

STUDY ON GREEN BUILDING RATING SYSTEMS TO THE CIRCULARITY
PRINCIPLES

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CIRCULARITY PRINCIPLES**

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ABSTRACT

STUDY ON GREEN BUILDING RATING SYSTEMS TO THE CIRCULARITY PRINCIPLES

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This study aims to find the possibilities of green building rating systems in the built environment with the combination of circularity principles and LCA tools. With the increase in waste and consumption, circularity principles have started to be adopted by the built environment. The circular design allows components to be designed to be reassembled and regenerated, which produces no landfill. Using circular design methods in architecture can create new alternatives to the materials and the components, which helps to divide the buildings into layers and the possibility of the act on them separately. These concepts have been used in circular design as it has the potential of increasing the lifetime of the materials and the buildings. Along with the circular design, the increase in the certification system was also visible. This study focuses on comparing the existing certification systems and their evaluations of the circular buildings. The comparison focuses on the way the material is addressed in the certification systems.

Keywords: Circular Design, Life Cycle Assessment, Green Building Rating Systems, Circular Buildings

ÖZ

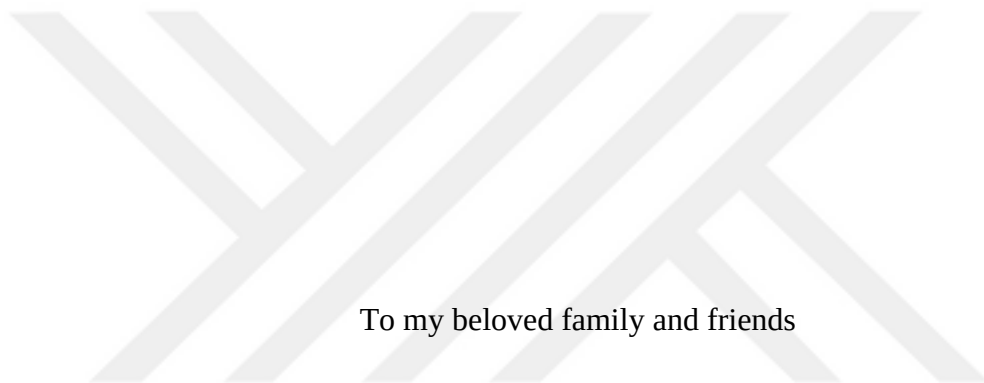
DÖNGÜSELLİK İLKELERİNE GÖRE YEŞİL BİNA DERECELENDİRME SİSTEMLERİ ÜZERİNE ÇALIŞMA

Köseoğlu, Atike Yağmur
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Bu çalışma, döngüsellik ilkeleri ve LCA araçlarının kombinasyonu ile yapıli çevrede yeşil bina derecelendirme sistemlerinin olanaklarını bulmayı amaçlamaktadır. Atık ve tüketimin artmasıyla birlikte döngüsellik ilkeleri yapıli çevre tarafından benimsenmeye başlamıştır. Döngüsel tasarım, bileşenlerin yeniden bir araya getirilecek ve yeniden üretilecek şekilde tasarlanmasına olanak tanır ve bu da atık depolama alanı oluşturmaz. Mimaride döngüsel tasarım yöntemlerinin kullanılması, malzemelere ve bileşenlere yeni alternatifler yaratabilir, bu da binaları katmanlara ayırmaya ve bunlar üzerinde ayrı ayrı hareket etme olasılığına yardımcı olur. Bu kavramlar, malzemelerin ve binaların kullanım ömrünü artırma potansiyeline sahip olduğu için döngüsel tasarımda kullanılmaktadır. Döngüsel tasarımla birlikte sertifikasyon sistemindeki artış da gözle görülür hale gelmiştir. Bu çalışma, mevcut sertifikasyon sistemlerinin karşılaştırılmasına ve döngüsel binalara ilişkin değerlendirmelerine odaklanmaktadır. Bu karşılaştırma, sertifikasyon sistemlerinde malzemenin ele alınış şekline odaklanmaktadır.

Anahtar Kelimeler: Döngüsel Tasarım, Yaşam Döngüsü Değerlendirmesi, Yeşil Bina Derecelendirme Sistemleri, Döngüsel Binalar



To my beloved family and friends

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LIST OF ABBREVIATIONS

ABBREVIATIONS

BIM	Building Information Modeling
CE	Circular Economy
C2C	Cradle-to-Cradle
DfD	Design for Disassembly
EMF	Ellen MacArthur Foundation
GBRS	Green Building Rating Systems
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
MP	Material Passport
SDGs	Sustainable Development Goals

CHAPTER 1

INTRODUCTION

Natural resources are at risk due to the growing population and increased landfill. The built environment is considered the most significant factor in global waste in terms of resources (Ellen MacArthur Foundation, 2021; United Nations Environment Programme, 2020, 2021). One reason for this situation is the linear approach adopted by the buildings, which is take-make-waste, where the resources are used in an end-of-life cycle and create landfill. In opposite of that, a circular economy proposes a cyclical flow where the resources are recycled, reused, and reduced. The main aim of the circular economy can be seen as preventing resources from turning into waste and extending their life span without losing quality.

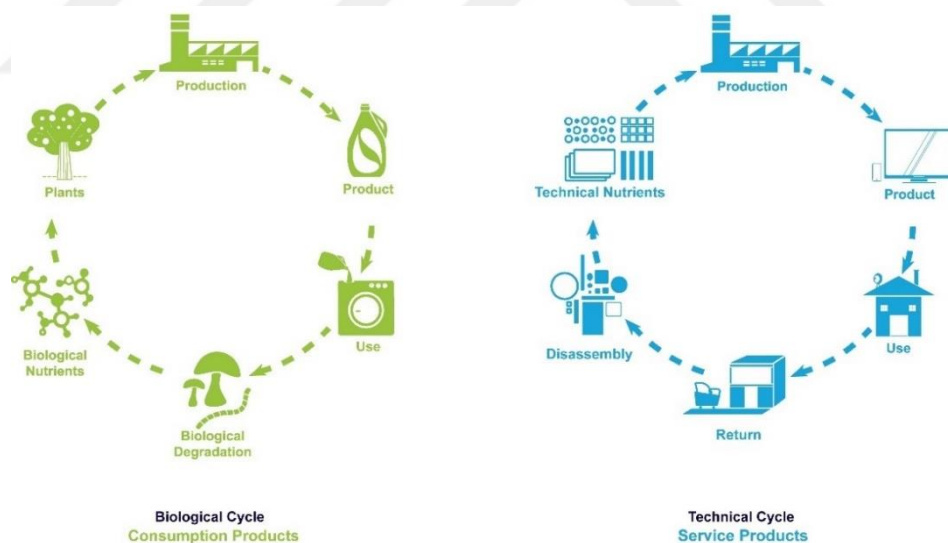


Figure 1.1 Biological and Technical Cycle (Retrieved from <http://c2cplatform.tw/en/c2c.php?Key=1> on 24.11.2022)

Along with the circular economy, the cradle-to-cradle concept was developed by McDonough and Braungart (2002). The linear process is mentioned as cradle-to-grave, where the resources have a one-way flow that ends with disposal, whereas the

cradle-to-cradle shows the idea of dividing the materials into two different flows and extending the life span of the materials, as seen in Figure 1.1. Ellen MacArthur Foundation also researched the division of the material, known as the Butterfly Diagram, which shows the biological and technical material flows (Ellen MacArthur Foundation, n.d.-b).

