cycle parking

1. Designated accessible parking
2. Shared surface
3. Campus entrance
4. Covered cycle parking
5. Relocated cycle parking

Appearance & materials

The design of the façades and the choice of materials have been inspired by the industrial heritage of the site – particularly the large brick warehouses still found along the Regent's canal.

A focus on sustainability has also influenced material choices. The brick and glass exteriors are robust and long lasting as well as appropriate to their setting.

Most windows incorporate metal louvres so that the internal spaces can be naturally ventilated. The heavy, highly insulated structure helps keep the building cool in Summer and warm in Winter.

The lower storeys are more highly glazed so that the building feels open and welcoming.

A sustainable brown roof with arrays of photovoltaics contributes to biodiversity and helps reduce energy demands.

Proposed Development

Grey brick | Natural ventilation - louvres | Contrasting spandrels | Bronze aluminium top storey | Photovoltaic panels on roof

Source:(*Queen Mary Univesity of London consultation displaying*, n.d.)

4.3.1 Step by step guidance

For the second case study, a Revit model for the building was available, which reduced the assessment steps as building materials were automatically inputted using One Click LCA Revit plugin. Importing is a core process of One Click LCA. It is built on a patent-pending technology for transforming models to life-cycle impact assessments. Using the plugin to enter the building data automatically and materials specifications trailed the following steps:

1. Download the plugin from the Revit store. In the store search for 'One Click LCA' and follow the steps for downloading the plugin.
2. Open the project on Revit and make sure using the Revit model in which the materials are defined.

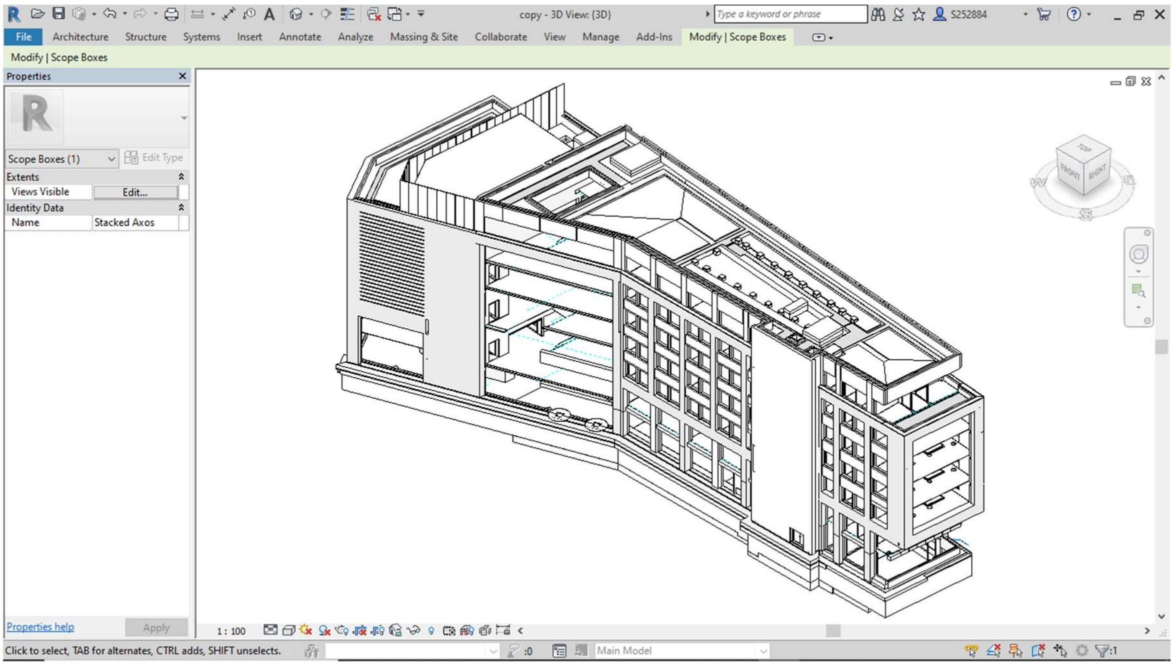


Figure 43: Queen Mary School of Business and Management Revit 3D model.

3. After making sure that the model is valid, the plugin can be opened from One Click LCA button in the Revit Add-Ins list. This takes to the One Click LCA plug-in to continue the process.

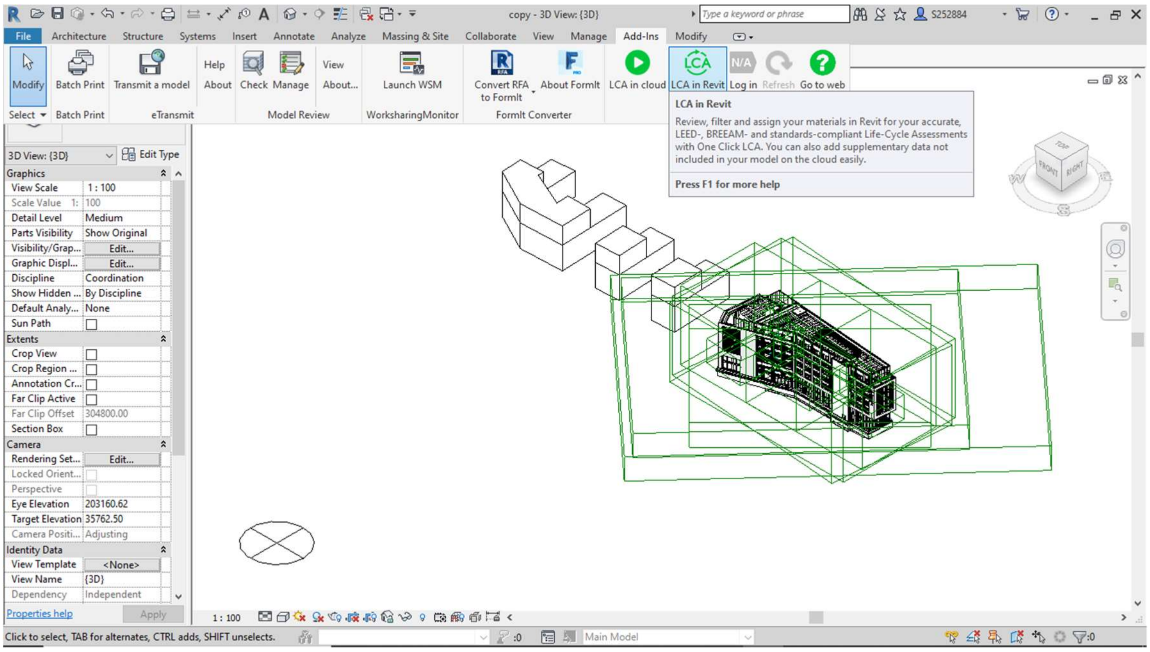


Figure 44: One Click LCA Revit Plug-In

- The plugin gives the ability to analyze the model and define all necessary for the export in the plug-in by using different functions. The desired material scope is selected to include in the analysis in the Categories tab. It is also possible to choose the unit in which the materials are exported.

