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Operational, embodied and whole life cycle assessment credits in green building certification systems: Desktop analysis and natural language processing approach

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ABSTRACT

Globally, the issue of climate change is becoming increasingly significant due to the rapid change in weather conditions, and the construction industry contributes significantly to this. Green building certification systems (GBCS) are vital for ensuring sustainable practices in the construction industry. As a result, it is essential to guarantee the effectiveness of the GBCS to capture adequate information on environmental impacts throughout the building life cycle and ensure best practices. However, limited works have holistically studied the operational, embodied and whole life cycle assessment (OEW) credits in GBCS. Therefore, this current study seeks to address the gap by critically assessing the OEW credits in notable GBCS to determine areas of strengths and weaknesses. This study applied desktop analysis and document similarity techniques of natural language processing to assess the technical manuals of the GBCS. Five GBCS (LEED, BREEAM, Green Star NZ, LOTUS and GREENSL) were selected from developed and developing countries, and the newly developed GBCS (IGBT and BSAM) were selected to have both perspectives. The analysis revealed that operational credits were given more attention compared to embodied credits. It is observed that waste-related credits are not prioritised. In addition, the concept of circular economy is yet to gain attention in the existing GBCS. Also, the document similarity among the GBCS indicates that the GBCS have some level of similarity. However, the LOTUS and BSAM certification systems were observed to have low similarity compared to other GBCS. The research proposed an improvement framework to enhance the effectiveness of the GBCS.

1. Introduction

The issue of climate change has continued to be a global challenge, and there is a need for every industry to play a critical role in enhancing the sustainability of their actions. The recently concluded United Nations Climate Change Conference (COP28) noted that the parties of the Paris Agreement are not on track with the goals. In addition, COP28 signals the end of the fossil fuel era [1]. The construction industry's contribution to environmental emissions is highly significant as the industry gears towards sustainable development to limit global warming temperatures below 1.5 °C [2,3]. As a result of the escalating challenges of climate change, several initiatives, such as life cycle assessments, environmental labels, and green building certification systems (GBCS), have been introduced to increase the construction industry's sustainability uptake. However, several studies have acknowledged poor information structures of the GBCS, such as Leadership in Energy and Environmental Design (LEED) and Green Star and Building Research Establishment Environmental Assessment Method (BREEAM) to assess the whole building life cycle comprehensively impacts due to poor consistency [4,5].

The GBCS have three critical credits that aid the comprehensive assessment of a building's environmental impact throughout its life cycle. The first is the operational credits that cover the environmental performance of a building during its operational phase, considering water usage, energy consumption, and emissions [6]. Secondly, the embodied credits focus on the environmental impact of the production, transportation, and assembly of building materials [7]. The third, the whole life cycle impact, integrates the operational and embodied impacts throughout the building life cycle to provide a detailed overview and optimise the building's environmental performance during the design, construction, or operation phase [8]. Peng [9] reported that the building operation stage accounts for over 80 % of the carbon emissions

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throughout its lifecycle. The operational impacts assessment in GBCS requires critical focus to support emission reduction throughout the building lifecycle.

Green building certifications have evolved into indispensable frameworks that guide building design, construction, and operation towards sustainable and energy-efficient practices [10,11]. In addition, many of the GBCS have been developed for several decades with minimal updates. There is a need for a more comprehensive GBCS that reflects new concepts such as circular economy and simplifies the assessment of the environmental impacts of buildings. The OEW credits are critical aspects of building environmental impacts throughout its lifecycle. However, the intricate interplay between operational efficiency, embodied environmental impacts, and the holistic evaluation of a building's life cycle necessitates a thorough examination to enhance the efficacy of these certification systems. It is important to acknowledge that some studies have attempted to study green building certification systems. Previous studies in the GBCS domain, as shown in Tabl e A1 in Appendix A, have focused on technology integration to GBCS criteria [12–16], GBCS comparative assessment [11,17–19], development of new GBCS [20,21], and whole life cycle assessment process and framework of GBCS [22,23]. As depicted in Ta ble A1, it is evident that the majority of the current studies are solely focused on the holistic assessment of the GBCS credits rather than addressing the essential areas of concern, such as the incorporation of circular economy concepts and simplification of OEW credits that have been reported to have lack of clarity within GBCS framework [5]. In addition, it is observed that the newly developed GBCS have still not adequately expanded the OEW credits but concentrated on including other dimensions of sustainability, such as economic and social dimensions [20,21]. Nevertheless, limited studies have holistically assessed the OEW credits of the GBCS through the lens of developed and developing countries and newly developed GBCS.

On the other hand, using natural language processing (NLP) is not too common in construction research. Very few studies have applied NLP to analyse accident cases [24], automate construction specification review [25], and process documents through classification [26], among others. The document similarity aspect of NLP has been rarely used in construction research. Additionally, NLP has not been applied in the GBCS domain to provide insights into the global relationship between GBCS and show GBCS development patterns. As a result, this current research seeks to apply the document similarity function of GBCS to provide insights into the relationship between different GBCS to ascertain the prioritisation hierarchy.

Against this backdrop, this study critically analyses the prominent GBCS in developed and developing countries and newly developed GBCS, focusing only on the OEW credits. Through a desktop review of existing GBCS and the application of NLP, this study seeks to provide insights into the limitations of existing GBCS in terms of OEW credits that are crucial to shaping the future of certification systems and advancing the building sustainability assessment process in the construction industry.

This paper is structured as follows: the first section provides a background on motivation, a state-of-the-art review of the current state of knowledge and the study's contribution. The section provides a detailed description of the methodology employed to address the research questions. The third section includes a thematic analysis of the findings from the desktop review of the selected GBCS. The fourth section of the paper presents the findings from the NLP application, while the fifth section provides a detailed analysis and discussion of results based on the findings from the thematic and NLP analysis. The sixth section covers recommendations for GBCS improvement. The seventh section of the paper summarises the main conclusions from the study, as well as the implications and areas for future research.

2. Research methods

Fig. 1 shows the entire research process. The research is divided into two phases: 1) GBCS selection and 2) analysis and findings. This research adopted a desk research approach, which includes a thorough analysis of existing documents on GBCS to have a broader understanding of the certification systems. Desktop research has been applied in several studies to evaluate current gaps in policies in sustainability and technology [27,28]. In addition, the document similarity aspect of NLP was integrated to provide deeper insights into the similarities of the existing GBCS. This research combined the power of desktop analysis and NLP with the view to provide answers to the following questions.

1. What is the percentage of operational and embodied credits in the selected green building certification systems in developing and developed countries?
2. What is the weightage of whole building life cycle assessment credits in the selected green building certification systems?
3. What is the similarity between green building certification systems?

2.1. Desktop analysis

Desktop analysis has been widely embraced by researchers in the GBCS domain [11,17]. Five GBCS were selected from developed and developing countries. LEED, BREEAM, and GreenStar NZ were selected due to their popularity in existing studies [11,18,29]. Level(s) was added due to its simplicity to provide a common language for sustainability assessment and reporting. Similarly, LOTUS and GREENSL were selected due to their peculiarity as GBCS from developing countries [30,31]. In addition, two newly developed GBCS (Iranian Green Building Assessment Tool [IGBT] and Building Sustainability Assessment Method [BSAM]) were selected [20,21,32]. Table A2 in Appendix A shows the summary of the OEW credits in the GBCS. The following documents from the five GBCS were selected for analysis due to their applicability for new construction.

1. BREEAM International New Construction Version 6.
2. GREENSL Rating System for New Constructions Version 2.1.
3. Green Star Design & As Built - New Zealand v1.1 Submission Guidelines.
4. LEED v4.1 - Building Design and Construction.
5. LOTUS New Construction V3 – Technical Manual.
6. BSAM Technical Manual.
7. IGBT - Research paper by Shad et al. [21].
8. Level(s) Technical Manual.

2.2. Natural language processing

Natural language processing (NLP) is a branch of artificial intelligence dealing with understanding textual data [33], while document similarity is an NLP technique that assesses the similarity between two or more documents. NLP was employed to determine any pattern in the selected GBCS technical manual documents.

2.2.1. GBCS technical manual preparation

The six selected GBCS (LEED, BREEAM, Green Star NZ, LOTUS, GREENSL and BSAM) portable document format (PDF) documents were checked individually and renamed based on their acronym. For instance, the LEED technical manual was renamed "LEED". Level(s) and IGBT were excluded due to the lack of one document for the technical manual.

2.2.2. Data preprocessing

Data preprocessing was a crucial first step in the analysis pipeline. It ensured that the textual data from the PDF files were suitable for subsequent analysis. The data processing includes text extraction aimed at

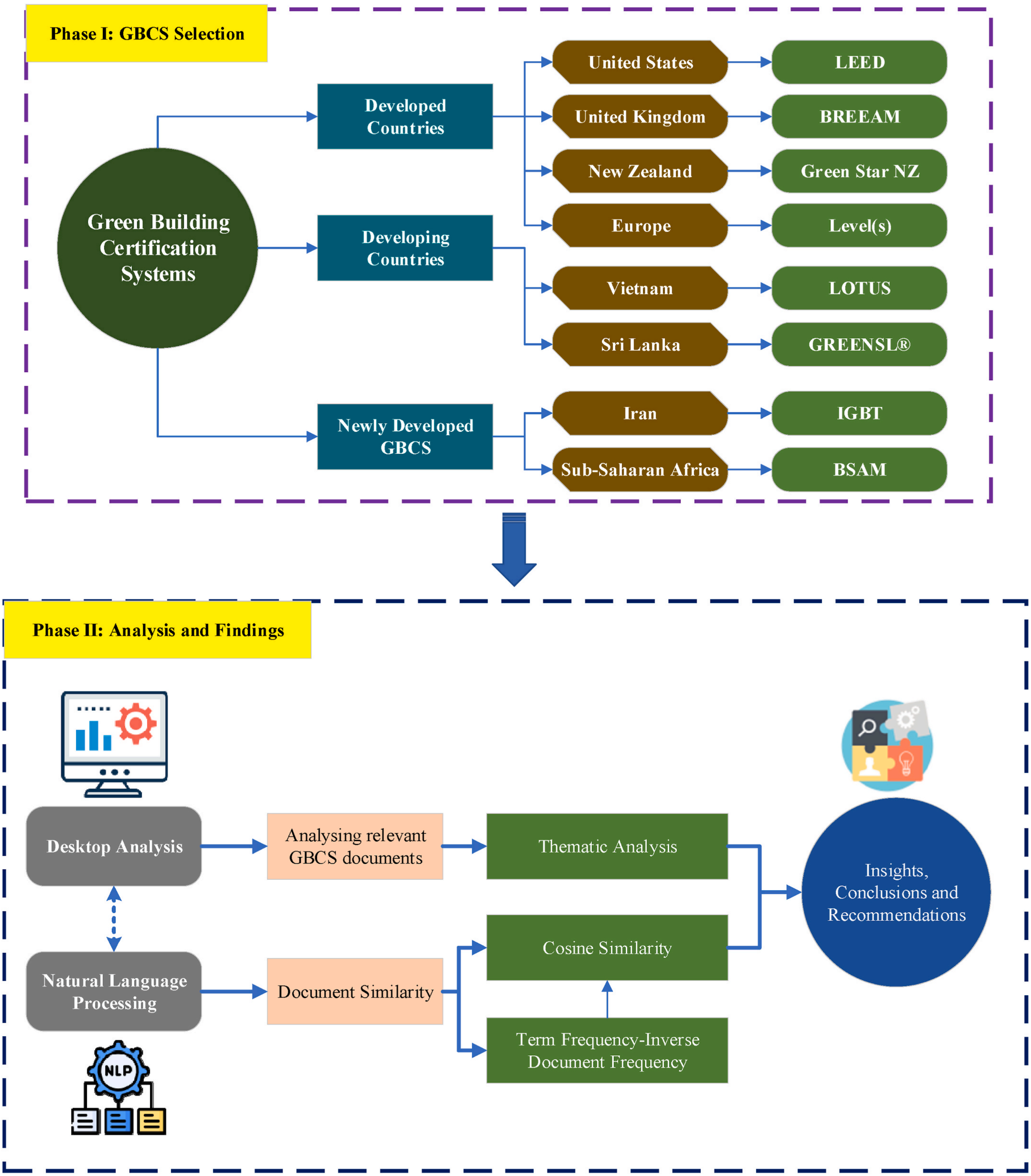


Fig. 1. Research process.

extracting the text from each GBCS technical manual using the PyPDF2 library [34]. The next is tokenisation, which aims to break the text into individual words or tokens using the Natural Language Toolkit (NLTK) word_tokenize function. In addition, the punctuation marks in the text were removed, and only alphanumeric tokens were retained. Lastly, the stopword removal step ensures that common and non-informative words are eliminated and achieved using the NLTK stopword corpus [35].

2.2.3. Document similarity

The document similarity approach in this research includes Cosine similarity and Term Frequency-Inverse Document Frequency (TF-IDF).

Cosine similarity identifies similarities between the word contents of documents in the text analysis field [36,37]. It is used to analyse the technical manual of the five GBCS selected (LEED, BREEAM, Green Star NZ, LOTUS and GREENSL). It can be expressed as shown in equation (1) as depicted in Rahutomo et al. [37]:

$$\cos(\theta) = \frac{A \bullet B}{\|A\|\|B\|} = \frac{\sum_{i=1}^{n} A_i B_i}{\sqrt{\sum_{i=1}^{n} A_i^2} \bullet \sqrt{\sum_{i=1}^{n} B_i^2}} \tag{1}$$

where:

$A \bullet B$ represents the dot product of vectors A and B.

$\|A\|$ and $\|B\|$ represent the magnitudes (Euclidean norms) of vectors A and B,.

respectively.

Vectors A and B are typically $TF-IDF$ vectors representing two documents.

On the other hand, the TF-IDF quantifies the importance of words by identifying the occurrence of selected terms within a document for use in data extraction, such as during text mining and information retrieval systems. $TF-IDF$ is the product of TF and IDF. $TF-IDF$ for a term t in a document d is expressed mathematically in equation (2) as depicted in Park et al. [36]:

$$TF-IDF(t,d) = TF(t,d) \times IDF(t) \tag{2}$$

where:

$TF(t,d)$ represents the Term Frequency of term t in document d, which is the number of times t appears in d..

$IDF(t)$ represents the Inverse Document Frequency of term t, $IDF(t)$ is calculated as shown in equation (3) as depicted in Park et al. [36]:

$$IDF(t) = \log\left(\frac{N}{n_t}\right) \tag{3}$$

where:

N is the total number of documents in the corpus.

n_t is the number of documents containing term t.

Lastly, L2 normalisation of the $TF-IDF$ values is performed to normalise the results with respect to the document length [38]. This helped eliminate bias associated with large documents, as in the case of the GBCS technical manuals.

3. Thematic analysis

Operational, embodied, and whole life cycle assessment credits of the selected GBCS from developed and developing countries are elaborated on in this section.

3.1. Developed countries

The GBCS in four developed countries is covered under this subsection. The selected GBCS from developed countries include LEED (the United States, Canada, and Spain), BREEAM (United Kingdom), and Green Star NZ (New Zealand).