The circular approach can be seen in various industries. In the context of products, many major companies have released actions regarding circularity. ISO and UN created standards and goals that encourage industries to shift from linear to circular methods (*International Organization for Standardization*, n.d.; *Sustainable Development Goals*, n.d.). As for the built environment, circularity principles have started to be considered in the design process. The buildings differ from the products in terms of their expected life span and method of use. This caused different methods and principles for different scales.

The circularity principles are employed to create more sustainable and flexible buildings. By adapting these methods, the materials' and buildings' life span can be increased, creating a long-lasting built environment. Due to these reasons, design understanding is anticipated to change from a linear to a more circular approach. This allows dismantling, deconstruction, and disassembly of the building to be a part of the design process (Crowther, 2005; Thomsen et al., 2011).

Several systems are developed in order to measure the circularity of the buildings, which are called Green Building Rating Systems (*B.E.S.T.*, n.d.; *BREEAM*, n.d.; *Green Star*, n.d.; *LEED*, n.d.; Environment and Urban Ministry (Turkey), n.d.). These systems rely on information about buildings and materials. A method for storing material information known as material passports has been created in the area of materials (*BAMB Material Passport*, n.d.; *Madaster*, n.d.). This term is mainly used in the product field; still, the idea of adding this term to the built environment creates possibilities to achieve a better understanding of the materials used in the buildings and their effects.

Juxtaposing BIM, LCA tools, MP and GBRS can create a better rating system that can reduce the time and effort of the existing process. The main aim of this thesis is to identify the gap in this system. This research focuses on the found gap in circularity principles and the way material is handled within this system.

1.1 Research Motivation and Problem Definition

The built environment is responsible for a significant part of the world's waste. The access to resources is decreasing, and the resources are destined for extinction in the near future. One of the reasons for the high waste in the built environment is that the materials are used in a linear way where the life span ends with the disposal. The circular design proposes reducing the landfill and extending the life of the materials as well as the buildings. For this reason, a transition from linear to circular is necessary for the built environment. The existing buildings should be adapted to the current situation and improved; in the meantime, new buildings should adopt the circular design principles and reduce their resources with a new mindset where the life cycle of the building never ends.

The circularity level of the existing and new buildings is measured with the green building rating systems, GBRS. Studies that include BIM or LCA tools in these systems show the possibility of a system with less time, effort, and more precise results. Information about the materials, components, and buildings is needed in this process, which is digitally stored with the material passport systems and can also be implemented into this system. The material aspect of GBRS is searched in this thesis. Within the context of the circularity principles and their impacts, the gaps in the existing systems, their outcomes, and how to adapt a system to the current situation in Turkey are investigated. Mismatches were found in the current GBRS, as there are differences in the rating systems, and many circular buildings remain uncertified. The current and future state of circularity and its occurrence in GBRS are also studied. The mismatches were found not only within the GBRS but also in its

relationship with circularity principles and standards. Materials have been identified as the issue where there is a gap in the relationship between circularity and GBRS.

1.2 Aim And Objectives of The Research

The main aim of this research is to explore the possibilities of the GBRS in the built environment with the combination of circularity principles and LCA tools and the gaps in this combined system. This thesis also researches the application of this proposed layout in Turkey's built environment. This research was done with the idea of extending the life span of the building and materials and applying circularity principles in the built environment. One of the main concerns of this research is to determine the success of the GBRS in demonstrating whether the rated buildings are circular.

To sum up, the hypothesis of this study is that there are mismatches and gaps when LCA tools, GBRS, and circularity principles are juxtaposed. Therefore, it is suggested that not every certified building is circular, and not every building can be circular. In order to examine the gaps in the system, the thesis focuses on the material in the GBRS, which allows a better comparison of these systems.

In order to achieve these objectives, the main research questions are listed as follows:

- Where is the biggest gap in the LCA tools, circularity principles, and GBRS in the built environment?
- What is the most critical point while combining LCA tools, circularity principles, and GBRS in the built environment?
- How is material handled in the GBRS with the consideration of circularity principles and standards?
- Is every certified building considered a circular building?

1.3 Scope

Chapter 1 gives the problem statement and the research objectives. Chapter 2 is the literature research part of this thesis. Information about the transition to a circular design, circular buildings, cycles, and circularity of the buildings are researched in this part. Chapter 3 is about the materials and methods. Chapter 4 is the case studies, results, and discussion part. The data collected from the experiment and the analysis of the research are presented in this part. Chapter 5 is the conclusion part, where the summary of the research, limitations, and recommendations for future research are given.

Table 1.1 Thesis Structure. (Developed by author)

Chapter 1 Introduction • Research Motivaiton and Problem Defination • Aim and Objectives of the Research • Scope
Chapter 2 Literature Review • Transition to Circular Design • Circularity Principles, Cycles, and Levels • Chances in the Built Environment • Circularity in Buildings • Life Cycle of Buildings and Life Cycle Tools • Green Building Rating Systems • Comparison of Certification Systems • Circular Design Assessments • BIM and LCA Tools • Critical Review of Literature
Chapter 3 Materials and Methods • Keyword Analysis • Research Materials • Critical View on the Circularity • Mismatch in the Certification Systems • The Mention of Material in the Certification Systems
Chapter 4 Case Studies • Case Studies • Case 1: Turkey Case • Case 2: Dual-Certified Case • Case 3: Circular Case • Results of the Case Studies
Chapter 5 Conclusion • Discussion • Limitations and Projections



CHAPTER 2

LITERATURE REVIEW

A literature review of circular design, circular buildings, cycles, and circularity of the buildings is given in this chapter. Information about circularity principles, their application, green building rating systems, circular design assessments, and how to combine circular design with the built environment are researched for this review.

2.1 Transition to Circular Design

Ellen Macarthur Foundation explained circular design as “the practice of applying circular economy principles at the design stage of everything” (Widmer, 2021, para. 11). This explanation shows that the design stages can be altered with the circularity principles, which results in sustainable and flexible outcomes. Circular design can be used for solving complex problems comprehensively in various industries. Many organizations started to shift to circular methods to achieve more sustainable progress, including IKEA, Philips, and H&M (Dokter et al., 2021).

Dokter et al. show a survey that one of the problems experienced in the transition to a circular design is stated as the financial risks, which is due to material and technological developments at the beginning of the design and continue that these designs will have more than one life cycle, and this situation should be taken into consideration (2021). The paper also shows the need for a clearer explanation of the circular economy idea since it is a wide topic and is given varied definitions by various professional groups (Dokter et al., 2021). Kanters (2020) states that because of the barriers in the field, the shift to circular design and buildings will happen, but it can be rather a slow transition.