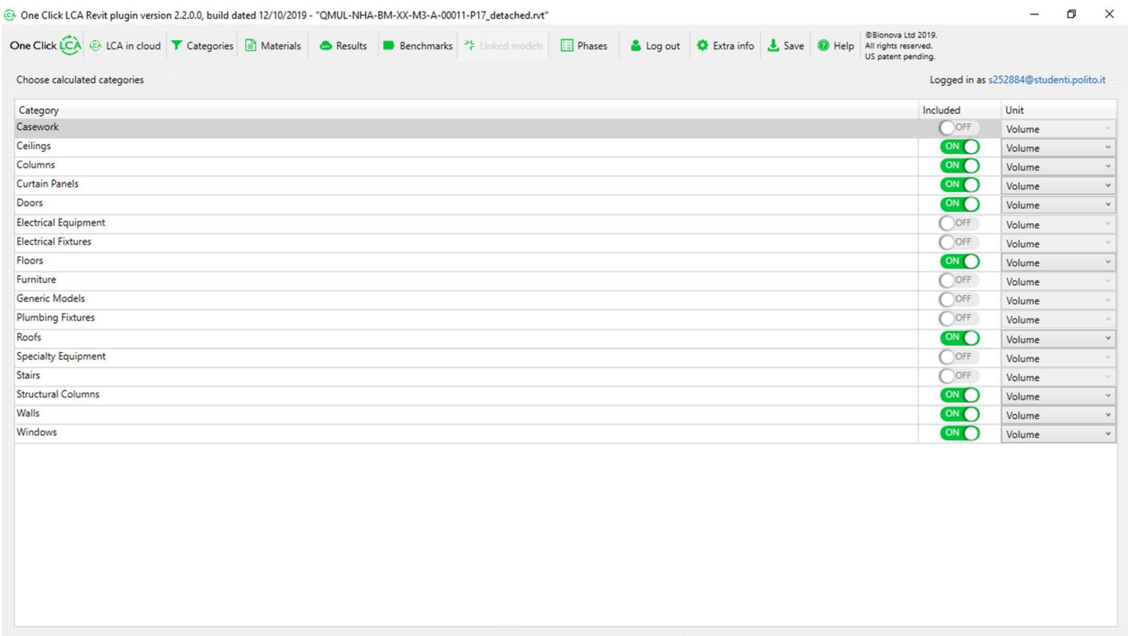


Figure 45: One Click LCA Revit Plugin home page.

4. Click 'Run LCA' to export the model to One Click LCA web-interface.

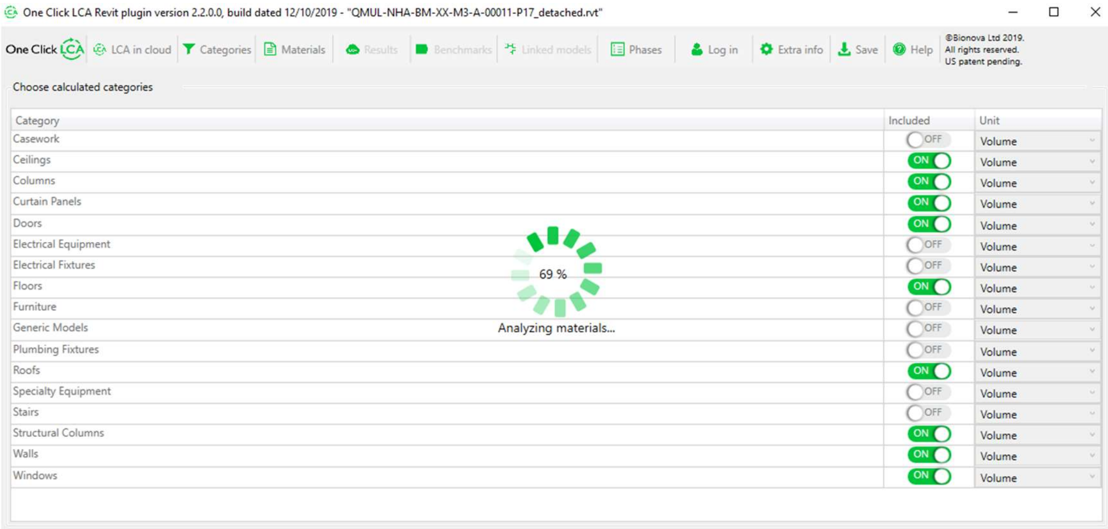


Figure 46: One CLick LCA analyzing materials.

5. Set the import target

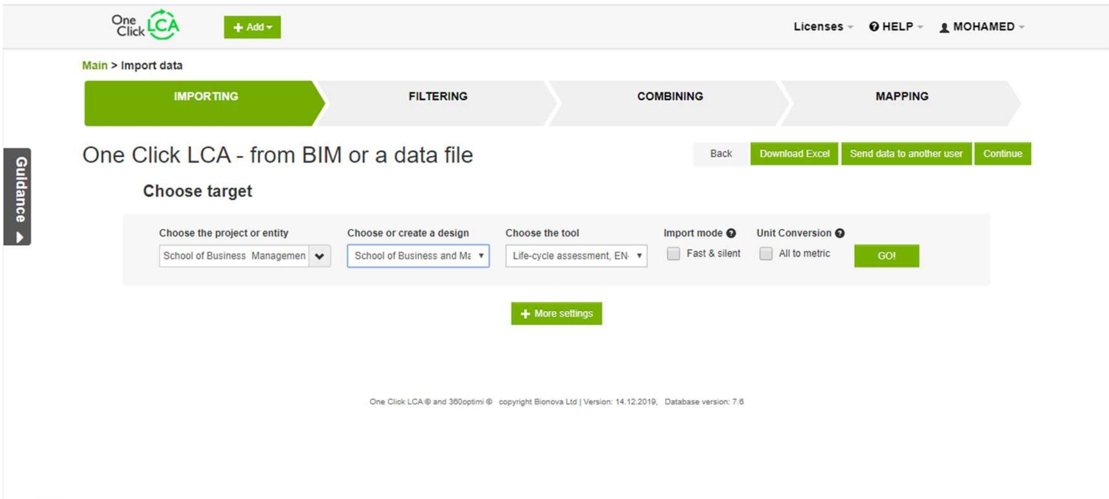


Figure 47:One Click LCA target setting.

6. Review and map the data

- Once the data is imported, One-click LCA delivers a summary of the percentages of identified and unidentified materials from the model data.

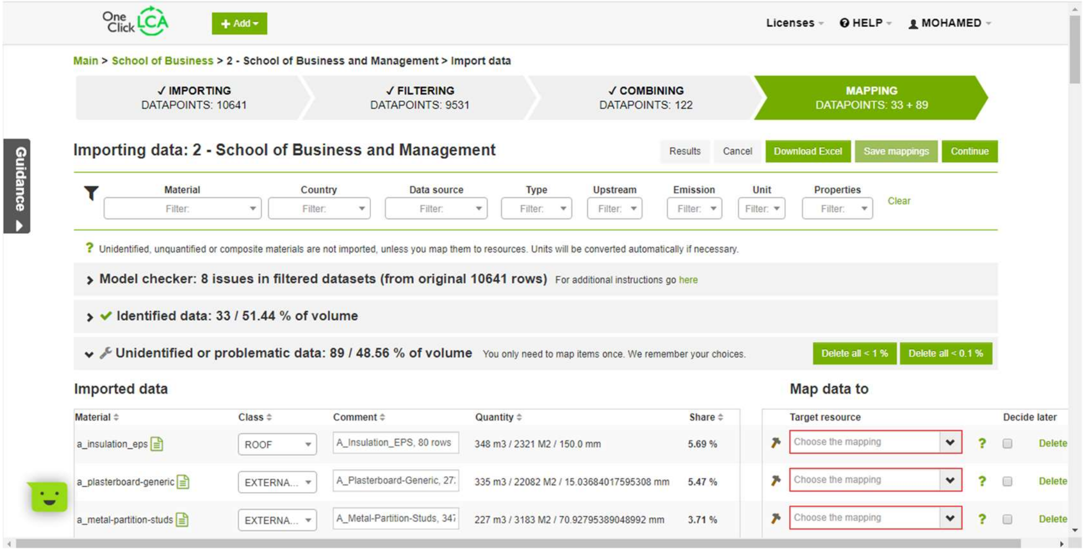
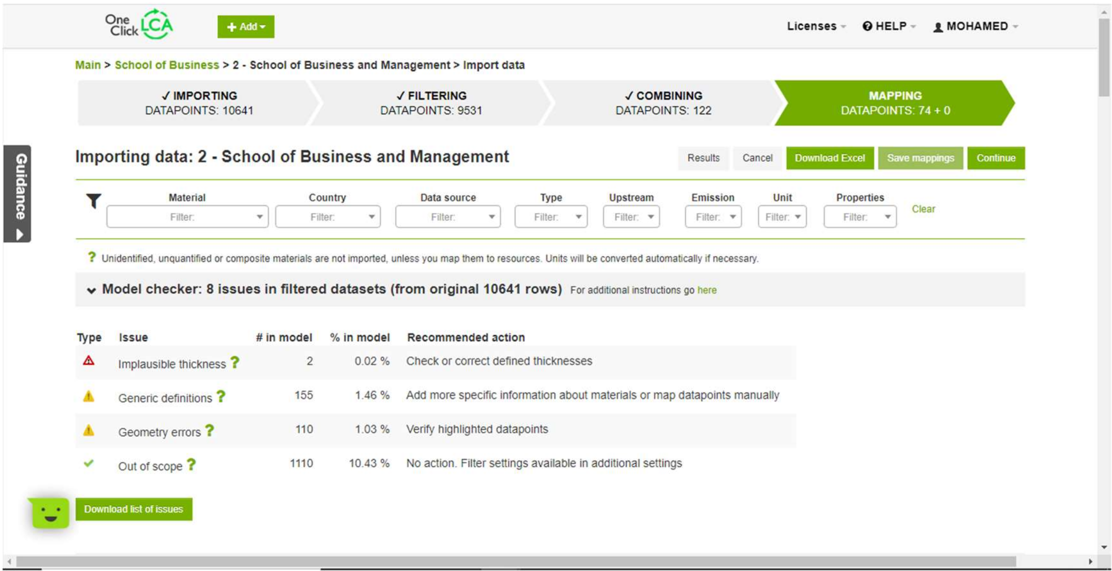