3.1.1. LEED

The LEED is one of the prominent GBCS in the global context, cutting across different countries of the world, including the United States of America, Canada, and Spain [16,39]. It was first introduced by the United States Green Building Council (USGBC) in 1998. Ever since its introduction, LEED has grown significantly with evolving green building technologies. It has moved from the pilot version (LEED New Construction [NC] v1.0) to LEED v4, which was introduced in 2013 [40]. LEED v5 (Operations and Maintenance: Existing Buildings draft), which is the latest, is expected to be fully operational for use by 2025 [41]. The scope of this research is at the building level. As a result, the Building Design and Construction (BD + C) variant of LEED was selected for further analysis.

The OEW credits of the LEED rating system are described as follows.

1. **Optimise Energy Performance:** This credit focuses on reducing the environmental impacts of excessive energy use and greenhouse gas emissions. It includes four options, as shown in Fig. 2, that the assessors can select. Option 1 necessitates that the project provides evidence of the Performance Cost Index falling below the target specified in Se ction 4.2.1.1 of ANSI/ASHRAE/IESNA Standard 90.1–2016. Option 2 mandates compliance with the scope requirements outlined in the Advanced Energy Design Guide. Option 3 underscores adherence to the ASHRAE 90.1–2016 Prescriptive compliance path, demanding improvements beyond the baseline of ASHRAE 90.1–2016 in areas such as interior and exterior lighting, daylight controls, building envelope, HVAC and service water heating equipment efficiency, and equipment and appliances. Lastly, Option 4, exclusively applicable to data centres, necessitates calculating the overall system design value, determined as the sum of the maximum design mechanical load component and maximum design electrical load component following ASHRAE 90.4–2016 Secti on 6.2, Sec tion 8.2, and Secti on 11. In this case, the project must demonstrate that the overall system design value is less than the maximum overall systems value by a margin of 10 %, 20 %, or 30 % [42].
2. **Renewable Energy:** This credit aims to mitigate the environmental and economic ramifications linked to fossil fuel-based energy sources while promoting the adoption of renewable energy alternatives. The project can incorporate a blend of on-site renewable energy generation, newly established off-site renewable energy, or procurement of off-site renewable energy. The credit is valued at a total of five points [42].
3. **Enhanced Refrigerant Management:** This credit category aims to mitigate ozone depletion and global warming potential, facilitating timely adherence to the Montreal Protocol, which includes the Kigali Amendment. Simultaneously, it strives to minimise direct contributions to climate change. It includes two options, as shown in Fig. 2. Option 1, designated with a single point, necessitates the use of refrigerants that either possess no ozone depletion potential and exhibit minimal global warming potential (GWP) below 50. On the other hand, Option 2 mandates an evaluation of refrigerant impact in accordance with ASHRAE Standard 15–2019, also known as the Safety Standard for Refrigeration Systems, or an approved equivalent standard by the US Green Building Council (USGBC), as per the project's specific requirements. Moreover, it entails the formulation and execution of a comprehensive refrigerant management plan, encompassing aspects such as leak detection, system retrofitting, and end-of-life disposal, tailored for all Heating, Ventilation, Air Conditioning, and Refrigeration (HVAC&R) systems that contain more than 225 g of refrigerant [42].
4. **Outdoor Water Use Reduction:** This credit category is designed to mitigate outdoor portable water consumption and safeguard inexpensive or freely available water resources. The project team can choose from two options, as shown in Fig. 2. Option 1 necessitates that the project refrains from establishing a permanent irrigation system lasting more than two years. Option 2, on the other hand, mandates a minimum 50 % reduction in the project's landscape water demands compared to the baseline peak watering month calculation. This reduction process may incorporate tailored plant species selection with minimal water requirements [42].
5. **Indoor Water Use Reduction:** This credit is similar to the outdoor water use reduction credit; however, its emphasis lies in the reduction of indoor water consumption. This credit necessitates the project's demonstration of water conservation efforts and the

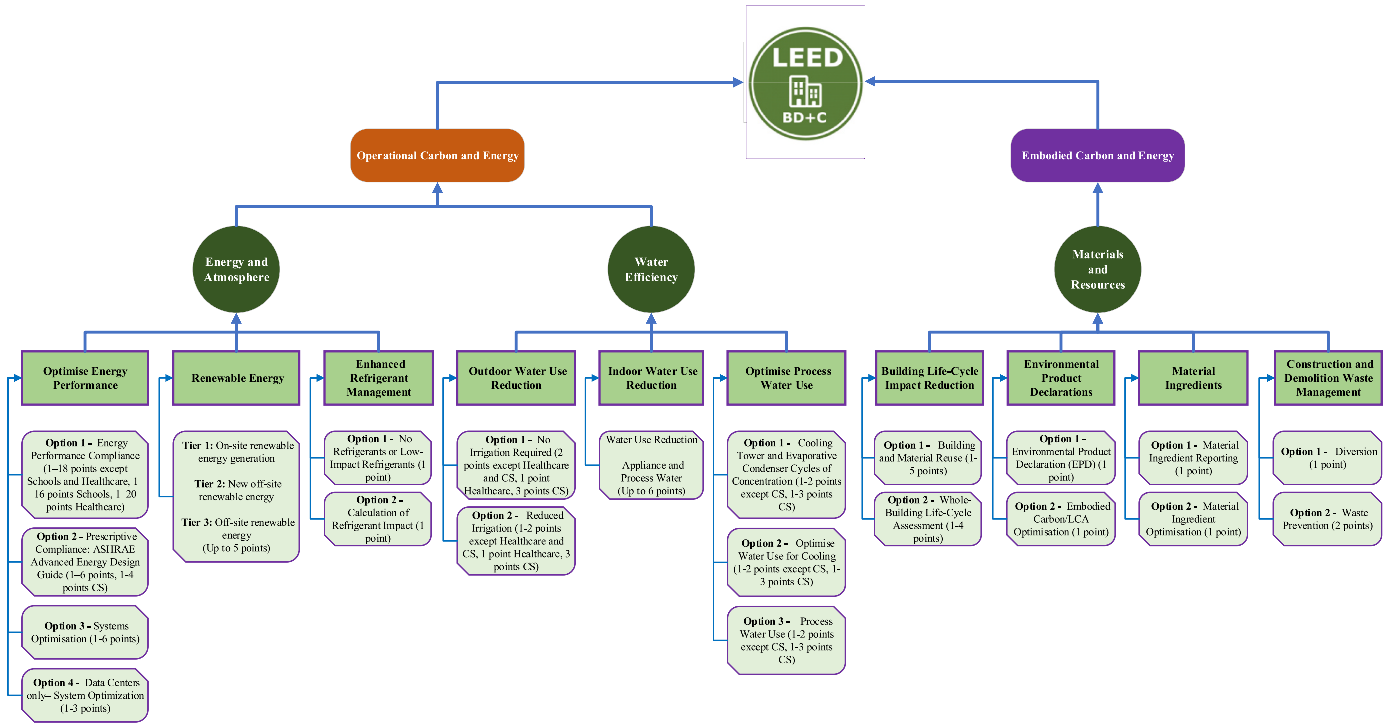


Fig. 2. Leed operational, embodied and whole life cycle assessment credits structure.

exploration of alternative water sources. Furthermore, it mandates the installation of appliances and water treatment processes that effectively reduce indoor water consumption [42].

6. **Optimise Process Water Use:** This credit with up to 3 points aims to preserve affordable, portable water resources utilised in the mechanical processes of the condenser system. This credit encompasses three distinct alternatives, as illustrated in Fig. 2. Option 1 necessitates the project to perform a single comprehensive analysis of potable water. In contrast, Option 2 is centred on diminishing annual water consumption compared to a water-cooled chiller system. Option 3, conversely, is realised when the project successfully showcases the utilisation of a minimum of 20–30 % recycled alternative water sources to meet its water requirements [42].
7. **Building Life-Cycle Impact Reduction:** This credit emphasises the evaluation of a building's environmental impact over its entire life cycle to encourage adaptive reuse and optimise the environmental impacts of construction products/materials. It includes *Building and Material Reuse* (option 1) and *Whole-Building Life-Cycle Assessment* (option 2). The first option supports the reuse of structural and non-structural elements in an existing space, such as walls, floors, roofs, doors, and floor coverings. The option has two paths for structural (1–5 points) and non-structural (1 point) elements. The project team can select one of the paths or combine the two [42].

   On the other side, the second option encourages projects to conduct a comprehensive whole-building life cycle assessment using a specified methodology. The aim is to evaluate and reduce environmental impacts across all life cycle stages, including material extraction, manufacturing, construction, use, and end-of-life. In addition, it is recommended that the LCA practitioners select any three of the following impact categories for reduction [42].

   - global warming potential (greenhouse gases) in kg CO_2e;
   - •depletion of the stratospheric ozone layer in kg CFC-11e;
   - •acidification of land and water sources in moles H+ or kg SO_2e;
   - •eutrophication, in kg nitrogen eq or kg phosphate eq;
   - •formation of tropospheric ozone in kg NO_x, kg O_3 eq, or kg ethene; and
   - •depletion of non-renewable energy resources in MJ using CML/depletion of fossil fuels in TRACI.
8. **Environmental Product Declaration:** This credit supports the use of materials/products with established life cycle information that can be adopted for WLCA. The credit has two options (*Environmental Product Declaration (EPD)* and *Embodied Carbon/LCA Optimisation*). The first option requires the use of at least 20 permanently installed products with compliant EPDs from at least five manufacturers, while the second option requires the use of five permanent products with embodied carbon optimisation reports or action plans from at least three manufacturers [42].
9. **Material Ingredients:** While not explicitly labelled as an LCA credit, the Material Ingredients credit promotes transparency and the reduction of hazardous substances in building materials. It encourages the use of products with disclosed actual impacts. EPDs often include information related to a product's environmental impact, as assessed through LCAs. It has two options, namely 1) *Material Ingredient Reporting* and 2) *Material Ingredient Optimisation,* worth 1 point each. The material ingredient reporting (option 1) requires the use of at least 20 products with an explicit declaration of environmental impacts from at least five manufacturers for the project. On the other hand, material ingredient optimisation (option 2) involves calculating the number of compliant products based on a specified formula [42].
10. **Construction and Demolition Waste Management:** Managing waste during the construction and demolition phases is crucial for reducing the environmental impact of a building [43]. The credit includes two options (*Diversion* and *Waste Prevention*). The first option encourages projects to divert at least 50 % of construction and demolition waste from landfills and incineration facilities, thereby extending the life of existing building materials, a key aspect of sustainability considered in LCAs. The second option requires adherence to a waste management plan and innovative

design strategies that utilise at least 50 % of demolition debris to minimise waste [42].

3.1.2. BREEAM

The BREEAM is a widely recognised and used tool for assessing the sustainability of buildings. It was first introduced in the United Kingdom in 1990 and has since been adopted in many countries worldwide [44]. BREEAM evaluates buildings on various sustainability criteria, including energy and water use, materials, and overall environmental impact. The New Construction was selected for further consideration.

The OEW credits in LEED New Construction are discussed as follows.

1. **Ene 01 – Reduction of Energy Use and Carbon Emissions:** the main goal of this credit is to minimise reliance on operational energy, primary energy utilisation, and the release of carbon dioxide emissions. It is divided into three parts as shown in Fig. 3. The first part, which is *Energy Performance* has two options namely: standard and basic routes. The standard route is based on approved building energy calculation software while the basic route is based on the implementation of energy-efficient features. The second part is centred on predicting '*Operational Energy Consumption*'. The third part, which is the *Exemplary Level Criteria* is awarded where the building demonstrates energy reduction beyond the net zero regulated carbon and a significant reduction in energy consumption at the post-occupancy stage [45].
2. **Ene 04 – Low carbon design:** This credit supports the utilisation of design strategies that reduce carbon emissions and building energy demand. It is divided into two parts, as shown in Fig. 3. The first part, which is *Passive Design,* is awarded if the building demonstrates that it can deliver the required thermal comfort levels based on the building design. The second part, which is the implementation of *Low and Zero Carbon Technologies* awards points for the use of low or zero carbon technologies that reduce carbon emissions [45].
3. **Ene 05 – Energy Efficient Cold Storage:** The credits encourage the use of energy-efficient refrigeration systems to reduce operational greenhouse gas emissions. The credit requires a demonstration of compliance with three sub-sections namely: 1) *Energy efficient design, installation, and commissioning,* 2) *Energy efficiency criteria*, and 3) *Reducing lifetime greenhouse gas emissions from energy use.* The '*Energy efficient design, installation, and commissioning*' subsection requires the design, installation and commission of the refrigeration system to meet the ten requirements in BRE Global [45]. The '*Energy efficiency criteria*' subsection ensures that the system is integrated with tested components that meet energy efficiency criteria. Finally, the subsection pertaining to the '*Reducing lifetime greenhouse gas emissions from energy use*' necessitates the refrigeration system to substantiate reductions in greenhouse gas emissions when contrasted with a conventional system specification [45].
4. **Ene 06 – Energy Efficient Transport Systems:** this credit support the use of energy-efficient transport systems such as lift and escalator within the building. The credit is divided into two parts: '*Energy Consumption*' and '*Energy Efficient Features*'. The first part requires the use of transport systems with minimal energy consumption estimated according to ISO 25745 (Energy performance of lifts, escalators and moving walks), while the second part, which is '*Energy Efficient Features*' requires the transport systems to have features such as standby condition when idle and regenerative drives [45].
5. **Ene 07 – Energy Efficient Laboratory Systems:** this credit includes three parts (Prerequisite, Design specification, and Best practice energy efficient measures. However, only '*Best Practice Energy Efficient Measures*' directly relate to operational energy and carbon emissions. This requires the adoption of strategies that reduce energy consumption by at least 2 % without compromising the safety of building occupants [45].
6. **Ene 08 – Energy Efficient Equipment:** The credit encourages using energy-efficient equipment to reduce the building's operational energy. It requires an analysis of equipment energy consumption and demonstrates a significant reduction in energy consumption for all equipment [45].
7. **Wat 01 – Water Consumption:** The credit classification, encompassing a maximum of 5 credits, is designed to facilitate the incorporation of water-efficient elements and recycling systems within new buildings aimed at mitigating the consumption of potable water for sanitary purposes. The evaluation of water usage is predicated upon the metric of litres per person per day, and it is juxtaposed against a predetermined baseline building [45].
8. **Wat 04 – Water Efficient Equipment:** The credit considers equipment that reduces water consumption significantly within

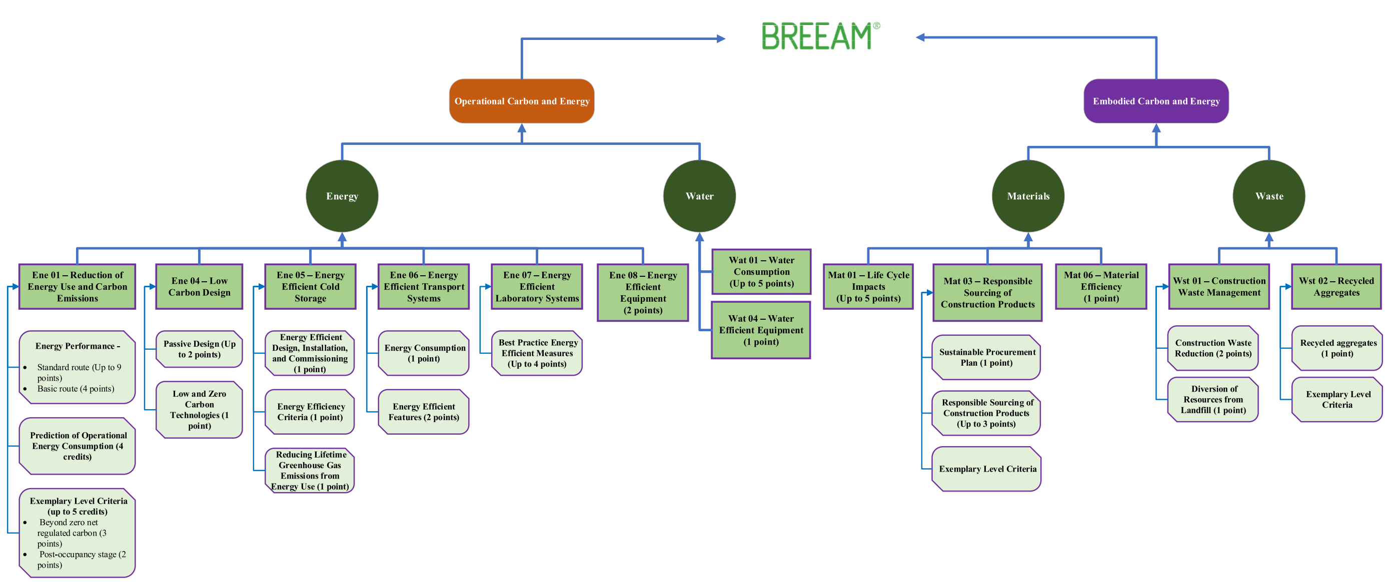


Fig. 3. Breeam operational, embodied and whole life cycle assessment credits structure.

the building. The overall goal is to ensure the adoption of water system components that minimise potable water consumption [45].