Transitioning to the circular design greatly benefits the built environment, reducing the raw materials and the environmental impacts while increasing the possibility of higher cost efficiency (Bouweconomie, 2018).

Circularity principles and cycles altered over time, which can be seen as the result of the shift toward circular design. The transition results in a change in the scale. One of the explanations of the scale in these fields is the meso, macro, micro, and nano levels, which is explained further. Cambier et al. (2020) note that even with the collaborations and experiments in the built environment and industrial products, shifting towards a circular design still faces problems, which can be eased with circular design tools and assessments, which are examined further. The following provides an explanation of the circularity concepts and levels employed in the built environment, as well as the changes that the transition to circular design brings.

2.1.1 Circularity Principles, Cycles, and Levels

One of the most known circular cycle definitions is the butterfly diagram created by EMF, which divides materials into two, renewable and finite, as seen in Figure 2.1. These terms can also be seen as biological and technical materials. Influenced by the C2C concept created for the industrial process, this diagram has become one of the most well-known frameworks that can be used in different areas, including the built environment.

The main important point of this diagram is that the biological materials are seen to be regenerated into nature; as for technical materials, regeneration is not possible (Ellen MacArthur Foundation, n.d.-b). This creates biological and technical cycles, which can be seen as the backbone of circularity. As mentioned in the 9R concept, recycling and recovery of the materials are the least recommended actions for the circular approaches, as the most sustainable action seems to maintain and prolong the materials. The butterfly concept is used by the products and the built environment. ARUP states that the six actions from the EMF ReSOLVE framework

can be used to apply a circular economy in the built environment (ARUP, 2016). The six mentioned actions are listed as “regenerate, share, optimize, loop, virtualize, and exchange” (Ellen MacArthur Foundation, 2015, p. 25).

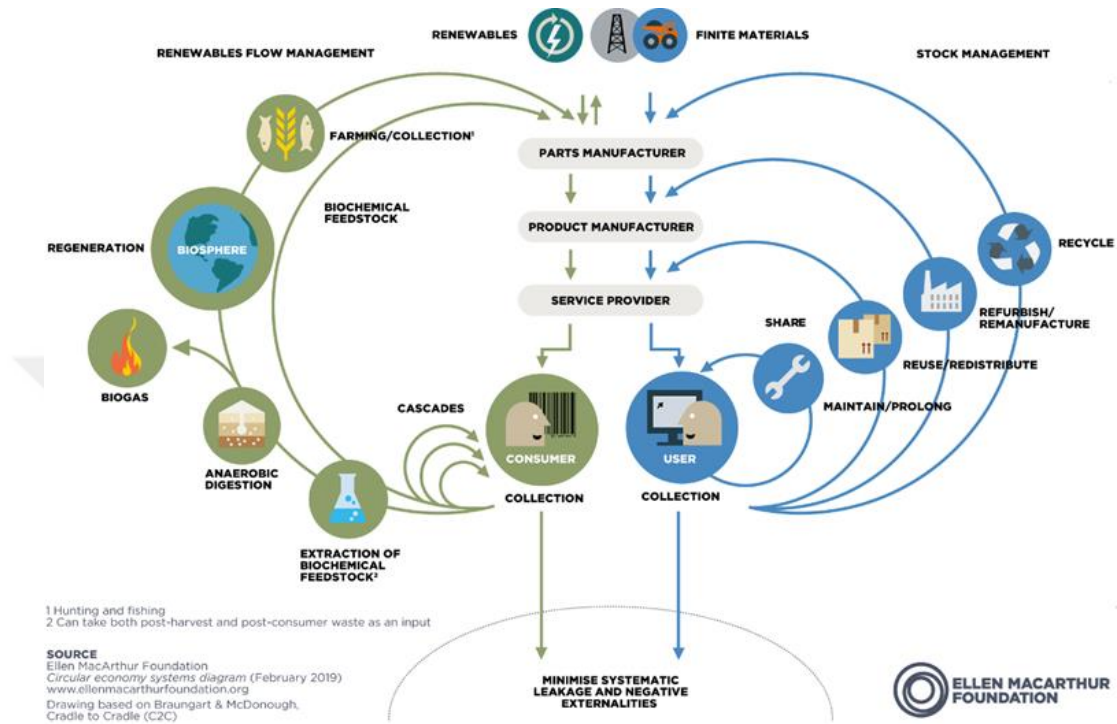


Figure 2.1 Circular Economy Butterfly Diagram (Retrieved from <https://ellenmacarthurfoundation.org/circular-economy-diagram> on 28.10.2022)

EMF stated that the main principles of circular economy are to eliminate, circulate and regenerate, which are used to shift the system (Ellen MacArthur Foundation, n.d.-a). Metabolic, a foundation focusing on circular design, explained that there are seven pillars of a circular economy, which can be seen in Figure 2.2 (Kubbinga et al., 2018). This figure shows that circular economy is addressed with seven principles while three priorities frame this structure. The circular built environment tends to achieve these principles and pillars in order to have a sustainable design. Çetin et al. (2021) note that there are five circular principles; regenerate, narrow, slow, close resource loops, and collaborate. Kirchherr et al. (2017) state that waste hierarchy, 4R framework, and systems perspective are the core principles of the circular economy. The paper explains that the frequency of 4R in the literature,

except for reuse, is decreasing. The reason for this decrease is the shifting to a systemic perspective, as macro, meso, and micro systems perspectives (Kirchherr et al., 2017).

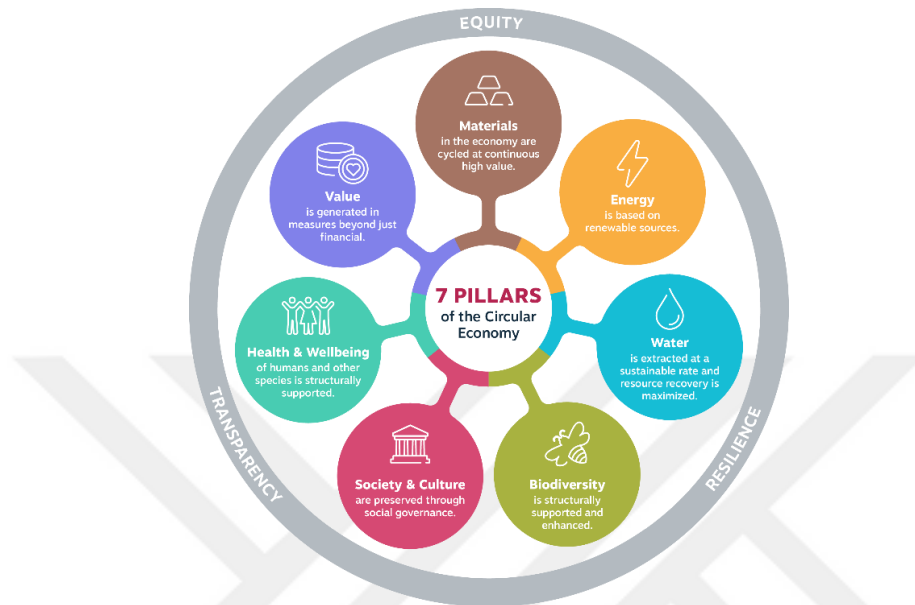


Figure 2.2 Seven Pillars of Circular Economy (Retrieved from <https://www.metabolic.nl/news/the-seven-pillars-of-the-circular-economy/> on 24.11.2022)