Figure 48: One-click LCA data summary.

- In this case, 48.56% of the building model data were unidentified automatically by the software, which required further mapping for the unidentified materials following different assumptions.

7. One Click LCA delivers a list of further issues that need to be resolved before obtaining the resulting analysis report.



- After mapping all unidentified materials and resolving all issues in the previous list, the assessment results are obtained, as showing in the following section.

4.3.2 Resulting report

One Click LCA generates a comprehensive report as the result of the analysis. Here is the resulting report of Queen Mary School of Business and Management building analysis:

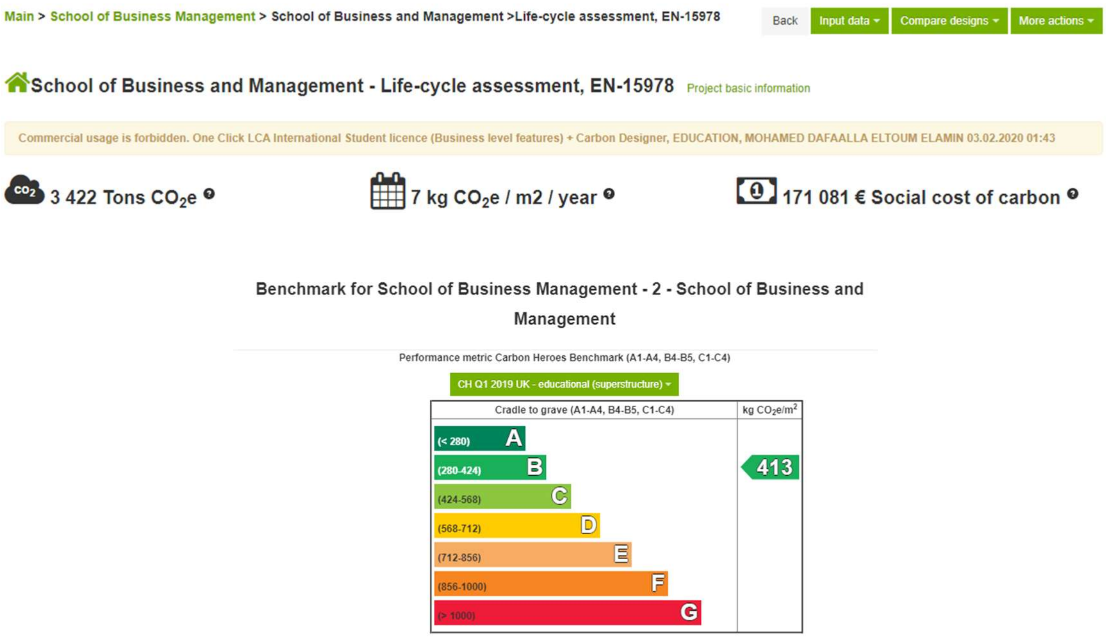


Figure 49: Queen Mary School Embodied carbon benchmark.

Results

Life-cycle assessment results

	Sector	Global warming kg CO2e	Acidification kg SO2e	Eutrophication kg PO4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ	
A1-A3	Construction Materials	2 064 874,81	6 888,26	902,71	0,23	1 408,89	2 142 719 732,3	Details
A4	Transportation to site	45 295,97	134,63	28,57	0,01	5,07	1 032 382,77	Details
A5	Construction/installation process							Hide empty
B1-B5	Maintenance and material replacement	1 150 662,55	4 141,28	674,56	0,18	1 196,85	2 135 879 760,71	Details
B6	Energy use							Hide empty
B7	Water use							Hide empty
C1-C4	Deconstruction	160 796,19	227,92	60,13	0,01	15,43	1 100 247,26	Details
D	External impacts (not included in totals)	-532 634,89	-1 535,16	-172,02	-0	-94,97	-8 264 212	Details
	Total	**3 421 629,52**	**11 392,09**	**1 665,97**	**0,42**	**2 626,25**	**4 280 732 123,05**	
	Results per denominator							
	Gross Internal Floor Area (IPMS/RICS) 8286.1 m2	412,94	1,37	0,2	0	0,32	516 616,03	

Table 16: Queen Mary School Life-cycle assessment results by stage.

Most contributing materials (Global warming)

No.	Resource	Cradle to gate impacts (A1-A3)	Of cradle to gate (A1-A3)	Sustainable alternatives
1.	Aluminium sheet, polyester coated, for roofing, cladding and facades panels, 1mm ?	644 tons CO_2e	31.2 %	show sustainable alternatives
2.	Portland cement, UK average ?	307 tons CO_2e	14.9 %	show sustainable alternatives
3.	Ready-mix concrete, normal-strength, generic ?	290 tons CO_2e	14.1 %	show sustainable alternatives
4.	Wooden acoustic panel ?	107 tons CO_2e	5.2 %	show sustainable alternatives
5.	Aluminum, extruded powder coated ?	103 tons CO_2e	5.0 %	show sustainable alternatives
6.	Mineral wool (facade insulation) ?	65 tons CO_2e	3.1 %	show sustainable alternatives
7.	Partitioning wall system (internal insulated wall) with: steel studs, glass wool core and gypsum board double siding ?	53 tons CO_2e	2.6 %	show sustainable alternatives
8.	EPS insulation panels ?	54 tons CO_2e	2.6 %	show sustainable alternatives
9.	Red brick, average production, UK ?	46 tons CO_2e	2.2 %	show sustainable alternatives
10.	Bitumen sheets for waterproofing of roofs, French average ?	46 tons CO_2e	2.2 %	show sustainable alternatives

Table 17: Queen Mary School's most contributing materials for global warming.