9. **Mat 01 – Life Cycle Impacts**: This credit focuses on reducing the environmental impacts of the building throughout its life cycle. It involves conducting a detailed whole building life cycle assessment to ascertain the environmental impact of different components of the building. It also encourages the use of sustainable and low-impact building materials with published EPDs [45].
10. **Mat 03 – Responsible Sourcing of Construction Products:** The credit has one prerequisite and three parts: 1) *Sustainable Procurement Plan*, 2) *Responsible Sourcing of Construction Products*, and 3) *Exemplary Level Criteria.* The credit requires the project team to use policies that support responsible sourcing of construction materials. It considers supply chain sustainability and materials transportation distance [45].
11. **Mat 06 – Material Efficiency:** This credit encourages material optimisation without compromising building quality to reduce environmental impacts at different stages of the building life cycle, from preparation and brief to the construction stage [45].
12. **Wst 01 – Construction Waste Management:** This category supports the effective management of construction waste, a significant part of environmental impacts. The credit category is divided into two parts, as shown in Fig. 3. The first part ('*Construction Waste Reduction*') requires effectively managing waste and continuously tracking waste produced on-site through accurate data collection. The second part ('*Diversion of Resources from Landfill*') awards points for diverting project waste from landfills [45].
13. **Wst 02 – Recycled Aggregates:** This credit category is divided into two parts, as shown in Fig. 3. The '*Recycled Aggregates*' part awards one point when at least 25 % of the high-grade aggregates are recycled aggregate, while the exemplary level criteria are met when more than 50 % of the aggregates used for the project are recycled aggregate [45].

3.1.3. *Green Star*

The Green Building Council of Australia (GBCA) was launched in 2002. It is a national, non-profit, and member-based organisation committed to developing Australia's sustainable property industry. The first decision was made with a Green Star assessment tool for new office buildings in 2003 due to the growth in the demand for green buildings at that time [46]. New Zealand and South Africa have adapted Green Star to rate and certify sustainable buildings in those countries [47]. The Green Star – Design and As-Built was considered for critical review since the scope of this research is at the building level.

The Green Star Design and As Built NZ have three credits related to operational carbon and energy, while four credits are related to embodied carbon and energy, as shown in Fig. 4. The Green Star rating system encourages the incorporation of LCA in building design and construction, offering LCA-related credits for projects that can demonstrate a reduction in their life cycle environmental impact. The OEW credits are elaborated as follows.

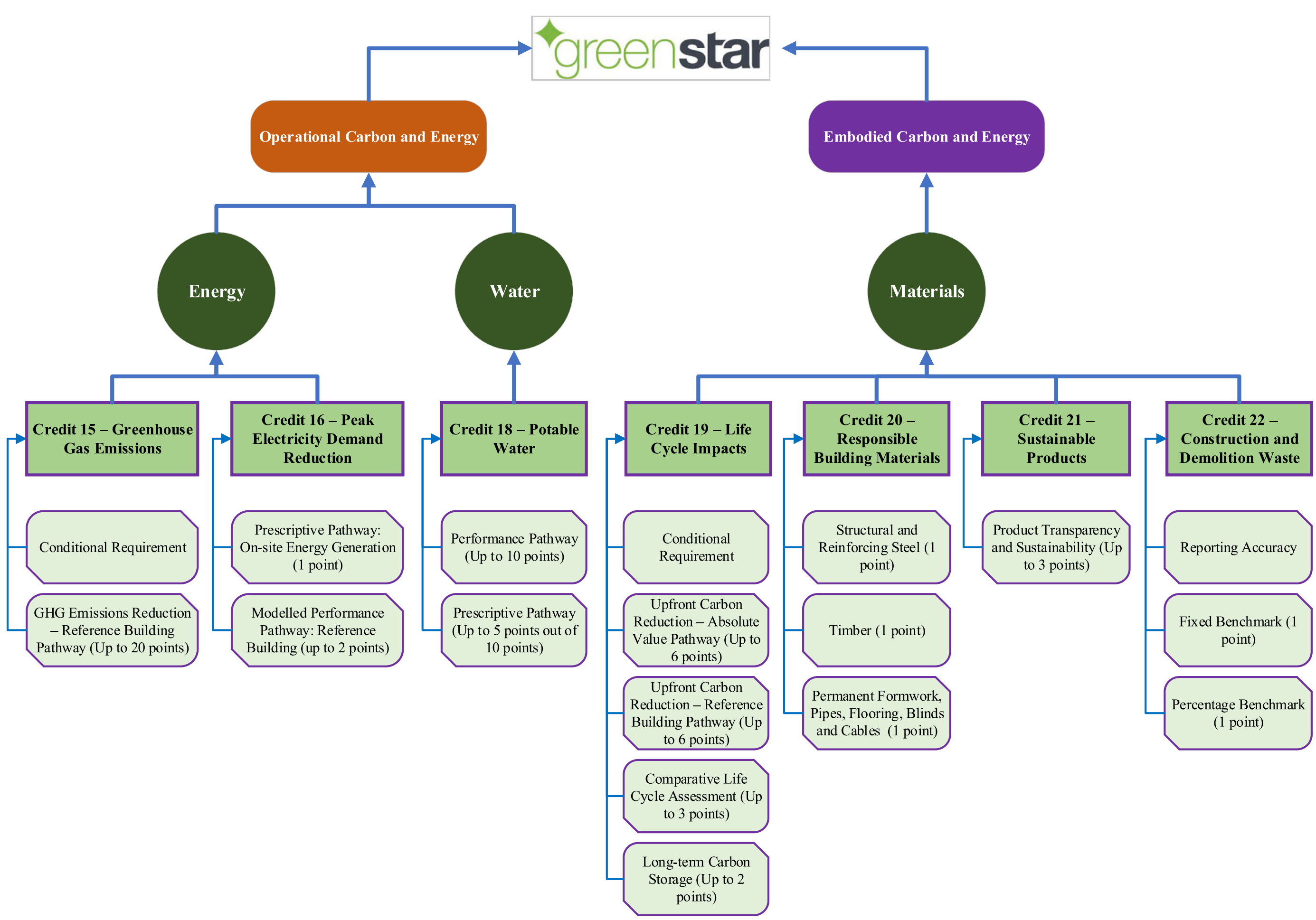


Fig. 4. Green star NZ operational, embodied and whole life cycle assessment credits structure. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

1. **Credit 15 – Greenhouse Gas Emissions:** This credit has two criteria: *Conditional Requirement* and *GHG Emissions Reduction* with up to 20 points. The conditional requirement requires the building to show a 10 % improvement on the reference building in terms of operational GHG emissions, and it is the basis on which a building qualifies for the Green Star – Design & As Built rating. The GHG emissions reduction – reference building pathway requires building reduction in energy consumption and GHG emissions based on a range of percentages [48].
2. **Credit 16 – Peak Electricity Demand Reduction:** This credit has two criteria: *Prescriptive Pathway: On-site Energy Generation* and *Modelled Performance Pathway: Reference Building* with one and up to two points, respectively. The first criterion (*Prescriptive Pathway*) awards 1 point where the project demonstrates at least a 15 % reduction in the total peak electricity demand through on-site electricity generation systems. Conversely, the second criterion awards 1 point and 2 points where the project demonstrates a 20 % and 30 % reduction respectively, in the predicted peak electricity with reference to the benchmark building [48].
3. **Credit 18 – Portable Water:** This credit requires the evaluation of a building's water usage. It includes two criteria: *Performance* and *Prescriptive Pathway*. The *performance pathway* is based on the magnitude of water consumption reduction compared to the reference building. In contrast, the *prescriptive pathway* considers water consumption reduction using best practice water-saving design features [48].
4. **Credit 19 – Life Cycle Impacts:** This credit includes one minimum mandatory criterion (*Conditional Requirement*) and three criteria (*Upfront Carbon Reduction*, *Comparative Life Cycle Assessment*, and *Long-term Carbon Storage*), totalling 11 points. The mandatory criterion requires 10 % upfront carbon emission reduction to achieve 4 and 5 Star while 6 Star requires 15 % upfront carbon emissions reduction. The upfront carbon reduction criteria (6 points) are achieved when there is a reduction in upfront carbon relative to the reference building. The comparative life cycle assessment criterion (3 points) is achieved when a whole-of-life cycle assessment is conducted to ascertain the reductions in life cycle impacts compared to the reference building. Lastly, the long-term carbon storage criterion (2 points) is achieved when the project incorporates long-term carbon storage in the building design [48].
5. **Credit 20 – Responsible Building Materials:** This credit emphasises incorporating responsibly sourced materials through a sustainable supply chain. The credit includes three criteria: 1) *Structural and Reinforcing Steel*, 2) *Timber*, and 3) *Permanent Formwork, Pipes, Flooring, Blinds and Cables* worth 1 point each. The first criterion awards 1 point where 95 % of the steel mass is sourced from an environmentally responsible steel maker, and at least 60 % of the fabricated steel in steel framed building is supplied by a responsible steel fabricator or supplier, including possession of New Zealand Sustainable Steel Council membership and recognised environmental management systems [48]. The concrete framed buildings require at least 60 % of the rebar and mesh to be produced using an energy-reduction process, or 60 % of the rebar and mesh holds Environmental Choice EC-41-15 certification. Secondly, the timber criteria award 1 point where 95 % of the timber used for the project is certified by a forest certification scheme or from a reuse source. Lastly, the third credit awards 1 point where permanent formwork, pipes, flooring, blinds and cables do not contain Polyvinyl chloride (PVC) and a valid EPD or meet the best practice guidelines for PVC [48].
6. **Credit 21 – Sustainable Products:** The credit has only one criterion (Product Transparency and Sustainability) with up to three points when a proportion of the project materials meets transparency and sustainability requirements through reused products, recycled content products, EPD, third-party certification, or stewardship programs [48].
7. **Credit 22 – Construction and Demolition Waste:** This credit includes one minimum mandatory criterion (*Reporting Accuracy*) and two criteria (*Fixed Benchmark* and *Percentage Benchmark*), totalling 2 points. The minimum criterion is met where the contractor and waste processing facilities demonstrate compliance with New Zealand Green Star Construction and Demolition Waste Reporting Criteria. The fixed benchmark criterion is awarded when the construction waste going to landfill is minimised compared to a typical building. The percentage benchmark criterion is awarded when construction waste is successfully redirected away from its destination of landfill disposal [48].

3.1.4. Level(s) framework

The Level(s) framework was launched by the European Commission in 2020 to promote a shift towards circular economy and life cycle thinking [49]. The framework provides a solid basis to assess and report the environmental performance of buildings throughout their life cycle using a common language. It includes six macro-objectives ("1 - *Greenhouse gas and air pollutant emissions along a buildings life cycle*", "2 - *Resource efficient and circular material life cycles*", "3 - *Efficient use of water resources*", "4 - *Healthy and comfortable spaces*", "5 - *Adaptation and resilience to climate change*", and "6 - *Optimised life cycle cost and value*") and 16 indicators ranging from "*1.1 – use stage energy performance*" to "*6.2 – value creation and risk exposure*" [50]. However, only the first three macro-objectives considered OEW credits, as shown in Fig. 5. One critical aspect of the Level(s) framework is its emphasis on circular economy principles as it considers indicators such as "*2.3 Design for Adaptability and Renovation*" and "*2.4 Design for Deconstruction, Reuse and Recycling*" [50]. These indicators are essential for promoting a circular economy in the construction industry for future construction projects. Level(s) implementation could be a critical consideration in the expansion of other GBCS such as BREEAM, LEED, Green Star, among others, through its inclination towards newer sustainability concepts such as circular economy. The influence of Level(s) may result in an evolution of the existing GBCS to consider concepts like circular economy.

The OEW credits in Level(s) are discussed as follows.

- **Macro-objective 1 - Greenhouse gas and air pollutant emissions along a buildings life cycle:** the objective has two main focuses, which include near zero energy consumption at the use phase and embodied greenhouse gas emissions for the building lifecycle. This macro-objective has two indicators ("*1.1 - Use Stage EnergyPerformance*" and "*1.2 - Life cycle Global Warming Potential*") focused on assessing the operational and embodied emissions throughout the building lifecycle. It also balances the trade-offs between operational and embodied emissions with the view to limit the overall building emissions [50].
- **Macro-objective 2 - Resource efficient and circular material life cycles:** the main focus of this objective is centred on material circularity and efficiency. It includes special considerations for the materials incorporated into the building from the design to the deconstruction stage of the building lifecycle in order to optimise material use, reduce waste and embrace circularity [50]. It includes four indicators focused on achieving the goals of this objective, as shown in Fig. 5.
- **Macro-objective 3 - Efficient use of water resources:** The third objective focuses on minimising water consumption and optimising water supply sources such as rainwater harvesting and greywater reuse [50]. It has only one indicator ("*3.1 Use Stage Water Consumption*").

3.2. Developing countries

The GBCS in two developing countries are covered under this subsection. The selected GBCS from developed countries include LOTUS (Vietnam) and GREENSL (Sri Lanka).