As mentioned above, the circular approach is discussed as reduce, reuse, and recycle, known as 3R's principles. This principle later developed into 6R, 7R, 9R, and 10R principles, known as R-ladder. 10R principles are explained by Potting et al. (2017) as strategies that go from high circularity to low circularity. Figure 2.3 shows the strategies: refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover. These strategies create the general framework used in the circular economy, as well as circular design. Adapting these actions to the built environment can create circular buildings with less environmental impact. Recover and recycle, as seen at the bottom of the strategies, are the least recommended actions as they have more environmental impacts than the other strategies (Potting et al., 2017).

Dokter et al. (2021) state that the 9R strategies can be a guiding framework for designers as they cover various circular strategies and are more beneficial to the micro level than the meso and macro levels. Reike et al. state that currently, the R-imperatives are not described clearly, as it is a multidisciplinary field that focuses on different parts of circular studies (2018). The article noted that as the R's increase, so does the length of the loops, and that even though academically this topic is neatly separated, in practice, this concept needs combinations (Reike et al., 2018).

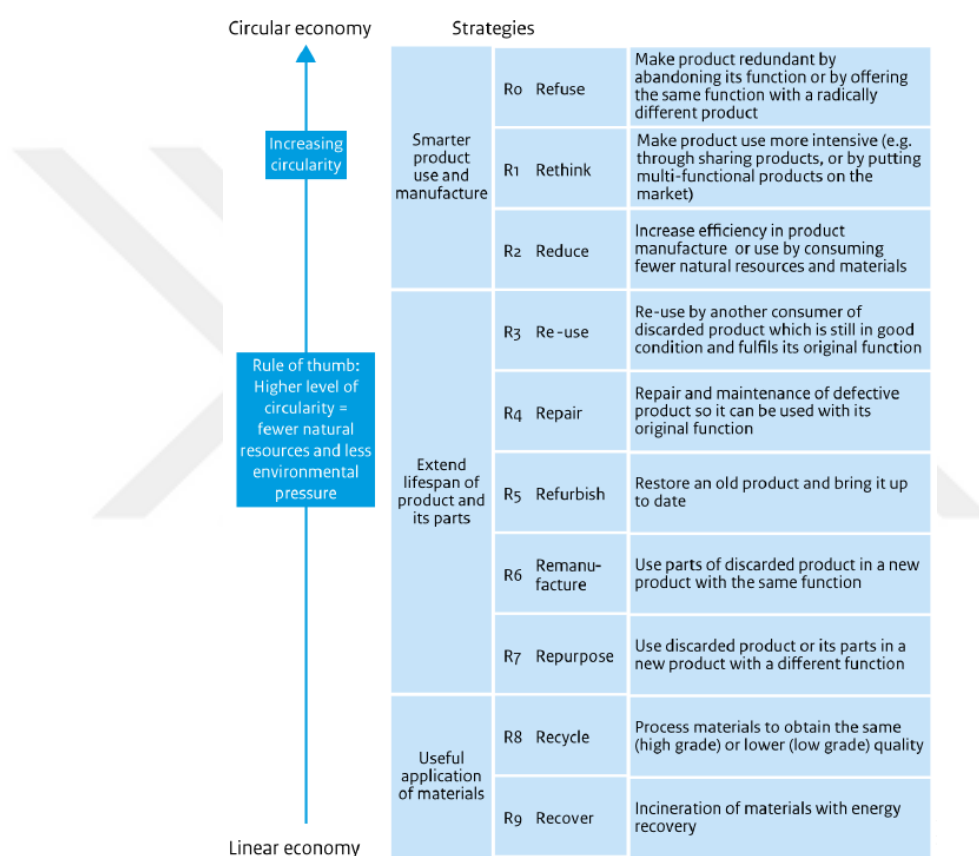


Figure 2.3 Circular Strategies of 9Rs (Potting et al., 2017)

As shown in the literature, there are many principles with the aim of completing the loop while prolonging the lifetime. One reason for the multiple principles is the changes in scale, such as city, building, material, and product; all of them require different actions with different details. Even though the mentioned principles and cycles are visible in the built environment, having so many alternatives can be perceived as confusing and discouraging by people in the industry and users. The

need to have a more precise explanation is required to clarify the confusion on this issue.

The transition to circular design has created opportunities for incorporating these principles and levels in the built environment. Adopting these circularity principles leads to a better understanding and implementation of circular and sustainable buildings.

2.1.2 Changes in the Built Environment

As stated earlier, the built environment greatly impacts the environment. Figure 2.4 shows the differences in the built environment between 2015 and 2020, which shows that even with the increase in awareness of building energy and a decrease in emissions, the buildings are responsible for “36 percent of global energy demand and 37 percent of energy-related CO₂ emissions in 2020”, which can be seen in Figure 2.8 (United Nations Environment Programme, 2021, p. 15).

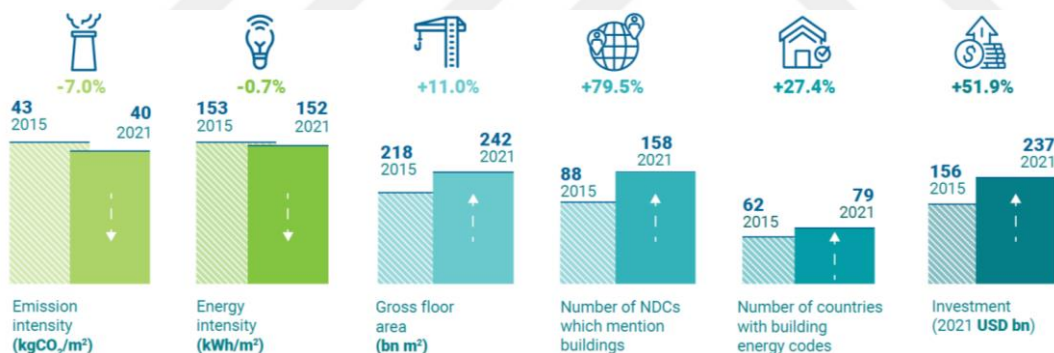


Figure 2.4 Changes Between 2015 and 2020 in the Built Environment (United Nations Environment Programme, 2022)

Changing climatic conditions are currently affecting buildings in terms of emission and consumption, and as this change increases over time, so does the impact (United Nations Environment Programme, 2021). Although according to the 2021 report by UNEP (United Nations Environment Programme, 2021), the peak level of emission in the built environment occurred in 2019, according to the 2022 report (United Nations Environment Programme, 2022), this record was surpassed in 2022. This

demonstrates that the attempts by buildings to adapt to changing conditions are currently falling behind, and more critical changes in the construction sector are required to reduce their emissions.