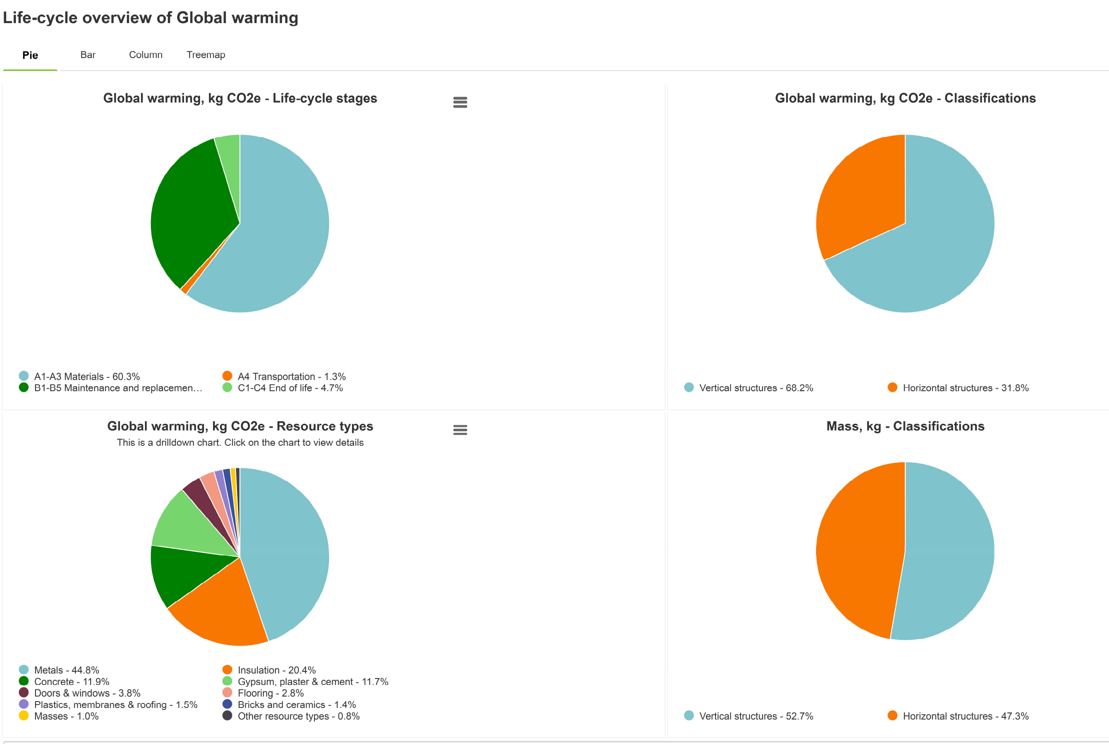


Figure 50: Visualization of annual impacts for Queen Mary School of Business and Management.

Chapter 5: Discussion

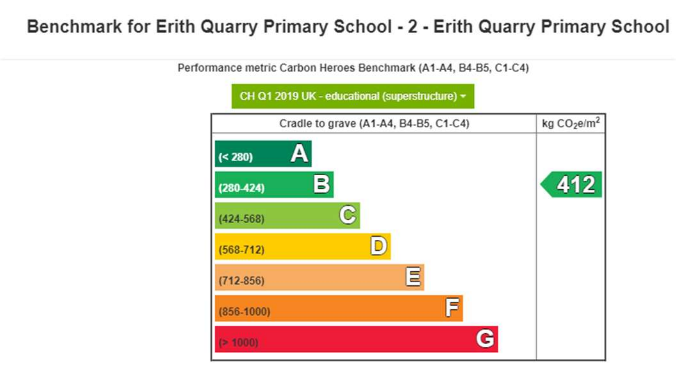
5.1 Overview

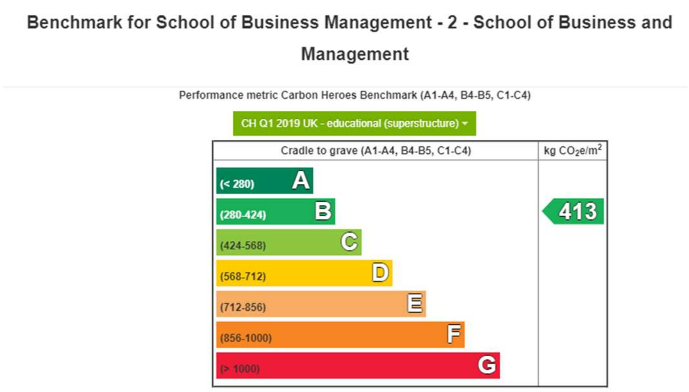
This chapter discusses the thesis findings and tells readers how the research and its findings help to reach the objectives.

5.2 Results

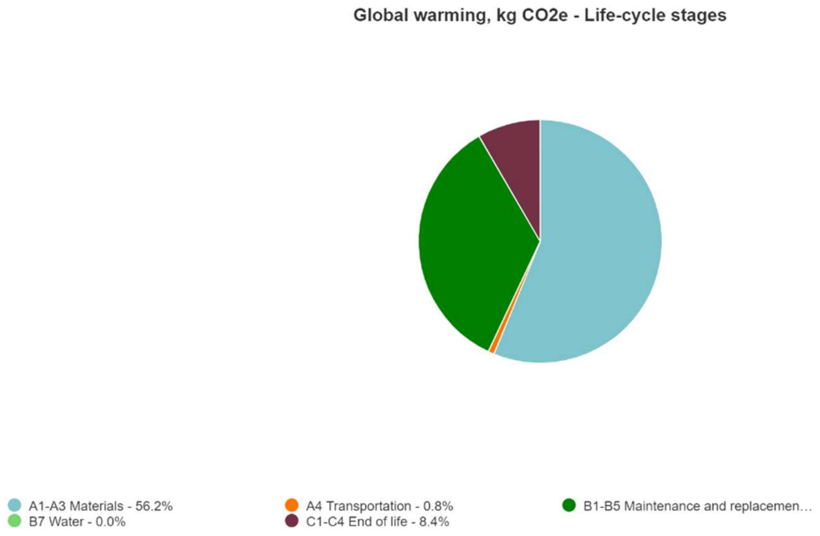
One Click LCA generates a comprehensive report as the result of the assessment. Reports for both buildings included:

1. Both buildings obtained a high embodied carbon benchmark (B) 412 and 413 kg CO2e/m^2. This is calculated for a fixed 60-year assessment period for all building materials, considering the given quantities of materials, materials transport, and materials replacements required during the building assessment period as well as the end of life processing.

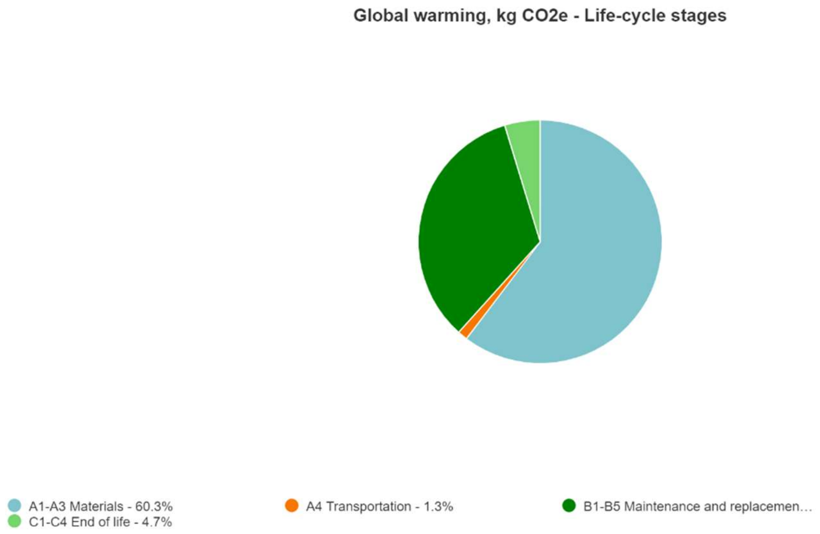




2. For the first building, the total carbon dioxide equivalent emissions were 1846 Tons CO2e, and 56.2% were caused by construction materials (A1-A3), and in second place with 34.6% comes maintenance and replacement emissions (B1-B5).