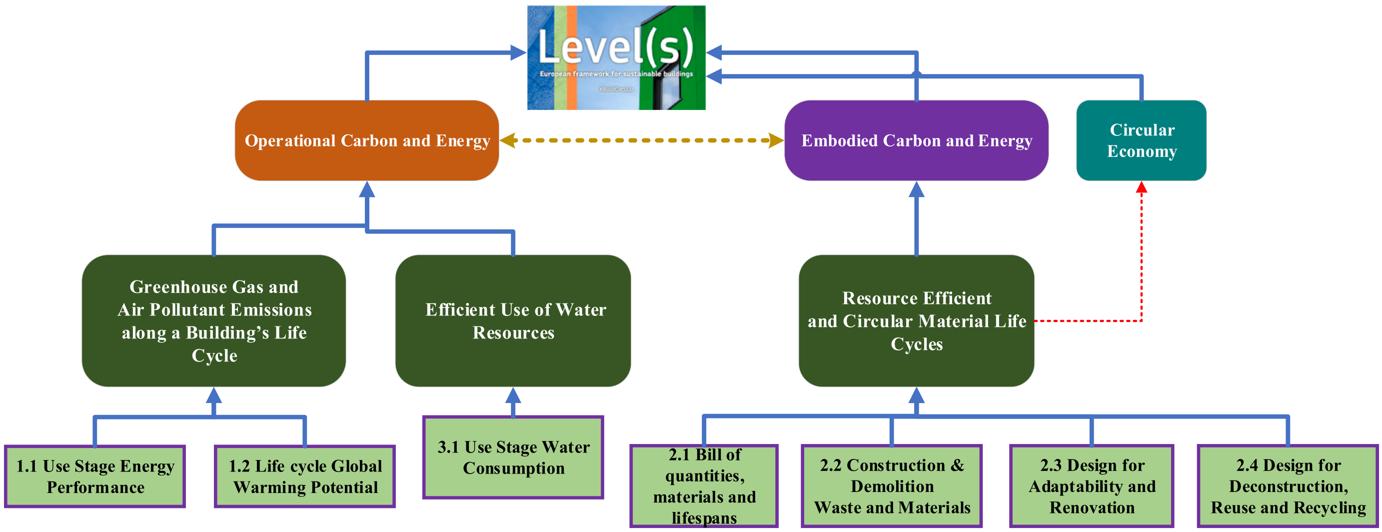


Fig. 5. Level(s) operational, embodied and whole life cycle assessment credits structure.

3.2.1. LOTUS

The LOTUS framework comprises a series of voluntary green building rating systems established by the Vietnam Green Building Council (VGBC) in conjunction with the Green Cities Fund in 2010. The administration and oversight of LOTUS assessment and training programs are entrusted to the Vietnam Green Building Social Enterprise Co. Ltd, an entity created by VGBC for this purpose [51]. LOTUS was conceived to guide the construction industry, aiming to ensure the efficient utilisation of sustainable materials and environmentally responsible construction practices.

LOTUS New Construction has 14 credit categories related to OEW credits, as shown in Fig. 6. The credits are discussed as follows.

1. **E-PR-2 & E-1 – Passive Design:** This credit category has one point and requires the building team to conduct a passive design analysis, including daylight and thermal simulation at the concept phase of the project with the view to identify opportunities that will reduce mechanical ventilation while ensuring optimal thermal comfort for building occupants [52].
2. **E-PR-3 & E-2 – Total Building Energy Use:** This credit category consists of fourteen points and has one prerequisite that requires the demonstration of a 10 % reduction in total building energy compared to the baseline building using energy simulation. For every 2.5 % reduction in energy consumption, one point is awarded up to 45 % [52].
3. **E-3 – Building Envelope:** The category has up to 3 points, and the project team is required to select one of the two options, as shown in Fig. 6, to fulfil the criteria. Option A requires the overall thermal transfer value to surpass the 'National Technical Regulation on Energy Efficiency Buildings' (QCVN 09: 2017/BXD) requirements by 15 %. Also, one additional point is awarded for every subsequent 15 % reduction in the building's average OTTV compared to QCVN 09: 2017/BXD [52]. Option B awards points for modification of the building envelope design through any of the four strategies: 1) solar radiation, 2) west facing façade, 3) window-to-wall ratio on the west and east facing façades, and 4) Effective external shading [52].
4. **E-4 – Building Cooling:** This credit category is focused on reducing energy consumption for space cooling [52]. It has two strategies that can be pursued for a maximum of 6 points. The first strategy awards the building one point for 10 % of occupied areas that are naturally ventilated. An additional one point is also

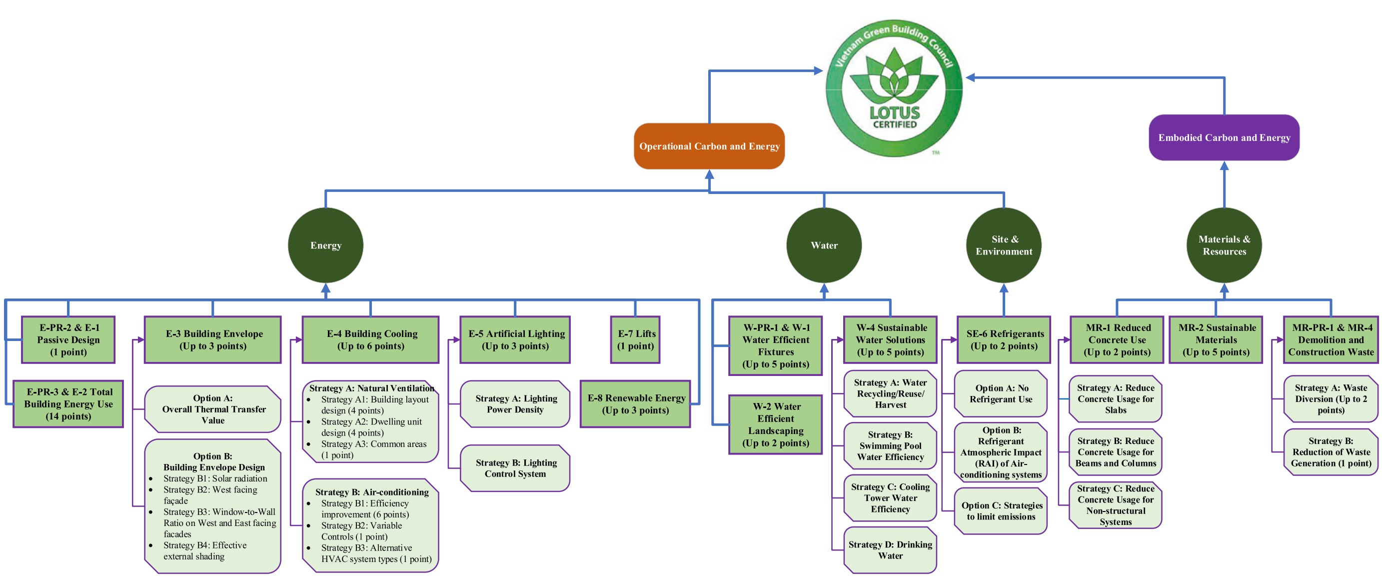


Fig. 6. Lotus operational, embodied and whole life cycle assessment credits structure.

awarded to the subsequent 15 % and 20 % of spaces naturally ventilated for non-residential and residential buildings respectively [52]. Natural ventilation can be enhanced for residential buildings through building layout design, dwelling unit design and common areas. The second strategy awards points for energy efficiency improvement and control for air conditioning systems [52].

5. **E-5 – Artificial Lighting:** This credit category has three points aimed at reducing energy consumption associated with artificial lighting systems. The credit is based on two strategies ("*Lighting Power Density*" and "*Lighting Control System*"). As shown in Fig. 6, Strategy A awards one point when the installed lighting power density exceeds QCVN 09: 2017/BXD requirements by every 15 % and 20 % for non-residential and residential buildings respectively [52].
6. **E-7 – Lift:** This credit category awards one point for buildings that significantly reduce lift operational energy through conformity to energy certification guidelines or incorporation of efficient controls, standby mode, lighting system, hoisting and energy regeneration [52].
7. **E-8 – Renewable Energy:** The credit category gives up to three points for construction projects that maximise the use of renewable energy sources. One point is awarded if 1 % of the total energy used in the building is from renewable sources, and an additional one point is awarded for every 1 % renewable energy [52].
8. **W-PR-1 & W-1 – Water Efficient Fixtures:** The credit category awards up to five points for using water-efficient fixtures that reduce water consumption. The prerequisite requires the water fixtures to reduce water consumption by 20 % compared to the baseline building. One point is awarded when water consumption is reduced by 25 %, and an additional one point is awarded for every 5 % reduction in water consumption [52].
9. **W-2 – Water Efficient Landscaping:** This credit group has up to two points and awards points for buildings with landscaped areas greater than 100 square meters. It is required that the building landscape design incorporate native species and demonstrate a reduction in water consumption for irrigation compared to the benchmark consumption [52].
10. **W-4 – Sustainable Water Solutions:** The credit category gives up to five points for projects implementing sustainable solutions that reduce the demand for domestic water. The sustainable water solution can be implemented through four strategies: water recycling, swimming pool water efficiency, cooling tower water efficiency, and drinking water treatment [52].
11. **SE - 6 – Refrigerants:** The credit classification has up to two points depending on building type and facilitates the choice of refrigerants that have a negligible impact on exacerbating global warming and causing depletion of the ozone layer [52]. There are three options, as shown in Fig. 6, that the project team can pursue based on the building type.
12. **MR-1 – Reduced Concrete Use:** The credit classification has two points for reducing concrete in construction projects [52]. This is due to the fact that concrete contributes significantly to global emissions. The credit category has three strategies, as shown in Fig. 6: reduction in concrete usage for structural (slabs, beams and columns) and non-structural systems.
13. **MR-2 – Sustainable Materials:** The category has a maximum of five points and encourages the use of sustainable materials for buildings. One point is awarded when 10 % of the total value of the materials are sustainable materials, and an additional one point is awarded for every additional 5 % up to 30 % [52].
14. **MR-PR-1 & MR-4 Demolition and Construction Waste:** The credit classification has up to two points and encourages recycling construction waste to reduce landfill disposal [52]. The credit has a prerequisite that requires developing and implementing a demolition and waste management plan. There are two strategies to reduce construction waste, as shown in Fig. 6 [52].

3.2.2. GREENSL

GREENSL was conceived as an indigenous initiative and formally introduced in 2012. The primary objective behind its inception was to incentivise and encourage the Sri Lankan construction industry to adopt sustainable practices. There are over 60 certified green buildings, 30 buildings awarded the green label, and a substantial number of more than 1000 professionals who have undergone training in this system. This rating system is designed to promote the construction of high-performance, resilient, health-conscious, and environmentally responsible buildings. It is worth noting that the GREENSL rating system features two distinct variants tailored for existing buildings and new constructions, each with its respective evaluation criteria and benchmarks.

The OEW credits of the GREENSL rating system have close similarities with the LEED rating system and are discussed as follows.

1. **Credit 3.1 – Water Efficient Construction:** This credit category seeks to reduce or completely avoid using potable water for construction activities. The project team must implement construction methodologies that reduce water consumption during construction. One point is awarded for a reduction between 50 and 75 %, while two points are awarded for a reduction beyond 75 % [53].
2. **Credit 3.2 – Cooling Tower Water Efficiency in Air-Conditioning System:** The credit category reduces or prevents potable water use within air-conditioning systems, and it is worth one point. It requires water consumption to be reduced by 50 % for air conditioning [53].
3. **Credit 3.3 – Indoor Water Use Reduction:** This credit category focuses on optimising water consumption within buildings to reduce the pressure on wastewater and water supply systems. One to four points are awarded for indoor water reduction up to 50 %, while 5 points are awarded for water use reduction from 51 % and above [53].
4. **Credit 3.4 – Innovative Wastewater Technologies:** The objective of credit classification is to mitigate the generation of wastewater and to optimise the replenishment of local aquifers while minimising the demand for potable water [53]. The credit has four sub-class, as shown in Fig. 7, that entails recycling water for reuse within the building.
5. **Credit 3.5 – Innovative Water Transmission:** The credit category limits the use of non-renewable energy for water transmission. One point is awarded for a 50 % reduction in non-renewable energy consumption in water transmission through renewable alternatives such as solar panels, wind, low-impact hydro generators, and biogas [53].
6. **Credit 4.1 – Optimise Energy Performance:** This credit focuses on mitigating environmental consequences stemming from excessive energy consumption. Within this credit, there are three distinct options, as illustrated in Fig. 7. These options (labelled 1 through 3) share similarities with the prerequisites found in the '*Optimise Energy Performance*' category within the LEED rating system.
7. **Credit 4.1 – Onsite Renewable Energy:** The credit category has up to five points awarded based on the ability of the project to replace fossil fuel energy use with renewable energy sources such as solar photovoltaic technology within the site [53]. The category closely resembles the '*Renewable Energy*' category in LEED.
8. **Credit 4.4 – Enhanced Refrigerant Management:** This credit category endeavours to mitigate ozone depletion and promote timely adherence to the Montreal Protocol while minimising its direct impact on climate change [53]. The credit is the same as

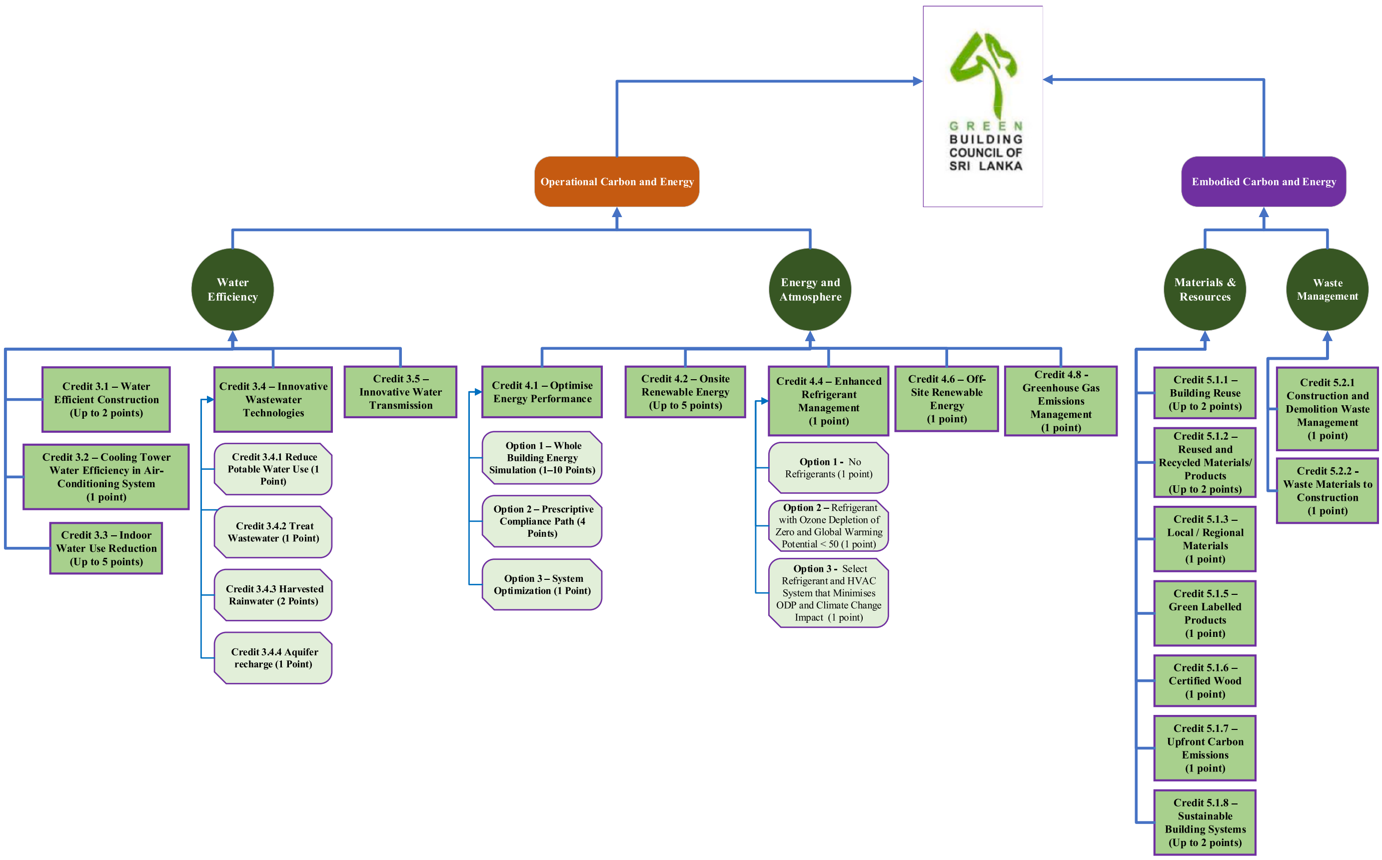


Fig. 7. Greensl operational, embodied and whole life cycle assessment credits structure.

the '*Enhanced Refrigerant Management*' under the LEED rating system.