Circular design principles have an impact on both the design process and the components employed in the design, which creates differences between a traditional design process and a circular project, as seen in Figure 2.5. According to Condotta and Zatta (2021), the traditional process embraces the linear economy, where the end-of-life of a building is demolition. The paper states that the reuse design project uses the elements recovered from a demolished building; therefore, it adopts circular principles. It can be seen that this workflow aims to prolong the lifetime of the buildings and the building elements with actions such as reuse and remanufacture, which shows the use of circular principles in the built environment.

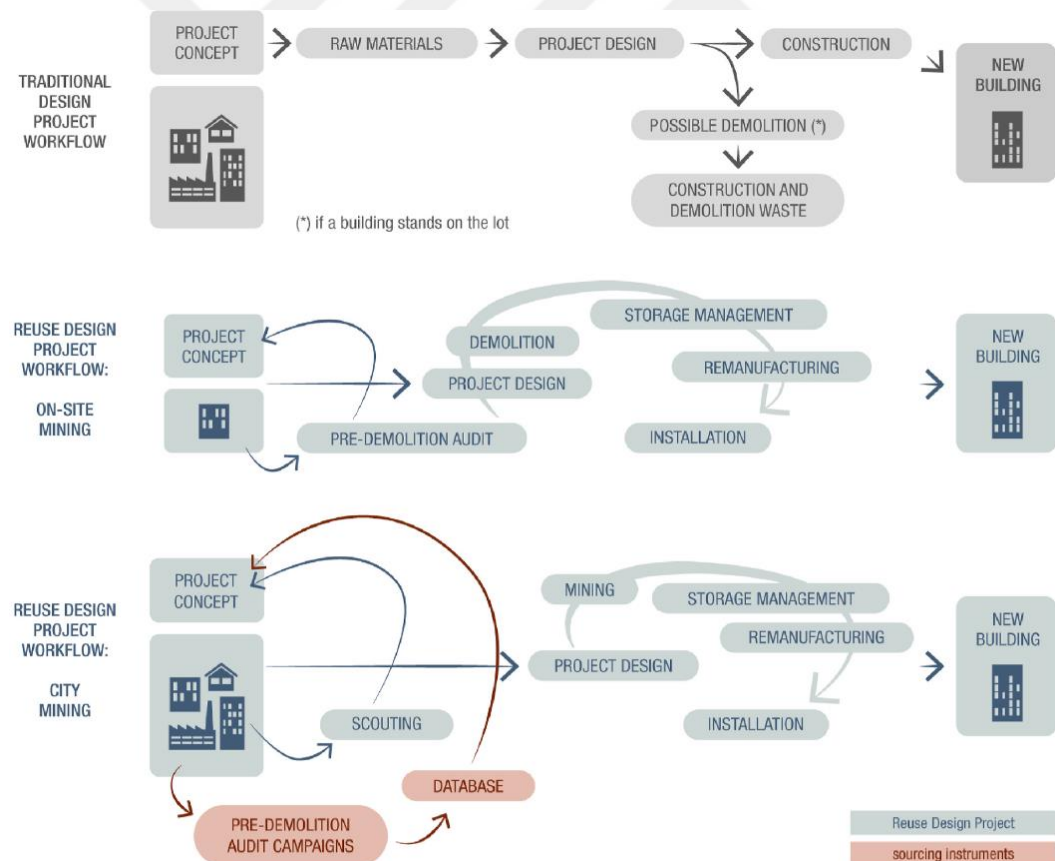


Figure 2.5 Different Approaches in Design Project Workflow (Condotta and Zatta, 2021)

The relationship between the levels, environment, and the built environment can be seen in Figure 2.6. The paper states that to achieve circularity in buildings, there should be implementations other than resource consumption and an increase in recycling. The research made by Pomponi and Moncaster (2017) shows that the approach to circular buildings can be different from the literature. The paper notes that the users and the lack of interdisciplinary research on circular buildings drive this difference.

According to Pomponi and Moncaster, the buildings are considered as “a meso-level, the macro-level being urban agglomerates and the micro-level as building components” (Pomponi & Moncaster, 2017, p. 711). This concept is used widely in the literature as it shows the built environment in a cascaded view where the levels are connected.

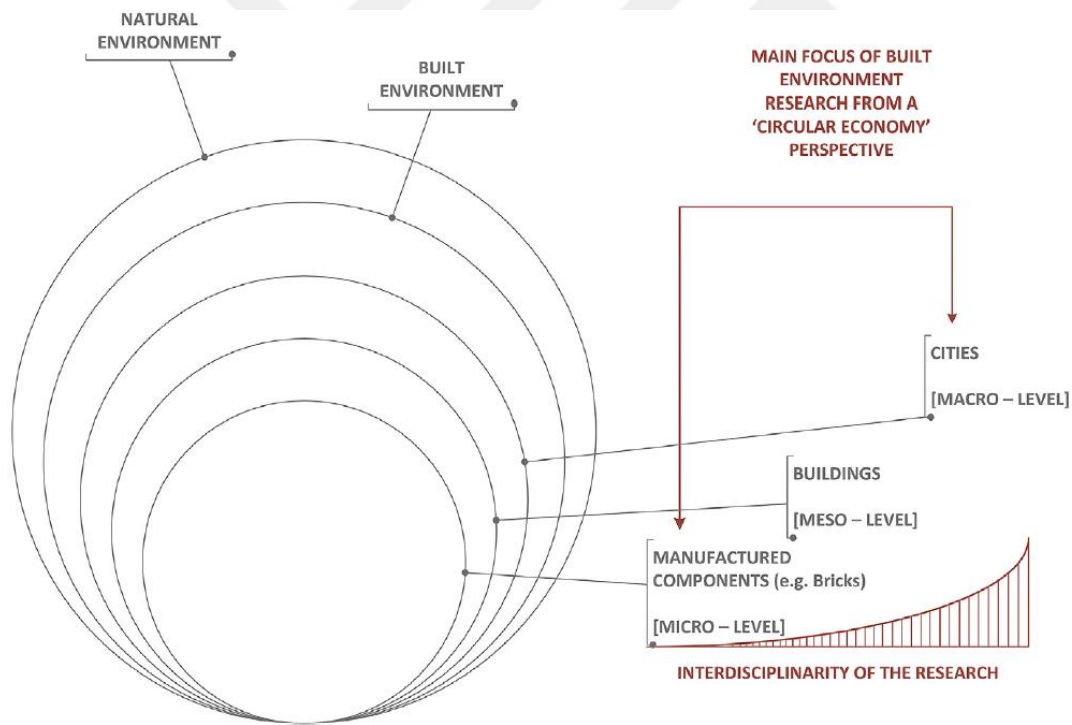


Figure 2.6 Relation Between Built Environment and Circular Economy (Pomponi and Moncaster, 2017)