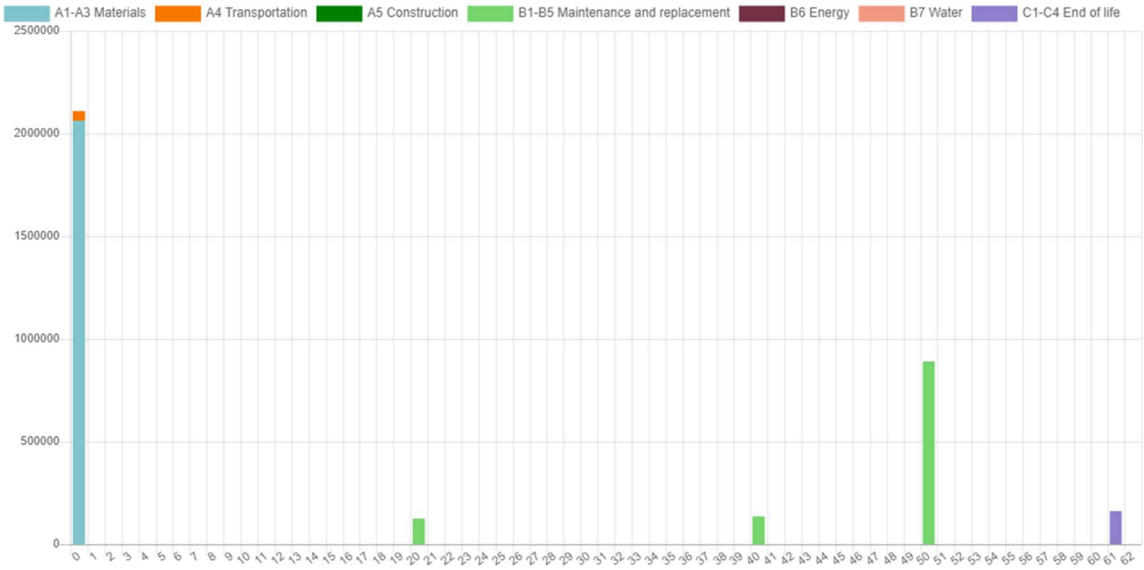
- Moreover, the same was evident in the second building case with total carbon dioxide equivalent emissions of 3422 Tons CO2e for the fixed assessment period. Still, construction materials (A1-A3) had the most significant percentage of that with 60.3%, and second, comes maintenance and replacement emissions (B1-B5) with 30.6% pf the totals emissions.



- This undoubtedly highlights the crucial role of construction materials selection and choices in the building overall emissions. Moreover, it emphasizes the importance of materials durability and lifespan as the maintenance and replacement emissions come second.

3. The report in both cases included a list of the ten Most contributing materials (Global warming). In the first case, an Erith Primary School building has a concrete frame; the concrete was the most contributing material for global warming potential.

4. The report clearly showed that most of the emissions in both cases were generated in the first year during the construction of the building (A1-A3) and after that every 20 years because of the maintenance and replacement (B1-B5).



- Visualization of annual impacts for Queen Mary School of Business and Management

5.3 Limitations of the assessment

1. The prime limitation of this research is the compatibility of building materials specifications with One Click LCA database. This forced many assumptions in terms of materials specifications, which is a very time-consuming process, and it reduces the accuracy of the results.
2. One Click LCA database includes very detailed materials specifications that were not applicable in both studied buildings. The variety of the same material name makes the search in the software very time-consuming. For example, to look for Vynil floor covering, assessors should also consider the word Vinyl with a different spelling. Moreover, as One Click LCA database includes different countries' martial names, assessors should consider the search in different languages.
3. The absence of a detailed Revit model in the first case study forced the manual input of materials using the materials-breakdown document. This introduced a significant difference in time consumed as in the second case due to the exitance of a Revit model, and the data input was automatically so fast and more

accurate. This emphasizes the importance of ready detailed BIM information in order to perform a holistic building sustainability assessment.

4. While the existence of a Revit model in the second building still there was a lake of essential data, for example, energy consumption as the energy model was not applicable from Revit due to model limitations.
5. The assessment is performed in an early design stage of both buildings, which forced the absence of essential data for the assessment, for example, energy consumption accurate data and detailed materials specifications; moreover, as materials mapping was done still, this reduced results accuracy.

Chapter 6: Conclusion and Future work

6.1 Overview

This chapter entirely summarizes the thesis providing an active call to action. It will also include the Future Review section, where it tells readers what areas of the thesis need further research.

This thesis goes under the topic “Rethink Sustainability Towards a Regenerative Economy. As the goal is to approach and achieve the desired results for the regenerative built environment. It aims to increase building sustainability by investigating the integration of One Click LCA in building design as a decision-making tool. Moreover, to test the ability of BIM as it can be used to enhance sustainability with positive impacts on the three pillars of sustainability (economic, social, and environmental quality).

The technological aspect of this research is fascinating and creates an excellent opportunity to develop a decision making or evaluation tool which can be used based on the data available. This will enhance the adaptability among the stakeholders, applying LCA as a decision-making tool.

6.2 Contributions to existing knowledge

1. This thesis highlights the importance of materials database in both BIM software and LCA tools and calls for the standardization of materials specifications (at least at the EU level).
2. This study highlights the actual use of an LCA BIM-based tool. It is essential to unify the databases to import of the BIM model in One Click LCA, throughout the design process, in configuration with the materials choices.
3. The adoption of BIM and LCA integration as consumer-based tools due to the detailed results were obtained and the easiness and importance of the assessment.
4. After conducting both building assessments, it is recommended that WBLCA must be considered in a moderate stage of the design. As in the very first stages, it was noticed that materials specifications and drawings are not complete.
5. It is possible to conclude from this study that One Click LCA is much more holistic and accurate than the Green Guide Rating System. However, one of the

significant limitations of One Click LCA is to assume materials data in order to map project data following One Click LCA database.

6. RIBA[65] requires the BREEAM assessment credit for buildings in the concept design stage (stage 2) of the eight stages. Stages of the RIBA Plan of Work:

   0 – Strategic Definition, 1 – Preparation and Brief, 2 – Concept Design, 3 – Developed Design, 4 – Technical Design, 5 – Construction, 6 – Handover and Close Out, and 7– In use

- After assessing the two-building, this study recommends that requirements should consider performing the whole life cycle assessment for buildings in an advanced stage of the design in module 4 (Technical design) or 5 (Construction). In order to have more explicit materials, specification and transportation and energy data are available.

7. Universities play a crucial role in the short-term implementation of SDGs for educating with new ways and contents the leaders of tomorrow (Sonetti, Barioglio, & campobenedetto, 2020). After looking at the architecture courses syllabus offered by Politecnico di Torino, it was noticed the lake of LCA integration knowledge delivered to the students. Further research could study how to reduce the distance between students and such LCA tools.

- Consequently, this thesis recommends that more attention should be devoted to further inclusion of LCA assessment methods in architecture courses offered by Politecnico di Torino in order to make architecture students aware of the critical role of building materials choices and how they can support a paradigm shift, from carbon-emitting building materials to carbon-storing materials designing more sustainable buildings.
- The thesis calls for action from the university bodies to update the curriculum of the faculty of architecture and design to include more LCA tools. Such inclusion will reduce the gap between the students and such software like One Click LCA, which are essential for their design courses knowledge, so they become more aware of the crucial role of material selection in building sustainability. Moreover, it will reduce the distance between the awareness of

[65] First developed in 1963, the RIBA Plan of Work is the definitive UK model for the building design and construction process ("RIBA Plan of Work 2013," n.d.).

the environmental impacts, the use of the software, the Students and the scientific papers' results

6.3 Future work and further possible research

1. Further research could investigate the interoperability of One Click LCA with other programs such as ArchiCAD, Tekla, and Integrated Environmental Solutions Virtual Environment (IES-VE).
2. Since this project is seen as an initiation of a path towards the integration of One Click LCA in the whole design process, the suggestions analyzed below will assist in its further evolution:

- Standardization of link between Revit materials and One Click LCA databases
- Standardization of the names of Revit materials with their classification as
- generic materials or materials with specified properties
- Automatization of the import in One Click LCA of the supplementary materials not designed in the BIM model
- Automatization of the control of the quantities take-off in One Click LCA

3. Further research could include economic and social dimensions of sustainability when investigating LCA tools, as this study focused more on the environmental impacts.

To conclude, this study was a first attempt to show at the experimental level that LCA could be successfully integrated into the BIM design process as a decision-making tool leading to more sustainable construction. It has been founded that the application of this tool is straightforward and useful and studied how to improve One Click LCA and make it more readable by BIM designs.