9. **Credit 4.6 – Off-Site Renewable Energy:** This credit has one point, and it encourages the company to install off-site renewable technologies to account for at least 50 % of the building's total energy requirement [53].
10. **Credit 4.8 – Greenhouse Gas Emissions Management:** The credit classification aims to mitigate operational greenhouse gas emissions associated with the building operational phase. This necessitates the quantification of carbon emissions released into the environment over one year by the assessor per the Greenhouse Gas Protocol and ISO14064-Part 1 Standard. It also requires developing a carbon management plan with yearly targets that reduce greenhouse gas emissions [53].
11 Credit 5.1.1 – Building Reuse: The credit category endeavours to prolong the operational lifespan of structures by promoting resource preservation and mitigating the ecological footprint associated with new construction projects. This particular category mandates the retention of a minimum of 75 % of structural elements and a minimum of 25 % of non-structural components [53].
12. **Credit 5.1.2 – Reused and Recycled Materials/Products:** This credit classification supports the use of recycled materials for new buildings to reduce the demand for virgin materials. It requires at least 10 % of the total building cost for recycled materials [53].
13. **Credit 5.1.3 – Local/Regional Materials:** The credit category encourages the use of local materials to reduce the emissions associated with the transportation of materials. In adherence to the stipulated requirement, a minimum of 50 % of the aggregate value of construction materials must originate from local sources [53].
14. **Credit 5.1.5 – Green Labelled Products:** The credit classification endorses the utilisation of ecologically sustainable materials and certified equipment, mandating that a minimum of 10 % of the overall construction expenses be allocated to materials possessing green certification from the Green Building Council of Sri Lanka or other third-party entities approved by the World Green Building Council [53].
15. **Credit 5.1.6 – Certified Wood:** The credit category advocates for promoting conscientious forest management, incorporating environmentally sustainable practices. It mandates that a minimum of 50 % of materials derived from wood be certified in adherence to the regulations set forth by the Department of Forest Conservation and the State Timber Cooperation within the purview of the Ministry of Environment [53].
16. **Credit 5.1.7 – Upfront Carbon Emissions:** The credit category requires quantifying carbon emissions during the building material production, transportation and construction stages. The WLCA is conducted using manual calculation or LCA software [53].
17. **Credit 5.1.8 – Sustainable Building Systems:** This credit category is designed to facilitate the incorporation of environmentally sustainable building designs and construction methods. It mandates integrating sustainable building systems across at least 25 % of the constructed floor area. This encompasses various strategies, such as using pre-stressed concrete components, composite structural elements, and lightweight concrete elements, among other potential approaches [53].
18. **Credit 5.2.1 Construction and Demolition Waste Management:** The credit category incentivises the redirection of waste generated from construction, demolition, and land-clearing activities away from disposal in landfills. This involves developing and implementing a waste management plan, with a stipulated

minimum requirement to recycle no less than 50 % of the generated waste materials [53]. It is related to the '*Construction and Demolition Waste Management*' credit category in the LEED rating system.
19. **Credit 5.2.2 - Waste Materials to Construction:** This credit classification seeks to reduce the demand for virgin materials by diverting waste from other industries for use in construction projects. It requires a minimum of 2.5 % of the total building material cost to be material waste from other industries, such as quarry dust, glass waste, and rice husk ash [53].

3.3. Newly developed GBCS

In addition to the GBCS from developed and developing countries, this study also considered two new GBCS for Iran [21] and the sub-Saharan Africa region [20,32] developed by researchers based on the limitations of the existing and lack of location-based GBCS. However, the newly developed GBCS are mainly focused on extending the rating systems to include social and economic dimensions of sustainability. For instance, the Iranian Green Building Assessment Tool (IGBT) included a criterion named "*Cost and Economic*" [21], while the Building Sustainability Assessment Method (BSAM) scheme for the sub-Saharan Africa region expanded the social dimension of sustainability including criteria such as "*Societal Engagement*", "*Safety and Health*" and "*Ethics and Equity*". They have not focused on improving the OEW credits. It is important to note that the OEW credits were similar to the respective sections in the notable GBCS, such as LEED and BREEAM. It was difficult to access the technical documentation for IGBT. Therefore, the researcher relied on the information provided within the paper to assess the OEW credits while BSAM was evaluated using the technical manuals.

Figs. 8 and 9 show the operational and embodied related credits in IGBT and BSAM respectively. Nonetheless, it is observed that the concept of WLCA is not well elaborated in the systems (IGBT and BSAM). This suggests the need for newly developed GBCS to enhance the OEW credits further in future GBCS.

4. Natural language processing

4.1. Word cloud analysis

The word cloud analysis is intended to find the key terms within the dataset, including selected GBCS. The word cloud visualisation (Figure A1) is a graphical representation of the most common words in the dataset. The word cloud displays words in varying font sizes, with the larger and bolder ones indicating higher frequency. The word cloud serves as an initial exploratory tool for understanding the dataset [54]. The word cloud analysis revealed several prominent keywords that offer insights into the dataset's content. Notable keywords include '*building*', '*design*', '*energy*', '*water*', '*green*', and '*project*'. These words dominate the visualisation due to their high frequency of occurrence. These prominent keywords serve as a starting point for understanding the dataset's primary focus. This shows that the existing GBCS focus more on energy, water and overall building design. Energy and water have operational impacts, while building design has embodied impacts.

4.2. GBCS document similarity

Natural language processing was employed to quantify the similarity between pairs of GBCS technical manuals within the corpus. The document similarity technique was employed as described in the methodology, which requires the computation of the TF-IDF before the cosine similarity. Table 1 summarises the cosine similarity scores for the technical manuals, while Figure A2 shows a heatmap created using the Seaborn library to visually represent the GBCS technical manual similarity matrix. The heatmap provided an at-a-glance view of the pairwise similarity scores between documents. On a colour scale from 0 (normally, zero similarity) to 1 (perfectly identical), it is clear that the degree of relatedness between these documents was not equal [55].

Table 1 revealed that the GREENSL has the highest cosine similarity scores, with all scores over 0.5 for the four GBCS (BREEAM [0.590], BSAM [0.521], GreenStar NZ [0.622], LEED [0.648], and LOTUS [0.550]). This shows that the GreenSL share significant similarities with the LEED rating system because it has the highest similarity score with GREENSL. In contrast, the second developing country GBCS considered in this research, LOTUS, has moderate similarity scores compared to the other existing GBCS from developed countries, while BSAM has a relatively poor similarity score compared to the other GBCS. This may indicate the certification systems' uniqueness or weakness in critical sustainability principles accountability. Nonetheless, it is important to acknowledge that different geographical locations have their primary sustainability goals.

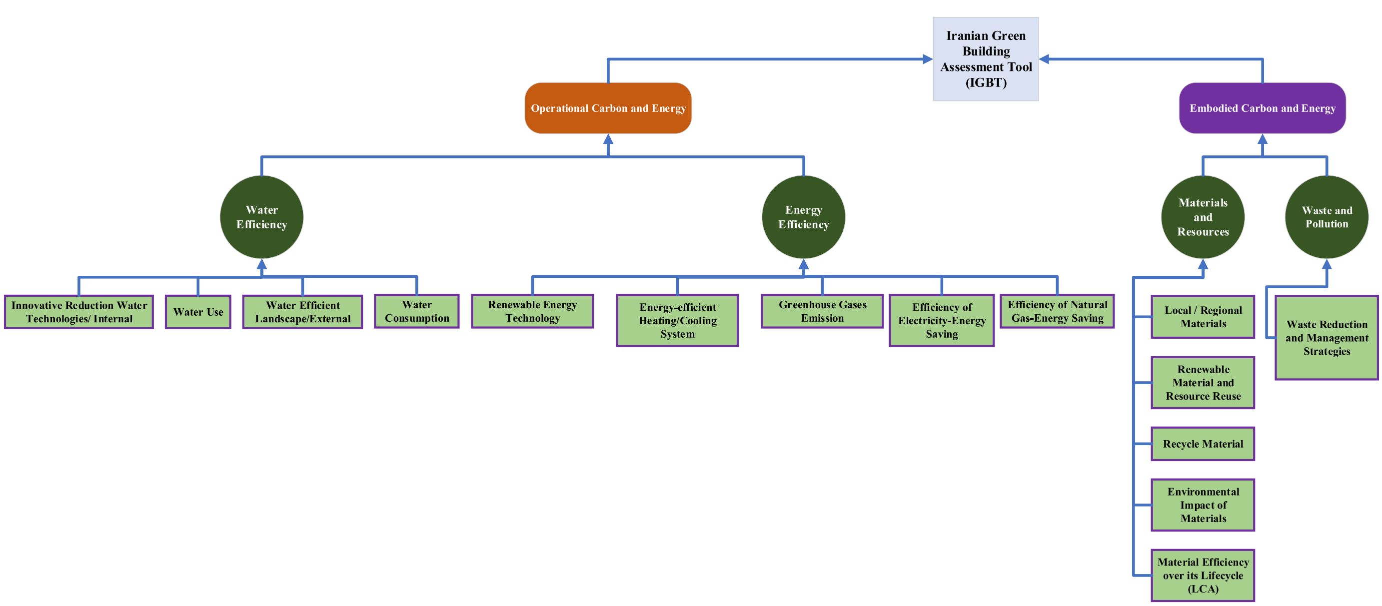


Fig. 8. Igbt operational, embodied and whole life cycle assessment credits structure.

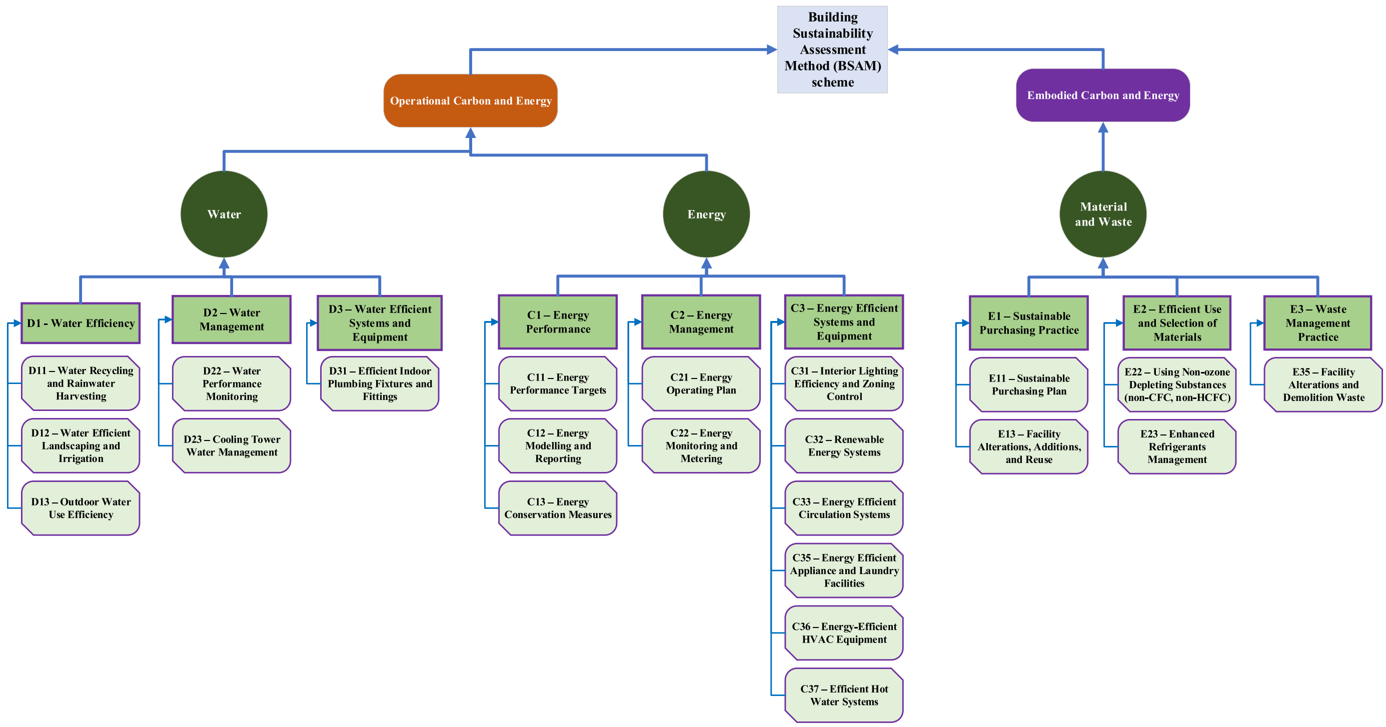


Fig. 9. Bsam operational, embodied and whole life cycle assessment credits structure.

Table 1
Cosine similarity GBCS.