The circular built environment is explained by Çetin et al. (2022) as a system with various independent scales, as seen in Figure 2.7. The paper shows that the scales

are nano, micro, meso, and macro, and the resources are regenerated, narrowed, closed, and slowed. The paper explains the terms as “nano (materials and products), micro (components and buildings), meso (neighbourhoods and real estate portfolios), and macro (areas, cities, and regions)” (Çetin et al., 2022, p. 213). The study discusses the research about enabling digital technologies for a circular built environment that considers BIM, MP, and Artificial Intelligence. The authors state that BIM and MP technologies are used in the nano (product) and micro (building) levels, where they “could be used for managing building portfolios circularly” (Çetin et al., 2022, p. 221). This shows that combining these tools and assessments in the built environment can help with the circularity of the buildings, which is discussed further.

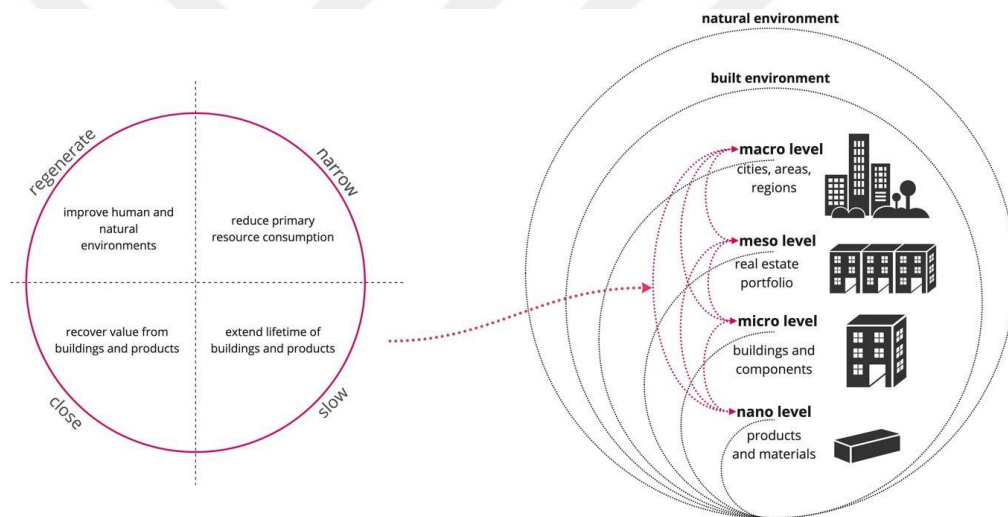


Figure 2.7 Circular Built Environment (Çetin et al., 2020)

Similar to the circularity principles, there are different definitions of the scales in the built environment, as seen in Figure 2.6 and Figure 2.7. These differences in terms vary according to the scale studied and can create different frames in the circular built environment. Even though the differences in the focus of the studies, there is still a need for a precise explanation of these terms and concepts so that there are no inconsistencies in the field.

2.2 Circularity in Buildings

As mentioned earlier, the construction industry has a great impact on the ecology and the economy. Rees (1999) states that in the 1990s, 40% of the materials and a third of the energy consumption are used by buildings. This situation continued in the 2010s; according to World Economic Forum (WEF, 2016), the construction industry is considered the largest consumer of raw materials, and they cause 25-40% of the world's carbon emissions. The waste created in the construction phase is noted as “15% of building materials are wasted in construction” (Ellen MacArthur Foundation, 2021, p. 22).

Buildings and constructions are responsible for emissions and energy usage worldwide, as seen in Figure 2.8. To prevent this, circular building concepts are suggested where the materials are reused, and the lifetime of the buildings is increased. With the application of circular design principles to the built environment, there have been developments in areas such as disassembly and reassembly, materials, and construction process, resulting in the evolution of circular buildings. The definition of the circular building made by Pomponi and Moncaster is “a building that is designed, planned, built, operated, maintained, and deconstructed in a manner consistent with CE principles” (2017, p. 711).

Figure 2. Buildings and construction's share of global final energy and energy-related CO₂ emissions, 2020

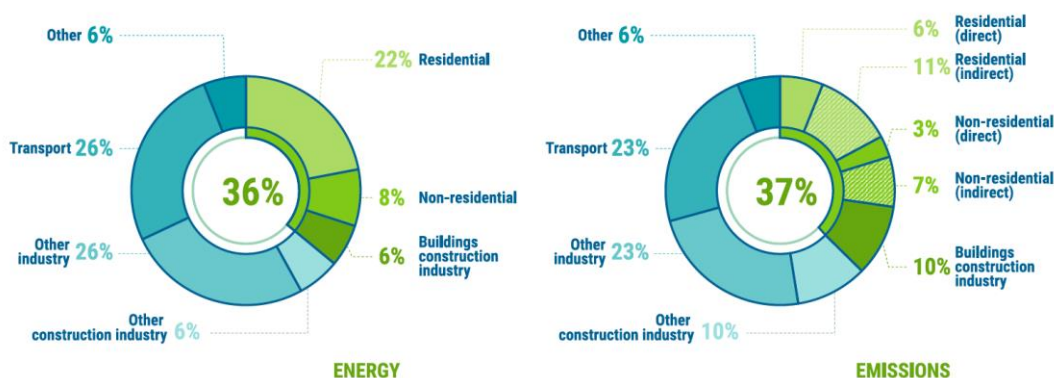


Figure 2.8 Buildings Energy and Emission Diagram (IEA, 2021, adapted by United Nations Environment Programme, 2021)

Circular construction is defined as “the development, use and reuse of buildings, areas and infrastructure without unnecessarily exhausting natural resources, polluting the living environment, and affecting ecosystems” (Bouweconomie, 2018, p. 10).

According to Gemeente Amsterdam, circular buildings have four principles, “reduction, synergy, production and procurement, management” (2017, p. 13). The paper explains these principles as reducing the need for raw materials, synergizing and reusing the available resources, supplying renewable resources, and managing feedback. Along with these principles, the themes of the circular building are created as “materials, adaptivity and resilience, water, energy, and ecosystems and biodiversity” (Gemeente Amsterdam, 2017, p. 13). Kanter (2020) notes that there is a lack of definition of circular building design and continues that this definition can be supported by the butterfly diagram made by EMF and the shearing layer concept developed by Brand.