References

Anderson, J. & Shiers D & Steele K BRE P, Shiers, D. (n.d.). The Green Guide to Specification book. Retrieved January 27, 2020, from https://www.architecture.com/riba-books/books/sustainability/product/the-green-guide-to-specification.html

Anink, D., Boonstra, C. and Mak, J. (1996). (n.d.). *Handbook of Sustainable Building: An Environmental Refurbishmment., Performance Method for Selection of Materials for Use in Construction and*.

Antón, L. A., & Díaz, J. (2014). Integration of life cycle assessment in a BIM environment. *Procedia Engineering*, *85*, 26–32. https://doi.org/10.1016/j.proeng.2014.10.525

Average material quantities. (n.d.). Retrieved January 27, 2020, from https://desk.zoho.eu/portal/oneclicklca/kb/articles/average-material-quantities

Azhar, S., Carlton, W. A., Olsen, D., & Ahmad, I. (2011). Building information modeling for sustainable design and LEED ® rating analysis. *Automation in Construction*, *20*(2), 217–224. https://doi.org/10.1016/j.autcon.2010.09.019

Berardi, U. (2013). Clarifying the new interpretations of the concept of sustainable building. *Sustainable Cities and Society*. https://doi.org/10.1016/j.scs.2013.01.008

BRE. (2014). SAP 2012 The Government ' s Standard Assessment Procedure for Energy Rating of Dwellings. *Energy*. https://doi.org/10.1007/s13398-014-0173-7.2

BRE Global | BRE Group. (n.d.). Retrieved January 13, 2020, from https://www.bregroup.com/about-us/bre-global/

BREEAM. (n.d.). Retrieved January 7, 2020, from https://www.breeam.com/

BREEAM UK new construction . (2014).

British Standard. (2017). Buildings and constructed assets - Service life planning Part 5 : Life-cycle costing, BS ISO 15686-5 :2017. In *BSI*.

British Standard Institution. (2014). BS EN 15804:2012 - Sustainability of construction works — Environmental product declarations — Core rules for the product category of construction products. In *International Standard*.

Brown, M., Haselsteiner, E., Apró, D., Kopeva, D., Luca, E., Pulkkinen, K.-L., & Rizvanolli, B. V. (n.d.). *Sustainability, Restorative to Regenerative An exploration in progressing a paradigm shift in built environment thinking, from sustainability to restora tive sustainability and on to regenerative sustainability COST Action CA16114 RESTORE: REthinking Sustainability TOwards a Regenerative Economy, Working Group One Report: Restorative Sustainability*. Retrieved from www.cost.eu/COST_Actions/ca/CA16114

BSI EN 15978. (2011). BS EN 15978:2011 - Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method. *International Standard*.

BSI EN 16627. (2015). BSI EN 16627:2015 - Sustainability of construction works - Assessment of economic performance of buildings - Calculation methods. *International Standard*.

Buildings: Specified Code for Sustainable Homes or BREEAM Standard | Brighton & Hove City Council. (n.d.). Retrieved January 24, 2020, from https://www.brighton-hove.gov.uk/content/buildings-specified-code-sustainable-homes-or-breeam-standard

Carmody, J., & Trusty, W. (2005). Life Cycle Assessment Tools. *Informedesign Implications*.

Cole, R. J. (1999). Building environmental assessment methods: Clarifying intentions. *Building Research and Information*. https://doi.org/10.1080/096132199369354

Cole, R. J. (2005). Building environmental assessment methods: Redefining intentions and roles. *Building Research and Information*. https://doi.org/10.1080/09613210500219063

Cooper, I. (1999). Which focus for building assessment methods - Environmental performance or sustainability? *Building Research and Information*. https://doi.org/10.1080/096132199369435

Crawley, D., & Aho, I. (1999). Building environmental assessment methods:

Applications and development trends. *Building Research and Information*. https://doi.org/10.1080/096132199369417

Curran, M A. (2015). Life Cycle Assessment Student Handbook. *Life Cycle Assessment Student Handbook*.

Curran, Mary Ann. (2006). *US EPA Life Cycle Assessment: Principles and Practice*.

Darío Gómez, A. R., Watterson Branca B Americano, J. D., Ha, C., Marland, G., Matsika, E., Nenge Namayanga, L., … Quadrelli, R. (n.d.). *Chapter 2: Stationary Combustion 2006 IPCC Guidelines for National Greenhouse Gas Inventories 2.1 C H A P T E R 2 STATIONARY COMBUSTION Volume 2: Energy 2.2 2006 IPCC Guidelines for National Greenhouse Gas Inventories Contributing Author*.

Databases incorporated in One Click LCA. (n.d.). Retrieved January 13, 2020, from https://desk.zoho.eu/portal/oneclicklca/kb/articles/databases

Ding, G. K. C. (2008). Sustainable construction-The role of environmental assessment tools. *Journal of Environmental Management*, *86*(3), 451–464. https://doi.org/10.1016/j.jenvman.2006.12.025

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). BIM Handbook: A Guide to Building Information Modeling For Owners. *Managers, Architects, Engineers and Contractors*.

Ecoinvent. (2016). Ecoinvent Centre. *EcoInvent v.3.3 Database*.

Ellison, L., & Brown, P. (2011). Sustainability metrics for commercial real estate assets - establishing a common approach. *Journal of European Real Estate Research*. https://doi.org/10.1108/17539261111157299

End of life scenarios for building products. (n.d.). Retrieved January 13, 2020, from https://desk.zoho.eu/portal/oneclicklca/kb/articles/end-of-life-scenarios-for-building-products

Energy impacts. (n.d.). Retrieved January 13, 2020, from https://desk.zoho.eu/portal/oneclicklca/kb/articles/energy-impacts

Epa, U., of Research, O., & Technology Division, S. (n.d.). *Tool for the Reduction* *and Assessment of Chemical and Other Environmental Impacts (TRACI) TRACI version 2.1 User's Guide*. Retrieved from www.epa.gov/research

European Commission. (2011). Roadmap to a Resource Efficient Europe. In *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of Regions*. https://doi.org/SWD(2013) 527

Functional/declared unit. (n.d.). Retrieved January 13, 2020, from https://desk.zoho.eu/portal/oneclicklca/kb/articles/functional-declared-unit

Gloria, T. P., Lippiatt, B. C., & Cooper, J. (2007). Life cycle impact assessment weights to support environmentally preferable purchasing in the United States. *Environmental Science and Technology*, *41*(21), 7551–7557. https://doi.org/10.1021/es070750+

Goodland, R., & Daly, H. (1996). Environmental Sustainability: Universal and Non-Negotiable. *Ecological Applications*, *6*(4), 1002–1017. https://doi.org/10.2307/2269583

How BREEAM Certification Works - BREEAM. (n.d.). Retrieved January 6, 2020, from https://www.breeam.com/discover/how-breeam-certification-works/

Hunt, C. A. (n.d.). *DigitalCommons@USU The Benefits of Using Building Information Modeling in Structural Engineering*. Retrieved from https://digitalcommons.usu.edu/gradreports

Impact assessment / characterisation methodology in One Click LCA. (n.d.). Retrieved January 13, 2020, from https://desk.zoho.eu/portal/oneclicklca/kb/articles/impact-assessment-characterisation-methodology

Impact assessment categories. (n.d.). Retrieved January 13, 2020, from https://desk.zoho.eu/portal/oneclicklca/kb/articles/impact-assessment-categories

International Organization for Standardization. (2006). ISO 14040-Environmental management - Life Cycle Assessment - Principles and Framework. In *International Organization for Standardization*. https://doi.org/10.1016/j.ecolind.2011.01.007

Jennifer O’connor, M. B. (2014). Advancing sustainable design with life cycle assessment (LCA) – SABMag. Retrieved January 13, 2020, from https://sabmagazine.com/quiz/advancing-sustainable-design-with-life-cycle-assessment-lca/

John, G., Clements-Croome, D., & Jeronimidis, G. (2005). Sustainable building solutions: A review of lessons from the natural world. *Building and Environment*. https://doi.org/10.1016/j.buildenv.2004.05.011

Joshi, S. (2010). *AIA Guide to Building Life Cycle Assessment in Practice Authorship and Acknowledgements A Guide to Life Cycle Assessment of Buildings 2*.