GBCS	BREEAM	BSAM	GREENSL	GreenStar	LEED	LOTUS
BREEAM	1.000	0.415	0.567	0.561	0.557	0.442
BSAM	0.415	1.000	0.498	0.410	0.455	0.348
GREENSL	0.567	0.498	1.000	0.645	0.722	0.535
GreenStar	0.561	0.410	0.645	1.000	0.646	0.468
LEED	0.557	0.455	0.722	0.646	1.000	0.507
LOTUS	0.442	0.348	0.535	0.468	0.507	1.000
Average Cosine Similarity	**0.590**	**0.521**	**0.661**	**0.622**	**0.648**	**0.550**

5. Analysis and discussion of results

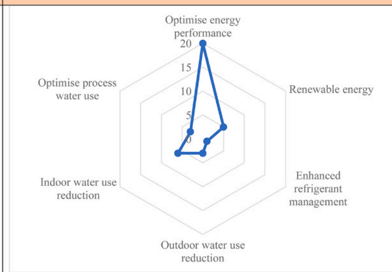
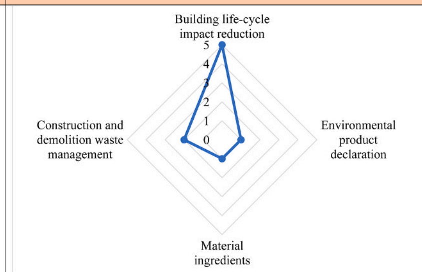
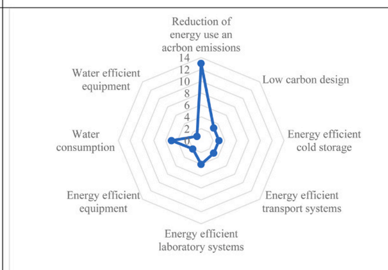
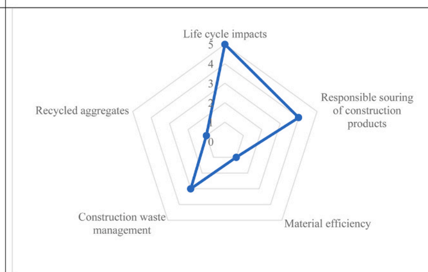
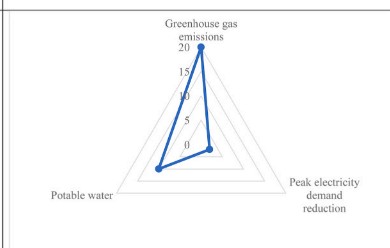
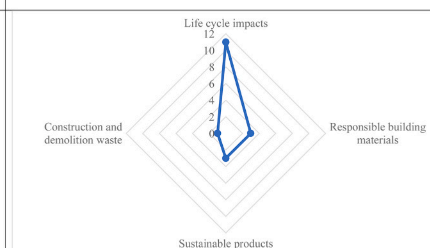
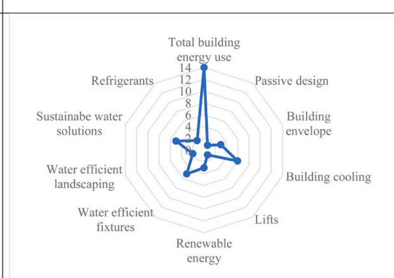
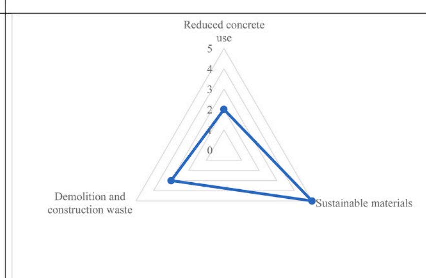
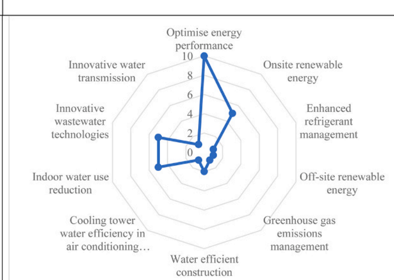
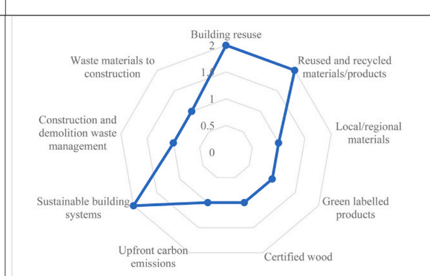
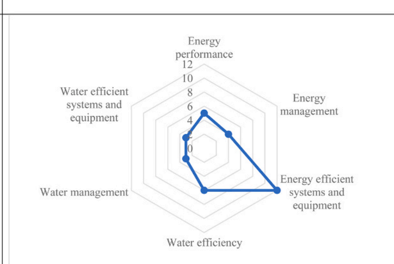
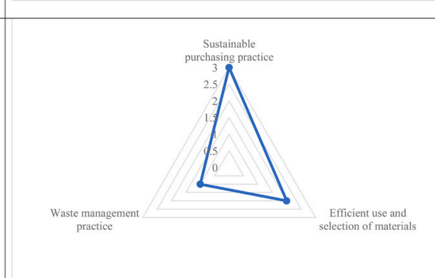
5.1. Operational and embodied credits

Fig. 10 shows that the certification systems from developed and developing countries showed that operational credits are prioritised compared to embodied credits in the six certification systems (LEED, BREEAM, Green Star NZ, LOTUS, GREENSL, and BSAM). On average, the operational carbon and energy-related credits are three times more than the embodied carbon and energy-related credits. This is due to the cumulative nature of the operational carbon and energy over the building's lifespan. Previous research by Peng [9] and Bullen et al. [56] has reported that operational carbon emissions are significantly higher than embodied carbon emissions.

Furthermore, Table 2 shows the operational and embodied credit distribution across the existing GBCS. For operational credits, it is observed that the '*Optimise energy performance*' (20 points) and '*Greenhouse gas emissions*' (20 points) of LEED and Green Star NZ, respectively have the highest credit points compared to the other GBCS. On the other hand, the '*Life cycle impacts*' (12 points) credit category of Green Star NZ has the highest embodied credits. In addition, it is observed that waste-related credits are given less attention in many of the existing GBCS. Only the LOTUS has a high waste-related credit point of 3 compared to the others. These findings agree with Lu et al. [57], who emphasised that GBCS do not greatly promote waste management practices. One possible reason for the lack of attention towards waste-related credits could be the historical focus of GBCS on indoor environmental quality, energy efficiency, and material selection, which have traditionally been considered the primary focus of sustainability in buildings. While these aspects are undoubtedly important, the growing recognition of the global waste crisis [58] and the significant environmental impact of construction and demolition waste [59] necessitate a more robust inclusion of waste-related credit points. Another contributing factor may be the complexity and variability of waste management practices across regions and building projects. Standardising waste-related assessment criteria can be challenging, as local regulations, recycling infrastructure, and waste disposal options vary widely. However, addressing these variations and offering flexible solutions within rating systems is essential to encourage responsible waste management practices.

It is evident from previous studies that buildings certified under the GBCS consistently demonstrate superior energy efficiency and reduced greenhouse gas emissions compared to non-certified buildings [60,61]. The energy savings often reduce operational costs for the building occupants and contribute to environmental sustainability. Despite the substantial benefits of the GBCS, the operational credit requirements within certain GBCS, such as LEED and BREEAM, can be complicated

Table 2
Operational and embodied credits distribution.

GBCS	Operational Credits	Embodied Credits
LEED		
BREEAM		
Green Star NZ		
LOTUS		
GREENSL		
BSAM		

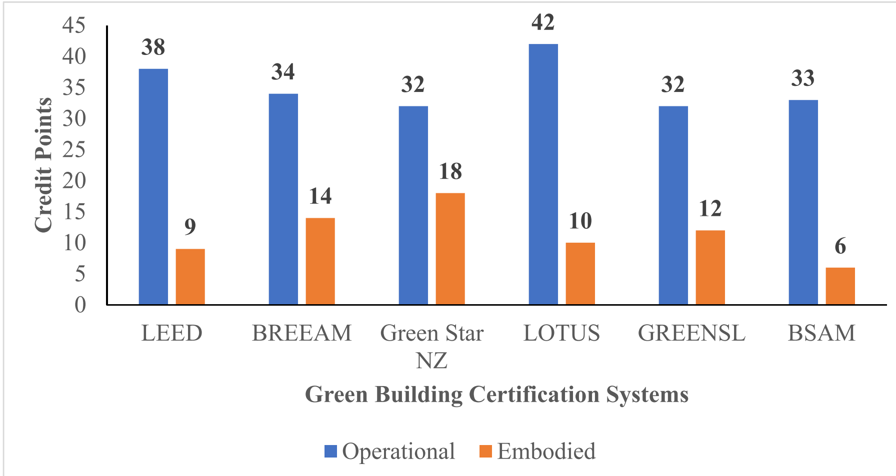


Fig. 10. Operational and embodied credits.

and daunting, particularly for smaller buildings or professionals with limited experience [62]. Simplifying these requirements without deviating from the sustainability goals could boost their accessibility and adoption. Although the focus on energy efficiency is justified as energy demand increases with population growth [63], a broader approach is needed to involve sustainability's social and economic facets. Obsession with energy could potentially overshadow other important metrics, such as the health and well-being of occupants and impacts on the broader community. Finding a balance in GBCS is critical for achieving sustainable development at all levels.

Embodied credits are crucial in encouraging the selection of sustainable materials, recycled products, and locally sourced materials. These choices significantly minimise the environmental impact associated with the construction process [64,65]. Embodied credits foster more sustainable construction practices by promoting efficient material use and minimising construction waste, which aids in the reduction of resource consumption [66]. The assessment of embodied impacts encounters inherent challenges stemming from variations in regional materials availability, divergent methodologies for impact measurement, and the absence of global standardisation [67]. Establishing consensus on a standardised approach is crucial to ensure equitable comparisons across regions and projects.

Furthermore, it is essential to acknowledge that incorporating sustainable materials and practices, as mandated by embodied credits, may lead to higher upfront costs. This financial hurdle has the potential to deter some building projects from embracing sustainable construction practices. As a result, striking a balance between building construction sustainability objectives and economic feasibility is critical [68].

5.2. *Whole life cycle assessment credits*

The connection between operational and embodied carbon and energy is critical to WLCA. Fig. 11 shows Green Star NZ has more WLCA credits than the other rating systems. Green Star NZ WLCA credits account for 22 % of the operational and embodied carbon and energy credits, while LEED and BREEAM have 11 % and 10 % respectively. GreenSL has 2 %, and LOTUS does not contain any WLCA-related credits. The LOTUS and BSAM only considered sustainable products rather than assessing the impact of these products over the building life cycle.

The WLCA credits in GBCS are critical to comprehensively evaluating a building's environmental impact over its entire life cycle. These credits emphasise factors such as durability, maintenance practices, and end-of-life options, pushing for selecting materials and practices that extend a building's life and reduce waste. This emphasis on longevity aligns well with the overarching sustainability principle of considering the present and the future [69]. In addition, WLCA credits necessitate the collection and analysis of data, thereby promoting data-driven decision-making.

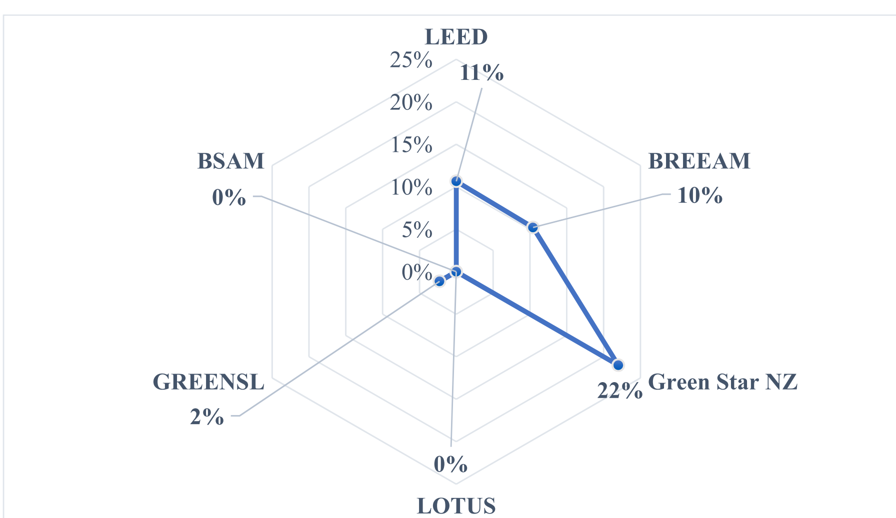


Fig. 11. Proportion of WLCA in operational and embodied credits.

This data-centric approach empowers stakeholders to make informed choices regarding materials, energy sources, and construction practices. By quantifying environmental impacts, LCA enables informed trade-offs, encouraging more sustainable options [8].

Despite these merits, there are areas where improvements are warranted. The complexity associated with WLCA can be time-consuming [70,71]. Simplifying LCA methodologies, providing accessible tools, and offering guidance on implementation can facilitate broader adoption [72,73]. Inconsistent data sources and methodologies can lead to variations in LCA results [74], undermining the credibility and comparability of assessments. Standardising data collection and reporting practices and promoting open access to relevant data are essential for more accurate and equitable assessments [75]. The EPD has grown to be a vital source of information that can simplistically support WLCA following the EN 15978 standard methodology [8]. However, many current GBCS have little provision for EPD under the embodied credits. Only the LEED rating system explicitly has credit for EPD, while BREEAM, GreenStar, LOTUS, and GREENSL embed EPD under the life cycle impacts or sustainable materials credits.

Fig. 12 shows the credit point distribution of the WLCA credits in the selected GBCS. It is observed that the WLCA processes in the certification systems are not consistent, as they have varying degrees of information and guidance. This has been acknowledged in previous studies [4,5]. Feng et al. [4] revealed that the WLCA credits in several certification systems are not properly structured. This indicates that the certification systems consider WLCA to some extent, and there is a need for an integrated approach embedded in LCA principles, including all phases of the building life cycle. Green building certification systems should embrace flexibility to accommodate geographical variations while adhering to global sustainability goals and standards.

5.3. Green building certification systems similarity

The NLP document similarity technique indicates that there is significant similarity between the existing GBCS from developing and developed countries with an average similarity of more than 0.600, as shown in Table 1. GREENSL from Sri Lanka has the highest average cosine similarity score, while LOTUS from Vietnam has the lowest average similarity score. It is observed that LEED (similarity score >0.500) has a significant relationship with the GBCS from developed and developing countries. All GBCS share common assessment areas such as energy efficiency, water use, and indoor environmental quality [76]. However, LEED and BREEAM offer broader and more diverse categories, reflecting their more extensive development over time [77]. In contrast, Green Star NZ, LOTUS, and GREENSL emphasise local environmental issues more heavily, showcasing a tailored approach to sustainability that aligns with regional challenges and construction practices. GBCS like LOTUS and GREENSL have innovated in addressing local sustainability challenges, such as adapting to tropical climates and focusing on local biodiversity. LEED and BREEAM, while maintaining global standards, also allow for regional adaptations, demonstrating the flexibility and evolution of these systems to cater to diverse environmental contexts.

The cross-comparisons suggest a highly intricate pattern of similarities and differences among the GBCS technical manuals. Some GBCS are relatively similar, while others are highly different. While each system has unique strengths, the lack of standardisation in certain criteria, especially in assessing embodied impacts, remains challenging. The variations also reflect the difficulties in setting up a single global standard for GBCS. Harmonising assessment methodologies and fostering collaboration among these systems could lead to a more unified and globally applicable framework for sustainable construction practices. It is recommended that the GBCS be improved in developed countries as this might profoundly impact the GBCS in developing countries. LEED has a significant relationship with BREEAM, GreenStar NZ, LOTUS, and GREENSL. The implementation of improvements can start from LEED to LOTUS and BSAM with a low cosine similarity score.

6. Recommendations for certification system improvement

Following the analysis of the GBCS technical documents and discussion of results, this research proposes the following improvements summarised in Fig. 13 to improve the OEW credits of the existing GBCS. The improvements proposed include.