- Shearing Layers

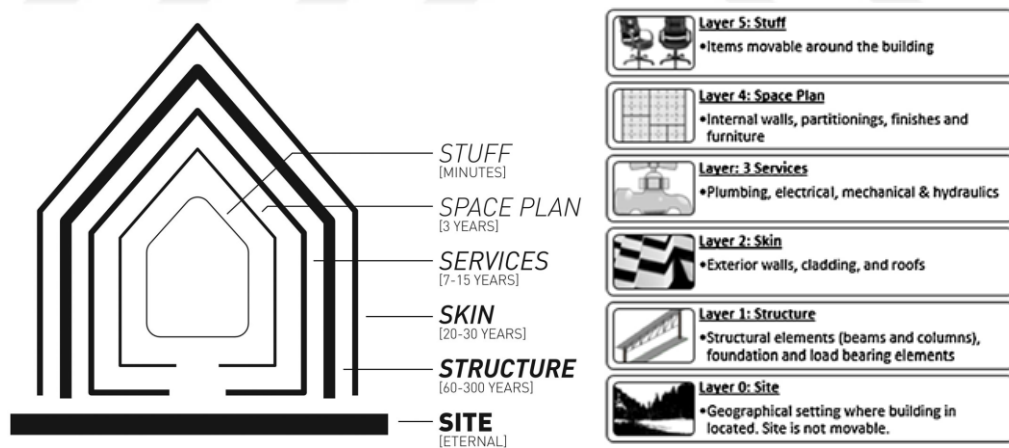


Figure 2.9 a) Layers of Change (Brand, 1995, as cited in Urquhart et al., 2019), b) Layers of the Building (Akinade et al., 2015)

The shearing layers, or the Six S's, created by Brand (1994), was developed from the 4S's concept of Duffy (1990): shell, services, scenery, and set. The shearing layers show the layers of the buildings and layers of change, which creates an

adaptive and hierarchical model. Brand (1994) states that the layers of the buildings are independent of each other, and the design should be done according to this. Figure 2.9 shows the layers, the rates of change, and the building layers where the components are demonstrated according to the life span. Circular buildings use the theory of shearing layers as it shows the expected life span of the building layers.

	Regenerate	Share	Optimize	Loop	Virtualise	Exchange
						
 System	Extraction and reuse of biological resources via anaerobic digestion to create and supply energy onto the grid	Sale of energy back to the grid	Optimisation of transport links between built assets. Integration of low carbon systems. Designing out waste strategies (HS2)	Renewables and circular resource flows (energy, water, waste etc). Adapt use over time, e.g. commercial to residential	Virtual/digital storage via cloud systems. Smart systems to improve systems integration	Integrated circular city design approach (Regen Villages)
 Site	Detoxify and regenerate brownfield land to revive the biosphere (Old Oak and Park Royal Development, London)	Online platforms to facilitate space sharing. Open source data platforms for sharing designs (WikiHouse)	Use of localised renewable energy sources and distributed networks.	Retrofit and reuse existing buildings and assets for different uses (Tata Steel)	Open source design via openly accessible online platforms (WikiHouse)	Construction using alternative sustainable and low impact materials (Hi-Fi mycelium tower)
 Structure	Nature-based design solutions. Low impact materials, design and construction (Madrid + Natural)	Reuse of structural elements of buildings, e.g. reclaimed timber or steel beams	Design for longevity and adaptability (White Collar Factory)	Design for disassembly. Regeneration of buildings for mixed use	Internet of Things / ICT / BIM to monitor performance and facilitate maintenance and repair	Use sustainable materials and approaches (Sky Believe in Better Building)
 Skin	Integration of green walls and surfaces. Extraction of green walls for composting and reuse	Pool or share assets, equipment and personnel. Design for disassembly (Globechain)	Leasing of façade in performance based contracts (Frener & Relfer façade)	Modular design and off-site prefabrication (Sky Believe in Better Building)	BIM to monitor performance and facilitate repair (Hong Kong sludge treatment plant)	Integration of bio-façades (SolarLeaf House)
 Services	AD recycling biological nutrients and biogas (Nestlé AD plant)	Reuse of building components e.g. pipes, metals, electronics	Leasing of lighting and energy. Sensor-based lighting (Phillips pay per lux)	Open design and operating standards. Rainwater harvesting, grey water recycling, battery storage on-site	Smart sensors. Monitor and deliver maintenance services remotely (Forth Replacement Crossing)	Shift to services over ownership. Internet of Things. LED light replacement
 Space	Use biodegradable and compostable materials (Ecovative)	Maximising space utilisation (HeadBox)	Design for flexible use. Maximise use of daylight and natural ventilation	Remanufacturing of products and components (Cat Reman)	Video and virtual conferencing	Natural lighting and ventilation solutions
 Stuff	Use biodegradable and compostable materials (Ecovative)	Maximising space utilisation (HeadBox)	Design for flexible use. Maximise use of daylight and natural ventilation	Remanufacturing of products and components (Cat Reman)	Video and virtual conferencing	Natural lighting and ventilation solutions

Figure 2.10 7S System with ReSOLVE framework (ARUP, 2016)

ARUP proposes a 7S model where a ‘system’ is added to demonstrate the effects on the city or district (2016). The model has been modified to be the system for the longest and stuff for the shortest time. A table showing the overlap of this model with the EMF ReSOLVE framework has been created, as shown in Figure 2.10.

The layers create opportunities for concepts such as disassembly, dismantling, deconstruction, and reuse, where the ability to see each layer and act on them

independently exists. The concept of shearing layers can be seen in various studies. The ability to divide the building and act on different levels without disrupting other layers changed the design of the built environment.

- Material Passports

Material passports (MP), also known as circularity passports or product passports, emerged from the idea of bringing the circular economy into the building industry (Heinrich & Lang, 2019). BAMB (Building as Material Banks) started in 2015 as an EU Horizon 2020 program and described material passport as “sets of data describing defined characteristics of materials in products that give them value for recovery and reuse” (Mulhall et al., 2017, p. 17). Madaster Foundation, started in 2017 and founded by the EU Horizon 2020, notes that the material passport is the concept of a passport implemented into the materials, products, and construction objects. Çetin et al. explained MP as “to refer to digitally registered data sets of an object describing its characteristics, location, history and ownership status” (2021, p. 20). The paper continues that depending on the context of the MP, the level of detail varies. It should be mentioned that the building is not a product, but a combination of products. For the rating of products, MP is used.



Figure 2.11 Building Layers and Circularity Score in Madaster (Madaster Foundation, 2021)

According to Mulhall et al., the products divide into four hierarchy levels that material passports focus on, similar to Brand’s shearing layers for the buildings. The main idea of the material passport is the increase the value of the materials while

providing data for the circular design. Another example that implements shearing layers in MP is Madaster (Madaster Foundation, 2021). As seen in Figure 2.11, Madaster uses building layers and their different lifespans in its system and the circularity indicator scores for different building phases.