Kibert, C. J. (2008). *Sustainable construction : green building design and delivery / Charles J. Kibert* (2nd ed). Hoboken: Hoboken : Wiley.

Life cycle stages. (n.d.). Retrieved January 13, 2020, from https://desk.zoho.eu/portal/oneclicklca/kb/articles/life-cycle-stages

Lippiatt, B. C., & Ahmad, S. (n.d.). *MEASURING THE LIFE-CYCLE ENVIRONMENTAL AND ECONOMIC PERFORMANCE OF CONCRETE: THE BEES APPROACH*.

Martins, L. (2019). *Sustainability and Building Certification Process - PowerPoint Presentation*.

Part L of the Building Regulations | isurv. (n.d.). Retrieved January 19, 2020, from https://www.isurv.com/info/35/part_l_of_the_building_regulations

Pearce, D. (2006). Is the construction sector sustainable?: Definitions and reflections. *Building Research and Information*. https://doi.org/10.1080/09613210600589910

Places – Studio Egret West. (n.d.). Retrieved January 26, 2020, from https://studioegretwest.com/places/erith

Queen Mary Univesity of London consultation displaying. (n.d.). Retrieved from https://www.qmul.ac.uk/media/qmul/media/publications/QMUL-SBM---Public-Consultation-Boards.pdf

Ragheb, A. F. (n.d.). *TOWARDS ENVIRONMENTAL PROFILING FOR OFFICE*

BUILDINGS USING LIFE CYCLE ASSESSMENT (LCA).

RIBA Plan of Work 2013. (n.d.). Retrieved February 4, 2020, from https://www.ribaplanofwork.com/

RICS. (2009). RICS Professional Guidance, Global. *RICS Professional Guidance, Global*.

RICS. (2017). *Whole life carbon assessment for the built environment*. 41. Retrieved from http://www.rics.org/Global/Whole_life_carbon_assessment_for_the_BE_PG_guidance_2017.pdf

Royal Institution of Chartered Surveyors. (2006). *Life expectancy of building components : surveyors' experiences of buildings in use : a practical guide.* BCIS.

Scheuer, C., Keoleian, G. A., & Reppe, P. (2003). Life cycle energy and environmental performance of a new university building: Modeling challenges and design implications. *Energy and Buildings*, *35*(10), 1049–1064. https://doi.org/10.1016/S0378-7788(03)00066-5

Schlueter, A., & Thesseling, F. (2009). Building information model based energy/exergy performance assessment in early design stages. *Automation in Construction*, *18*(2), 153–163. https://doi.org/10.1016/j.autcon.2008.07.003

Schultz, J., Ku, K., Gindlesparger, M., & Doerfler, J. (2016). A benchmark study of BIM-based whole-building life-cycle assessment tools and processes. *International Journal of Sustainable Building Technology and Urban Development*, *7*(3–4), 219–229. https://doi.org/10.1080/2093761x.2017.1302839

Service life of materials. (n.d.). Retrieved January 13, 2020, from https://desk.zoho.eu/portal/oneclicklca/kb/articles/service-life-of-materials

Soust-Verdaguer, B., Llatas, C., & García-Martínez, A. (2017). Critical review of bim-based LCA method to buildings. *Energy and Buildings*, *136*, 110–120. https://doi.org/10.1016/j.enbuild.2016.12.009

Standards supported in One Click LCA. (n.d.). Retrieved January 13, 2020, from https://desk.zoho.eu/portal/oneclicklca/kb/articles/standards-supported

The Green Guide Explained : BRE Group. (n.d.). Retrieved January 6, 2020, from https://www.bregroup.com/greenguide/page.jsp?id=3612

Todd, J. A., Crawley, D., Geissler, S., & Lindsey, G. (2001). Comparative assessment of environmental performance tools and the role of the Green Building Challenge. *Building Research and Information*, *29*(5), 324–335. https://doi.org/10.1080/09613210110064268

Trozzi, C. (n.d.). *Emission estimate methodology for maritime navigation*.

Whitehead, B., Andrews, D., Shah, A., & Maidment, G. (2015). Assessing the environmental impact of data centres part 2: Building environmental assessment methods and life cycle assessment. *Building and Environment*. https://doi.org/10.1016/j.buildenv.2014.08.015

William, B. F. (2008). *The Importance of BIM in Structural Engineering The Greatest Change in Over a Century*. Retrieved from www.STRUCTUREmag.org

Williams, C. C., & Millington, A. C. (2004). The diverse and contested meanings of sustainable development. *Geographical Journal*. https://doi.org/10.1111/j.0016-7398.2004.00111.x

Yudelson, J. (2016). *Reinventing Green Building: Why Certification Systems Aren't Working and what We Can Do about it*. Retrieved from https://books.google.com/books?hl=en&lr=&id=VYi0CwAAQBAJ&oi=fnd&pg=PP1&dq=Reinventing+Green+Building+Jerry+Yudelson&ots=cOG3gNu6cY&sig=gK3uZGL1_PKH31H_1qCvwwSxyvE

Zalejska-Jonsson, A. (2013). *In the business of building green: The value of low-energy residential buildings from customer and developer perspectives*.

Zanni, M., Soetanto, R., & Ruikar, K. (n.d.). *Towards a BIM-enabled sustainable building design process: roles, responsibilities, and requirements Blue-Green Infrastructure in Semarang (BuGIS) View project LOD Object Content Specification for Manufacturers within the UK Using the IDM Standard View project*. https://doi.org/10.1080/17452007.2016.1213153

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Appendix A: Erith Quarry Primary School Material Breakdown

BREEAM Mat 01 - Life Cycle Impacts & Mat 02 - Hard Landscaping and Boundary Protection SEW

GUIDANCE ON THE MATERIALS SPECIFICATION NEEDED FOR THIS CREDIT PLEASE SEE THE GREEN GUIDE WEBSITE:

http://www.bre.co.uk/greenguide

Element type	Material build-up - layers / element description:	Area in m^2.	Green Guide rating	Green Guide Element no.	Kg of CO_2 eq. (60 years)	Drawings/ Specification references
WINDOWS						
Type 1: (EWS-04, 05, 07)	GLAZED CURTAIN WALLING SYSTEM with Tiger Draylac Powder Coated aluminum frame; Insulating window frame; anchor bracket	2280	**B**	1206510009	200	0235-EW-SC-ZZ-DR-A-002403 0235-EW-SC-ZZ-SP-A-000001
Type 2: (RFL-01, 02, 03)	PPC ALUMINIUM FRAMED GLAZED ROOF LIGHTS	82.6	**A+**	1231500011	100	0235-EW-SC-ZZ-DR-A-302400 0235-EW-SC-ZZ-SP-A-000001
EXTERNAL WALLS						
Type 2: (EWS-02)	GEOTEXTILE MEMBRANE: Non-woven polyester/polypropylene; DRAINAGE MEMBRANE; CONCRETE RETAINING WALL; DAMP PROOF MEMBRANE; INSULATION: Kingspan K12 or equivalent with a low emissivity composite foil facing on both sides,	317.6	**A+**	**79898118**	342.07	

	mechanically fixed back to non-combustible substrate; INTERNAL DRY LINGING SYSTEM: Gypliner system or equivalent; PLASTERBOARD; PLASTER SKIM					
Type 3: (EWS-03)	Tiger Draylac Powder Coated ALUMINIUM PANEL; PLYWOOD; VENTILATED CAVITY With Aluminum Fixing Railing System; 'HELPING HAND' BRACKET with neoprene or plastic gasket; INSULATION: Kingspan K15 or equivalent with a low emissivity composite foil facing on both sides, mechanically fixed back to non-combustible substrate; CONCRETE SHEAR WALL	317.1	**A**	1206280012	110	
Type 2: (EWS-06)	PPC ALUMINIUM FACING PANEL with Tiger Draylac Powder Coated insulated aluminium facing panel; Powder coated aluminium frame; Insulating window frame; anchor bracket	42	**A+**	79905259	93.89	
Type 4: (EWS-08)	GRC PANELS; PLYWOOD; VENTILATED CAVITY with Aluminium Fixing Railing System; 'HELPING HAND' BRACKET with neoprene or plastic gasket; INSULATION: Kingspan K15 or equivalent with a low emissivity composite foil facing on both sides, mechanically fixed back to non-combustible substrate; CEMENT BONDED PARTICLE	71.2	**C**	806230430	260	