- **Improve the operational and embodied credits balance:** Evidence from the thematic analysis shows that operational credits are prioritised over embodied credits. Considering the cumulative impact of the operational emissions over the building life cycle [9], ensuring a proper balance between the operational and embodied credits of the GBCS is important to adequately enhance future GBCS's effectiveness. While operational credits excel in promoting ongoing energy efficiency, water use and performance improvement, simplifying their requirements and broadening their sustainability focus is essential. Embodied credits, emphasising sustainable materials and waste reduction, require standardisation efforts and economic feasibility considerations.
- **WLCA method standardisation through EN 15978 integration:** The integration of EN 15978 into the WLCA framework of existing GBCS would streamline the procedure for conducting WLCA, as evidenced in Feng et al. [8]. Only the Level(s) framework has integrated EN 15978 [50]. This integration offers several advantages,

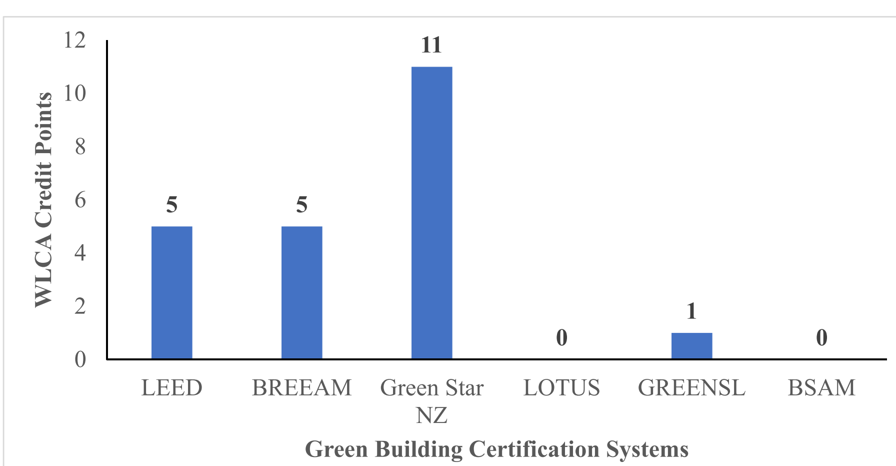


Fig. 12. Credit points of WLCA in selected GBCS

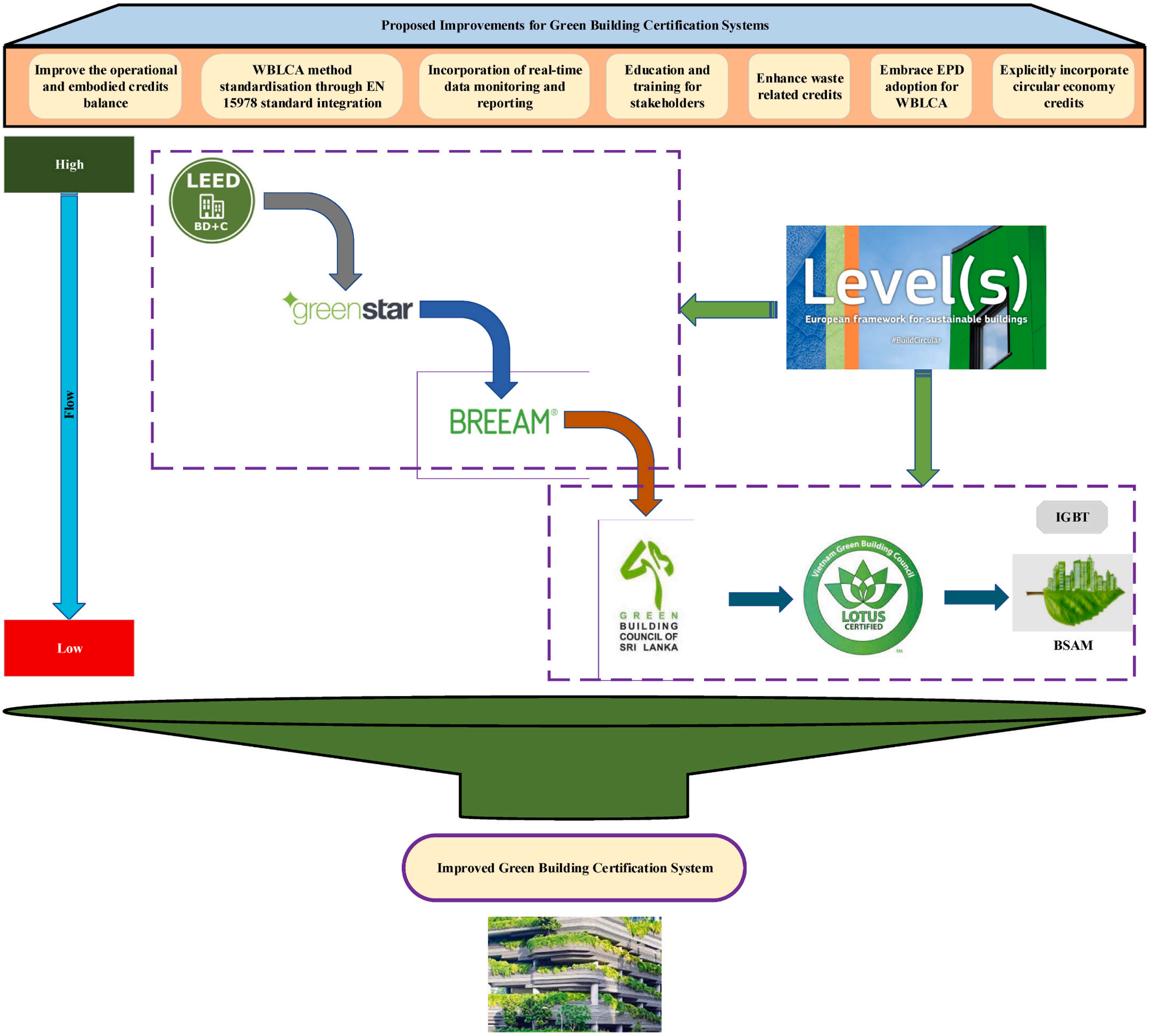


Fig. 13. Proposed GBCS improvement framework.

including enhanced comparability in results for different building projects and areas. The standardisation of methodologies and data collection processes can be facilitated by aligning them with EN 15978, thus increasing WLCA's credibility and accuracy. Nevertheless, it is also crucial to be aware that full standardisation could sometimes be challenging because of differences in regional availability of materials used for construction, the procedures employed and regulatory frameworks. In order to keep WLCA as a global phenomenon appropriate for different regions worldwide, it is necessary to strike an optimal balance between standardisation and flexibility.

- **Incorporation of real-time monitoring and reporting:** Certification systems should strive to incorporate real-time data monitoring and reporting mechanisms for operational assessments. This would ensure that the actual environmental performance of buildings during their operational phase aligns closely with the anticipated outcomes at the design stage. The Internet of Things and digital twins can support real-time data collection for dynamic sustainability assessment [78–80]. Real-time monitoring and reporting technologies enable continuous tracking of a building's performance [81], providing valuable data for optimising, reducing operational costs, enhancing resource efficiency, and enhancing occupant comfort and well-being. Real-time monitoring and reporting systems allow facility managers and occupants to make timely adjustments based on emerging anomalies, enhancing sustainability by giving immediate information on energy utilisation, indoor air quality and water use. Furthermore, the transparency enabled by these technologies promotes increased accountability and allows occupants to become more environmentally responsible. However, factors such as data privacy concerns and cost implications [82,83] of implementing real-time monitoring systems should be considered cautiously to ensure their efficiency and accessibility are optimally maximised.
- **Education and Training for Stakeholders:** Existing GBCS could introduce criteria to incorporate the stakeholders' knowledge level in life cycle assessment principles. This will foster a deeper understanding of the implications of design decisions on the building's

entire life cycle, encouraging more sustainable practices. Education and training programs increase stakeholders' awareness of green building practices. This empowerment facilitates a better understanding of sustainability principles and their practical application. Stakeholders who have participated in extensive training programs will likely show higher engagement and commitment towards green building projects [84]. As a consequence of this increased engagement, project results and practices linked to sustainability can be improved.
- **Enhance Waste-Related Credits:** More attention towards waste-related credits is crucial as this helps understand the construction materials' life cycle dynamics and circular economy integration. The efforts to include waste-related credit points in GBCS are crucial for sustainable construction practices [57]. These credits could stimulate reductions in construction waste due to the efficient use of materials, recycling and sustainable disposal methods [85]. Also, they can encourage the use of materials with lower embodied energy and waste generation potential [86], leading to a more circular and resource-efficient construction industry.
- **Embrace EPD Adoption for WLCA:** The GBCS should increase their uptake in EPD adoption for WLCA. The use of EPD helps ensure the reliability of the WLCA process based on material-specific data rather than generic datasets [8]. The integration of EPD for WLCA can be very tedious, depending on the complexity of the building components and project size. However, the use of WLCA tools such as One Click LCA, as itemised in Olanrewaju et al. [16], can help enhance the overall process. Streamlining data collection for WLCA becomes feasible and convenient with the availability of EPDs. Additionally, incorporating EPDs within WLCA assists the construction industry's movement towards circular economy concepts by promoting materials with lesser environmental effects throughout their whole life cycle.
- **Explicitly Incorporate Circular Economy Credits:** It is observed that the concept of circular economy is not widely embraced in most of the GBCS. Only the Level(s) framework explicitly recognises circular economy principles. It is crucial for the existing GBCS to embrace circular economy integration into their assessment framework as the industry continues to promote the concept of circular economy. The circular economy integration action plan presented in Figure A3 in Appendix A can be implemented as a guide to enhance circular economy integration in GBCS.

7. Conclusions, implications and future research

Green building certification systems are critical to sustainable development and reducing the impact of climate change on the construction industry. The assessment of the OEW credits of the GBCS from the perspective of developed and developing countries and newly developed GBCS provides critical insights into the strengths and weaknesses of the GBCS. The combined qualitative desktop analysis and quantitative cosine similarity scores comprehensively provide an overview of the OEW credits in LEED, BREEAM, Green Star NZ, LOTUS, GREENSL, BSAM and IGBT. This dual approach enhances the discussion's robustness, providing an in-depth assessment of GBCS-specific nuances and quantifying their comparative similarities and differences. Based on the study findings, the following conclusions can be made.

- There is a need for a shift in developing new GBCS and concentrating more on improving the existing GBCS for more geographical adaptation.
- The newly developed GBCS has mainly focused on extending the dimensions of sustainability with no improvement on the OEW credits. It is also evident from the findings that some developing countries' GBCS, such as LOTUS and the newly developed GBCS, such as BSAM, completely omitted WLCA credits. Hence, there is a need to include WLCA-specific credits within their system.
- Circular economy measures are not integrated into most of the existing GBCS. Only the Level(s) framework explicitly defines circular economy within the assessment framework. There is a need to include points for circular economy adherence in order to promote circular economy for the construction industry.
- The use of NLP, particularly cosine document similarity, in analysing GBCS offers a quantitative approach to understanding how different GBCS relate to each other, allowing for more objective comparisons. The cosine similarity analysis highlights the uniqueness of each certification system, reflecting distinct approaches to sustainable building practices.
- The study reveals common credits and divergent approaches across various GBCS regarding OEW credits. This insight benefits stakeholders looking to adopt or refine green building standards.
- Findings suggest that while operational efficiency is crucial for immediate sustainability goals, the long-term environmental impact is significantly influenced by embodied carbon, emphasising the need for more embodied credits inclusion in GBCS criteria.
- The differences in criteria and emphasis, particularly in systems like BREEAM and LOTUS, underscore the importance of considering regional contexts in developing and applying sustainability standards.
- Lastly, the GBCS variations highlight the challenges in achieving a globally applicable framework. Efforts toward standardisation and harmonisation could enhance consistency in evaluating sustainable construction practices.

This research offers several practical implications. The assessment of the OEW credits in the GBCS shows that a more holistic approach is required to enhance its effectiveness. This requires collaboration between the GBCS bodies. The World Green Building Council can act as an umbrella to drive the changes proposed to improve the GBCS in terms of OEW credits. Furthermore, the developed improvement framework shows how the changes can be implemented across LEED, BREEAM, Green Star NZ, LOTUS, GREENSL, and BSAM. The framework can be used by policymakers, green building councils, professionals, and the government to enhance the effectiveness of GBCS. In addition, the study's findings can inform certification bodies and policymakers about the evolving trends in green building practices, aiding in developing more comprehensive and effective sustainability standards. Finally, the circular economy integration action plan can be implemented by GBCS bodies to enhance the inclusion of circular economy in GBCS.

This study significantly contributes to the GBCS domain. Firstly, this study lays a solid foundation for a more comprehensive understanding of how OEW credits can be refined and integrated into GBCS, thereby contributing to the ongoing discourse on sustainable construction practices and fostering a more resilient built environment for future generations. Secondly, it is the first study to apply the document similarity technique of NLP to analyse the technical manuals of existing GBCS. This provides a solid foundation for future studies using document similarity to analyse sustainability documents. Thirdly, the study reveals the gaps in the OEW credits of the existing GBCS from the perspective of developed and developing countries, which is crucial considering many developing countries' population and housing needs.

The research also provides possible areas for future research due to the limitations of this current study. The study only considered seven existing GBCS, including four from developed countries, two from developing countries and two newly developed GBCS. Future research should consider implementing the recommendations arising in this study to improve the OEW credits in existing GBCS as the construction industry evolves. It was difficult to compare the scoring of the Level(s) framework with other assessment tools. Thus, future research should focus on developing a quantitative scale that includes an aggregated score for the Level(s) framework.

CRediT authorship contribution statement

Oludolapo Ibrahim Olanrewaju: Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Wallace Imoudu Enegbuma:** Conceptualization, Funding acquisition, Supervision, Writing – review & editing. **Michael Donn:** Conceptualization, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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Nomenclature

Acronym	Name
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BD + C	Building Design and Construction
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
BSAM	Building Sustainability Assessment Method Scheme
EPD	Environmental Product Declaration
GBCA	Green Building Council of Australia
GBCS	Green Building Certification System
GBCSL	Green Building Council of Sri Lanka
GHG	Greenhouse Gas
Green Star NZ	Green Star New Zealand
GREENSL	Green Sri Lanka
GWP	Global Warming Potential
HVAC&R	Heating, Ventilation, Air Conditioning, and Refrigeration
IESNA	Illuminating Engineering Society of North America
IGBT	Iranian Green Building Assessment Tool
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LEED	Leadership in Energy and Environmental Design
MCDM	Multi-Criteria Decision-Making Methods
NLP	Natural Language Processing
NLTK	Natural Language Toolkit
NZGBC	New Zealand Green Building Council
OEW	Operational, Embodied and Whole life cycle assessment
OTTV	Overall Thermal Transfer Value
PDF	Portable Document Format
PVC	Polyvinyl Chloride
TF-IDF	Term Frequency-Inverse Document Frequency
USGBC	United States Green Building Council
VGBC	Vietnam Green Building Council
WLCA	Whole Life Cycle Assessment

Symbol	Meaning
$TF(t,d)$	Term Frequency of term t in document d, which is the number of times t appears in d.
$IDF(t)$	represents the Inverse Document Frequency of term t
N	Total number of documents in the corpus
n_t	Number of documents containing term t.
$A \bullet B$	The product of vectors A and B.
$\|A\| and \|B\|$	Magnitudes (Euclidean norms) of vectors A and B
t	Frequency

References

[1] United Nations Framework Convention on Climate Change, COP28 Agreement Signals “Beginning of the End” of the Fossil Fuel Era., 2023 [cited 2023 18/12/2023], https://unfccc.int/news/cop28-agreement-signals-beginning-of-the-end-of-the-fossil-fuel-era.