	BOARD; METAL STUD FRAME with MINERAL WOOL; PLASTERBOARD; PLASTER SKIM					
Type 5: (EWS-09)	GRC PANELS; PLYWOOD; VENTILATED CAVITY with Aluminium Fixing Railing System; 'HELPING HAND' BRACKET with neoprene or plastic gasket; INSULATION: Kingspan K15 or equivalent with a low emissivity composite foil facing on both sides, mechanically fixed back to non-combustible substrate; CONCRETE SHEER WALL	13.8	**B**	806260464	240	0235-EW-SC-ZZ-DR-A-002403 0235-EW-SC-ZZ-SP-A-000001
Type 8: (EWS-10)	Tiger Draylac Powder Coated ALUMINIUM PANEL; PLYWOOD; VENTILATED CAVITY With Aluminium Fixing Railing System; 'HELPING HAND' BRACKET with neoprene or plastic gasket; INSULATION: Kingspan K15 or equivalent with a low emissivity composite foil facing on both sides, mechanically fixed back to non-combustible substrate; CEMENT BONDED PARTICLE BOARD; METAL STUD FRAME with MINERAL WOOL; PLASTERBOARD; PLASTER SKIM	48.6	**A**	1206250007	130	

Appendix A: Erith Quarry Primary School Material Breakdown

FLOOR COVERINGS						
Type 1:	CARPET TILES - DESSO STRATOS with 100% recycled Econyl material	1465	**A+**	821570033	69	0235-EW-SC-ZZ-DR-A-002713 0235-EW-SC-ZZ-SP-A-000001
Type 2:	VYNIL / LINO - FORBO MARMOLEUM	924.7	**A+**	821570017	28	
Type 3:	SLIP RESISTANT VYNIL - FORBO	988.2	**A+**	921570010	45	
Type 4:	14mm HARDWOOD TIMBER	451.4	**A+**	821580003	-46	
UPPER FLOOR SLAB						
Type 1: (ARC-02)	EXPOSED IN-SITU REINFORCED CONCRETE SLAB	5187.4	**D**	807280017		0235-EW-SC-ZZ-SP-A-000001 Structure Engineer's specifications
Type 2: (CP-ARC02)	EXPOSED IN-SITU REINFORCED CONCRETE SLAB	3575.1	**D**	807280017		0235-EW-CP-ZZ-SP-A-000001 Structure Engineer's specifications
ROOF						
Type 1: (RFS-01, 02)	(PLANTERS), PEBBLES; WATER CONTROL LAYER; XPS RIGID INSULATION; STRUCTURAL WATERPROOFING SYSTEM	1647.6	**D**	812530040	220	0235-EW-SC-ZZ-DR-A-002211 0235-EW-SC-ZZ-SP-A-000001

Type 2: (RFS-03)	CONCRETE PAVING SLABS; WATER CONTROL LAYER; XPS RIGID INSULATION; STRUCTURAL WATERPROOFING SYSTEM	185.4	**D**	812530039	250	
Type 3: (CP-ARC02)	3G ASTRO TURF CARPET; RUBBER PAD, POROUS ASPHALT, GEOTEXTILE MEMBRANE; SUBGRADE; WATERPROOF MEMBRANE	3575				0235-EW-CP-ZZ-DR-A-252314 0235-EW-CP-ZZ-SP-A-000001
INTERNAL WALLS						
Type 1: (IWS-01)	PAINT FINISH; BRITISH GYPSUM WALLBOARD BOARD Taped and skimmed, to meet National Class 3 (fire spread); ISOVER ACOUSTIC PARTITION ROLL between GYPFRAME METAL; BRITISH GYPSUM WALLBOARD BOARD; PAINT FINISH	689.3	**A+**	816110026	39	0235-EW-SC-ZZ-DR-A-002503 0235-EW-SC-ZZ-SP-A-000001
Type 2: (IWS-02)	PAINT FINISH; BRITISH GYPSUM WALLBOARD BOARD **(2 no.15mm boards)** taped and skimmed, to meet National Class 3 (fire spread); ISOVER ACOUSTIC PARTITION ROLL between GYPFRAME METAL; BRITISH GYPSUM WALLBOARD BOARD **(2 no. 15mm boards)**; PAINT FINISH	379.4				

Type 3: (IWS-03)	PAINT FINISH; BRITISH GYPSUM **SOUNDBLOCK BOARD** (2 no. 15mm boards) taped and skimmed, to meet National Class 3 (fire spread); ISOVER ACOUSTIC PARTITION ROLL between GYPFRAME METAL; BRITISH GYPSUM **SOUNDBLOCK BOARD** (2 no. 15mm boards); PAINT FINISH	893.5				
Type 4: (IWS-04, 05)	PAINT FINISH; BRITISH GYPSUM SOUNDBLOCK BOARD (2 no. 15mm boards) taped and skimmed, to meet National Class 3 (fire spread); ISOVER ACOUSTIC PARTITION ROLL with **RESILIENT BAR** on one side between GYPFRAME METAL; BRITISH GYPSUM SOUNDBLOCK BOARD (2 no. 15mm boards); PAINT FINISH	398.9				
Type 5: (IWS-06)	PAINT FINISH; BRITISH GYPSUM SOUNDBLOCK BOARD (2 no.15mm boards) taped and skimmed, to meet National Class 3 (fire spread); ISOVER ACOUSTIC PARTITION ROLL with **RESILIENT BAR on both sides** between GYPFRAME METAL; BRITISH GYPSUM SOUNDBLOCK BOARD (2 no. 15mm boards); PAINT FINISH	35.7	**A+**	79905308	32.82	

Type 6: (IWS-07)	PAINT FINISH; BRITISH GYPSUM WALLBOARD BOARD Taped and skimmed, to meet National Class 3 (fire spread); GYPLYNER METAL CHANNELS; **REINFORCED CONCRETE SHEAR WALL**; BRITISH GYPSUM WALLBOARD BOARD; PAINT FINISH	268.2	**E**	79905311	99.89	
HARD STANDING & BOUNDARY PROTECTION						
Type A	Fence Type A - Timber fin fence	359	**A+**	827020011	-8.3	0235-EW-SL-ZZ-DR-L-002813
Type B	Fence Type B - Timver fin fence	59	**A+**	827020011	-8.3	0235-EW-SL-ZZ-DR-L-002813
Type C	Fence Type C - Timber fin fence	612	**A+**	827020011	-8.3	0235-EW-SL-ZZ-DR-L-002814
Type 1	Surfacing for Heavily Trafficked Areas: Asphalt (40mm) over recycled sub-base	1427.6	**A+**	822120034	100	0235-EW-SL-ZZ-SP-L-002805 0235-EW-SL-ZZ-SP-L-000001 (Q22/140)
Type 2	Surfacing for Lightly Trafficked Areas: Asphalt (40mm) over recycled sub-base	120	**A**	830120020	46	0235-EW-SL-ZZ-SP-L-002805 0235-EW-SL-ZZ-SP-L-000001 (Q22/140)

Type 3	Surfacing for Pedestrian Areas: Clay pavers (85mm) with recycled sub-base	842.6	**A**	822120035	150	0235-EW-SL-ZZ-SP-L-002805 0235-EW-SL-ZZ-SP-L-000001 (Q24/121A)
Type 4	Surfacing for Pedestrian Areas: Resin bound gravel (central courtyard)	302	**A**	830120028	23	0235-EW-SL-ZZ-SP-L-002805 0235-EW-SL-ZZ-SP-L-000001 (Q23/132A)