[2] M. Hanifa, et al., *A review on CO2 capture and sequestration in the construction industry: Emerging approaches and commercialised technologies.* Journal of CO2 Utilization 67 (2023) 102292.

[3] L.H. Horup, H. Birgisdóttir, M.W. Ryberg, Defining dynamic science-based climate change budgets for countries and absolute sustainable building targets, Build. Environ. 230 (2023) 109936.

[4] H. Feng, R. Sadiq, K. Hewage, Exploring the current challenges and emerging approaches in whole building life cycle assessment. Canadian Journal of Civil Engineering 49 (2) (2022) 149–158.
[5] S. Politi, E. Antonini, S.J. Wilkinson, Overview of building LCA from the sustainability rating tools perspective, in: ZEMCH 2018 international conference, Melbourne, Australia, 2018, pp. 237–250.
[6] H. Alhazmi, et al., Environmental performance of residential buildings: a life cycle assessment study in Saudi Arabia, Sustainability 13 (6) (2021) 3542.
[7] W. Chen, et al., Embodied energy and carbon emissions of building materials in China, Build. Environ. 207 (2022) 108434.
[8] H. Feng, et al., Whole Building Life Cycle Assessment at the Design Stage: A BIM-Based Framework Using Environmental Product Declaration. International Journal of Building Pathology and Adaptation, 2022.
[9] C. Peng, Calculation of a building's life cycle carbon emissions based on Ecotect and building information modeling, J. Clean. Prod. 112 (2016) 453–465.
[10] S.G. Al-Ghamdi, M.M. Bilec, Green building rating systems and whole-building life cycle assessment: comparative study of the existing assessment tools, J. Architect. Eng. (1) (2017) 23.
[11] D.T. Doan, et al., *A critical comparison of green building rating systems.* Building and Environment 123 (2017) 243–260.
[12] P.H. Chen, T.C. Nguyen, Integrating web map service and building information modeling for location and transportation analysis in green building certification process, Autom. ConStruct. 77 (2017) 52–66.
[13] A. GhaffarianHoseini, et al., Amplifying the practicality of contemporary building information modelling (BIM) implementations for New Zealand green building certification (Green Star). Engineering, Construction and Architectural Management 24 (4) (2017) 696–714.
[14] F. Jalaei, A. ade Jr., Integrating Building Information Modeling (BIM) and energy analysis tools with green building certification system to conceptually design sustainable buildings. Journal of Information Technology in Construction 19 (2014) 494–519.
[15] M.F. Muller, et al., *A systematic literature review of interoperability in the green Building Information Modeling lifecycle.* Journal of Cleaner Production 223 (2019) 397–412.
[16] O.I. Olanrewaju, et al., Building information modelling and green building certification systems: a systematic literature review and gap spotting, Sustain. Cities Soc. (2022) 103865.
[17] I.C.S. Illankoon, et al., Key credit criteria among international green building rating tools, J. Clean. Prod. 164 (2017) 209–220.
[18] B. Mattoni, et al., Critical review and methodological approach to evaluate the differences among international green building rating tools. Renewable and Sustainable Energy Reviews 82 (2018) 950–960.
[19] D.T. Doan, et al., Green building rating systems: a critical comparison between LOTUS, LEED, and Green Mark. Environmental Research Communications 5 (7) (2023) 75008.
[20] T.O. Olawumi, D.W. Chan, Application of generalized choquet fuzzy integral method in the sustainability rating of green buildings based on the BSAM scheme, Sustain. Cities Soc. (2020) 102147.
[21] R. Shad, M. Khorrami, M. Ghaemi, Developing an Iranian green building assessment tool using decision making methods and geographical information system: case study in Mashhad city. Renewable and Sustainable Energy Reviews 67 (2017) 324–340.
[22] V. Pai, H. Elzarka, Whole building life cycle assessment for buildings: a case study ON HOW to achieve the LEED credit, J. Clean. Prod. 297 (2021) 126501.
[23] T. Sartori, et al., A schematic framework for life cycle assessment (LCA) and green building rating system (GBRS). Journal of Building Engineering 38 (2021) 102180.
[24] T. Kim, S. Chi, Accident case retrieval and analyses: using natural language processing in the construction industry. Journal of Construction Engineering and Management 145 (3) (2019) 4019004.
[25] S. Moon, G. Lee, S. Chi, Automated system for construction specification review using natural language processing. Advanced Engineering Informatics 51 (2022) 101495.
[26] C.H. Caldas, L. Soibelman, J. Han, Automated classification of construction project documents. Journal of Computing in Civil Engineering 16 (4) (2002) 234–243.
[27] S. Litleskare, W. Wuyts, Planning reclamation, diagnosis and reuse in Norwegian timber construction with circular economy investment and operating costs for information. Sustainability 15 (13) (2023) 10225.
[28] J.-J. Ortega-Gras, et al., Twin transition through the implementation of industry 4.0 technologies: desk-research analysis and practical use cases in Europe, Sustainability 13 (24) (2021) 13601.
[29] M. Shan, B.-g. Hwang, Green building rating systems: global reviews of practices and research efforts, Sustain. Cities Soc. 39 (2018) 172–180.
[30] S. Abeysinghe, et al., Integrating disaster resilience into green rating systems–a modification of the Sri Lankan green building rating tool, Smart and Sustainable Built Environment 12 (4) (2023) 765–786.
[31] T.L. Pham, T.T. Nguyen, Green building certification as a policy to promote green-building-A study of Singapore, taiwan, Australia, UK, US and lessons for Vietnam, International Journal of Sustainable Construction Engineering and Technology 12 (3) (2021) 135–141.
[32] T. Olawumi, D.W. Chan, Mendeley data, Building Sustainability Assessment Method (BSAM)-for countries in sub-Saharan region, 2019, pp. 1–77.
[33] A.R. Martinez, Natural language processing. Wiley Interdisciplinary Reviews: Comput. Stat. 2 (3) (2010) 352–357.
[34] Z. Dong, et al., Transformation from human-readable documents and archives in arc welding domain to machine-interpretable data, Comput. Ind. 128 (2021) 103439.
[35] N. Hardeniya, et al., Natural language processing: python and NLTK, Packt Publishing Ltd, Birmingham, United Kingdom, 2016.
[36] K. Park, J.S. Hong, W. Kim, A methodology combining cosine similarity with classifier for text classification. Applied Artificial Intelligence 34 (5) (2020) 396–411.
[37] F. Rahutomo, T. Kitasuka, M. Aritsugi, Semantic cosine similarity, in: The 7th International Student Conference on Advanced Science and Technology ICAST, 2012.
[38] A.M.d.J.C. Cachopo, Improving Methods for Single-Label Text Categorization, Instituto Superior Técnico, Portugal, 2007.
[39] R.J. Cole, M. Jose Valdebenito, The importation of building environmental certification systems: international usages of BREEAM and LEED. Building Research & Information 41 (6) (2013) 662–676.
[40] USGBC, in: M. Long (Ed.), USGBC Announces Extension of LEED 2009, 2014.
[41] USGBC, LEED V5 Is the Newest Version of LEED, 2023. https://www.usgbc.org/leed/v5.
[42] USGBC, LEED v4.1, Building Design and Construction, in Getting Started Guide for Beta Participants, US Green Building Council, 2023.
[43] S. Butera, T.H. Christensen, T.F. Astrup, Life cycle assessment of construction and demolition waste management, Waste Manag. 44 (2015) 196–205.
[44] BRE. BREEAM. 2023 [cited 2023 16/10/2023]; Available from: https://bregroup.com/products/breeam/.
[45] B.R.E. Global, BREEAM international new construction version 6, in: Technical Manual - SD250, BRE Global: Bucknalls Lane, Watford, WD25 9XX, United Kingdom, 2021.
[46] S. Gandhi, J. Jupp, BIM and Australian green star building certification, in: Computing in Civil and Building Engineering, vol. 2014, 2014, pp. 275–282.
[47] K.N. Le, C.N. Tran, V.W. Tam, Life-cycle greenhouse-gas emissions assessment: an Australian commercial building perspective, J. Clean. Prod. 199 (2018) 236–247.
[48] NZGBC, Green star design & as built - New Zealand version 1.1, submission guidelines, New Zealand Green Building Council, New Zealand, 2022.
[49] Directorate-General for Environment, A Background to Level(s) and Overview of the Testing Phase, European Commission, 2018.
[50] N. Dodd, S. Donatello, M. Cordella, Level(s) – a common EU framework of core sustainability indicators for office and residential buildings, in User Manual 1, in: Introduction to the Level(s) Common Framework (Publication Version 1.1), European Commission, 2021.
[51] VGBC, LOTUS certification system. https://vgbc.vn/en/rating-systems/, 2023.
[52] Vgbc, LOTUS new construction version 3, Technical manual, Vietnam Green Building Council, Vietnam, 2019.
[53] Gbcsl, GREENSL® rating System for new constructions version 2.1, in: Green Building Council of Sri Lanka, Vidya Mawatha, Colombo 07, Sri Lanka, 2022.
[54] L. Yang, et al., The influence of font scale on semantic expression of word cloud, J. Visual 23 (2020) 981–998.
[55] N. Cao, W. Cui, Introduction to Text Visualization, vol. 1, Springer, 2016.
[56] L. Bullen, et al., Absolute sustainability of New Zealand office buildings in the context of climate targets, Build. Environ. 205 (2021) 108186.
[57] W. Lu, et al., Evaluating the effects of green building on construction waste management: a comparative study of three green building rating systems, Build. Environ. 155 (2019) 247–256.
[58] M.H. Masud, et al., *Generation Of Waste: Problem to Possible Solution in Developing and Underdeveloped Nations*, in *Waste Management and Resource Recycling in the Developing World*, Elsevier, 2023, pp. 21–59.
[59] D.R. Rondinel-Oviedo, Construction and demolition waste management in developing countries: a diagnosis from 265 construction sites in the Lima Metropolitan Area. International Journal of Construction Management 23 (2) (2023) 371–382.
[60] P. Eichholtz, N. Kok, J.M. Quigley, Doing well by doing good? Green office buildings, Am. Econ. Rev. 100 (5) (2010) 2492–2509.
[61] L. Zhang, R. Li, Impacts of green certification programs on energy consumption and GHG emissions in buildings: a spatial regression approach, Energy Build. 256 (2022) 111677.
[62] J. Yudelson, Reinventing Green Building: Why Certification Systems Aren't Working and what We Can Do about it, New Society Publishers, 2016.
[63] A. Allouhi, et al., Energy consumption and efficiency in buildings: current status and future trends, J. Clean. Prod. 109 (2015) 118–130.
[64] S. Barbhuiya, B.B. Das, Life Cycle Assessment of construction materials: methodologies, applications and future directions for sustainable decision-making, Case Stud. Constr. Mater. 19 (2023) e02326.
[65] T. Malmqvist, et al., Design and construction strategies for reducing embodied impacts from buildings–Case study analysis, Energy Build. 166 (2018) 35–47.
[66] E. Allen, J. Iano, Fundamentals of building construction: materials and methods, Seventh edition, John Wiley & Sons, Inc, Hoboken, New Jersey, United States, 2019.
[67] S. Saxe, et al., Taxonomy of uncertainty in environmental life cycle assessment of infrastructure projects, Environ. Res. Lett. 15 (8) (2020), 083003.
[68] E.H. Yung, E.H. Chan, Implementation challenges to the adaptive reuse of heritage buildings: towards the goals of sustainable, low carbon cities, Habitat Int. 36 (3) (2012) 352–361.
[69] C.J. Kibert, Sustainable construction: green building design and delivery, Fourth edition,John, Wiley & Sons, Inc, Hoboken, New Jersey, United States, 2016.
[70] P. Del Rosario, E. Palumbo, M. Traverso, Environmental product declarations as data source for the environmental assessment of buildings in the context of level (s) and DGNB: how feasible is their adoption? Sustainability 13 (11) (2021) 6143.

[71] M. Gelowitz, J. McArthur, Insights on environmental product declaration use from Canada's first LEED® v4 platinum commercial project. Resources, Conserv. Recycl. 136 (2018) 436–444.

[72] S. Beemsterboer, H. Baumann, H. Wallbaum, Ways to get work done: a review and systematisation of simplification practices in the LCA literature. The International Journal of Life Cycle Assessment 25 (2020) 2154–2168.

[73] C. De Wolf, et al., Whole life cycle environmental impact assessment of buildings: developing software tool and database support for the EU framework Level (s). Resources, Conserv. Recycl. 188 (2023) 106642.

[74] E. Crenna, et al., Global environmental impacts: data sources and methodological choices for calculating normalization factors for LCA. The International Journal of Life Cycle Assessment 24 (2019) 1851–1877.

[75] H. Feng, Whole Building Life Cycle Assessment for Residential Buildings: a Design Improvement Framework, University of British Columbia, 2020.

[76] W. Wei, O. Ramalho, C. Mandin, Indoor air quality requirements in green building certifications, Build. Environ. 92 (2015) 10–19.

[77] W.L. Lee, A comprehensive review of metrics of building environmental assessment schemes, Energy Build. 62 (2013) 403–413.

[78] I. Calvo, et al., *Scalable IoT Architecture for monitoring IEQ Conditions in Public and private buildings.* Energies 15 (6) (2022) 2270.

[79] G. Coulby, et al., *Low-cost, multimodal environmental monitoring based on the Internet of Things.* Building and Environment 203 (2021) 108014.

[80] L.C. Tagliabue, et al., Leveraging digital twin for sustainability assessment of an educational building, Sustainability 13 (2) (2021) 480.

[81] C.V. Gallagher, et al., *IntelliMaV: a cloud computing measurement and verification 2.0 application for automated, near real-time energy savings quantification and performance deviation detection.* Energy and buildings 185 (2019) 26–38.

[82] X. Chen, et al., Implementation of technologies in the construction industry: a systematic review. Engineering, Construction and Architectural Management 29 (8) (2022) 3181–3209.

[83] C. Nnaji, I. Awolusi, Critical success factors influencing wearable sensing device implementation in AEC industry, Technol. Soc. 66 (2021) 101636.

[84] A.P.C. Chan, et al., Critical barriers to green building technologies adoption in developing countries: the case of Ghana, J. Clean. Prod. 172 (2018) 1067–1079.

[85] B. Chi, et al., Construction waste minimization in green building: a comparative analysis of LEED-NC 2009 certified projects in the US and China, J. Clean. Prod. 256 (2020) 120749.

[86] M.U. Hossain, S.T. Ng, Influence of waste materials on buildings' life cycle environmental impacts: adopting resource recovery principle. Resources, Conserv. Recycl. 142 (2019) 10–23.