Table 2.1 Comparison of Existing Passports (Adapted from Debacker and Manshoven, 2016) (Developed by author)

Passport Name	Initiator's name	Composition	Sustainable Resources Use During Production	Materials Health	Design For Disassembly	Biological/Technical Cycle	Product/Component Re-use Potential	Material Re-use Potential	Noise Reduction/ Safety/ Fire	Positive Impacts	Certifications	Tax Credits	Removal Costs/Residual Value	Building Context	Automated Entry of Existing Data	Updated During Operations
BIM Object		✓	○	○	○	X	?	?	?	X	?	X	X	Link to BIM	○	X
C-passport	Cirmar	✓	?	✓	?	✓	✓	✓	✓	?	✓	?	✓	?	?	?
Circularity Passports	EPEA	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	?	✓
Cradle-to-Cradle Passport	Sustainable Shipping Initiative	✓		?	✓	?	?	?	?	?	?	?	?	?	?	?
Declaration of Performance (DoP)	EC Product Directives	?	✓	?	X	X	X	?	✓	X	✓	X	X	X	?	X
Environmental Product Declaration (EPD)	ISO	✓	✓	Hazards	X	X	?	?	?	X	✓	X	X	X	X	X
Health Product Declaration (HPD)	Health Product Declaration Consortium	✓	✓	✓	X	X	X	X	○	X	✓	X	X	X	X	X
Material Safety Data Sheet (MSDS) & Safety Data Sheets (SDS)	The Hazard Communication Standard, OSHA	✓	?	?	X	X	X	X	✓	X	?	X	X	X	?	X
Product Passport	European Resource Platform	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
Raw Materials Passport	Turntoo & Double Effect	✓	?	?	?	?	?	✓	?	?	?	?	?	?	?	?
Recycling Passport Based on WEEE	Agfa-Gevaert & Electrocyling GmbH	○	X	○	✓	X	○	○	○	X	?	X	X	X	?	X
Resource Identity Tag or Tool	Groene Zaak/Metabolic/Fairmeter.org	✓	?	✓	✓	?	✓	?	○	?	✓	?	?	✓	?	?
Technical Passport for Equipment	Kazakhstan & Russia	○	X	○	○	X	X	○	○	X	○	X	X	X	?	X
Workwear Passport	Dutch Awearness	?	?	?	?	?	?	?	?	?	?	?	?	n/a	?	?

Non-Governmental Organizations
Private sector for building-related products
Government agency driven
Marketplace status uncertain

Similar to the GBRS, there are multiple material passports, many of which have been developed for products. Debacker and Manshoven (2016) show the existing passports and their features, as seen in Table 2.1. It can be seen that these passports are used in different areas for different purposes. It is mentioned that BAMB Material Passports are based on the EPEA Circularity Passport (Debacker & Manshoven, 2016). The report also shows that using MP and reversible design, such as deconstruction and disassembly, will result in building as material banks (Debacker & Manshoven, 2016).

ARUP states that the built environment is going through a troubled time due to the obscurity supply chain and the unknown material information (2016). The paper states that this problem can be solved with MP with the provided material information, and the 3D models can be shared with the inclusion of BIM. ARUP explains MP as “provide information on the value of materials and products, their reusable or toxic content and the ease with which they can be disassembled” (2016, p. 89). It is noted that the gathered information is stored in a database to access the actions of the materials more efficiently.

Mulhall et al. (2017) state that material passports are used to provide the other parties the information since they cannot be used alone to evaluate the data. The paper continues that the Materials Passport Platform (MPP) is a software used to generate material passports and provide data in all building-use phases. Rahla et al. state that material passport provides information about the physical, chemical, and biological aspects of the materials, which can be qualitative and quantitative information that can be used in the circular economy concept (2021). Munaro and Tavares (2021) state that the concept of material passports in the built environment currently needs more studies in order to achieve a sustainable and circular design phase, longer material and business lifespan, and better business opportunities.

Similar to circular design and buildings, the material passport information still lacks enough studies and practices. It can be seen that these systems can be seen as additional cost by the industry and the users; it has actual benefits to the longevity

of the building materials and the products. Still, the various types of MP can be intimidating for people who want to choose one. For this reason, there is still a need to understand MP better to increase the scope of use and find a convenient passport.

2.2.1 Life Cycle of Buildings and Life Cycle Tools

ISO defines the life cycle as “consecutive and interlinked stages of a product system, from the raw material acquisition or generation from natural resources to final disposal” (International Organization for Standardization, 2006, p. 2). It is stated that the life cycle “can be understood as a set of subdivided modules,” and the life cycle of the building can be viewed from different perspectives (International Organization for Standardization, 2010, p. 10). Figure 2.12 shows the building life cycle from a physical perspective. It is visible that the actions in these stages are in line with the circularity principles, and the end-of-life stage has different alternatives, such as deconstruction, transport, recycling/reuse, or disposal.

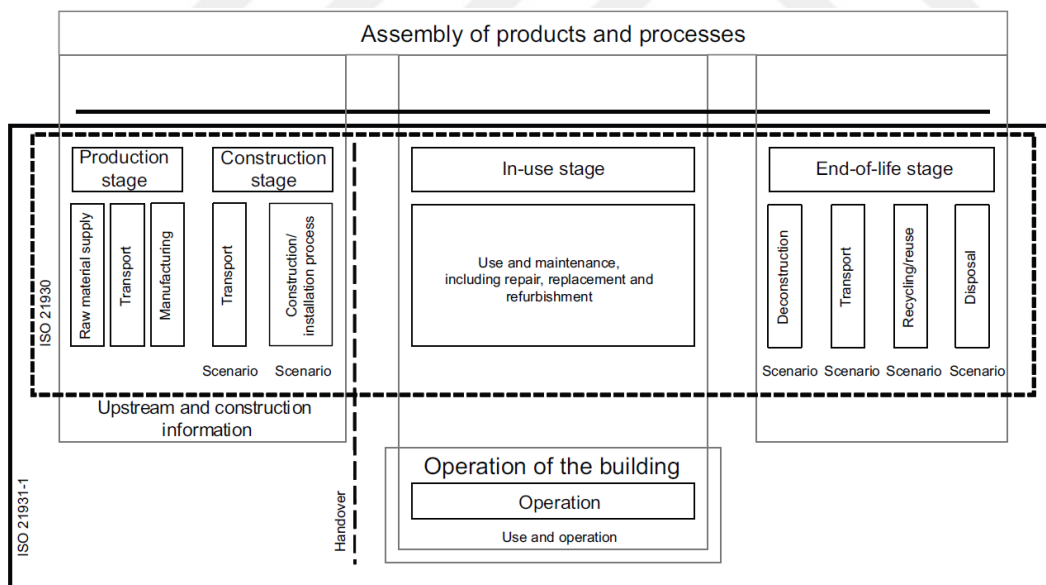


Figure 2.12 Building Life Cycle (International Organization for Standardization, 2010)

As mentioned before, the buildings have a life cycle with various stages, which can be seen in Figure 2.13. In a linear process, the life cycle starts with the design and

ends with the demolition of the building, which creates lots of landfill throughout the life cycle (Bertino et al., 2021). Contrary to the linear process, in a circular process, the life cycle of the building does not have to end with a demolition.

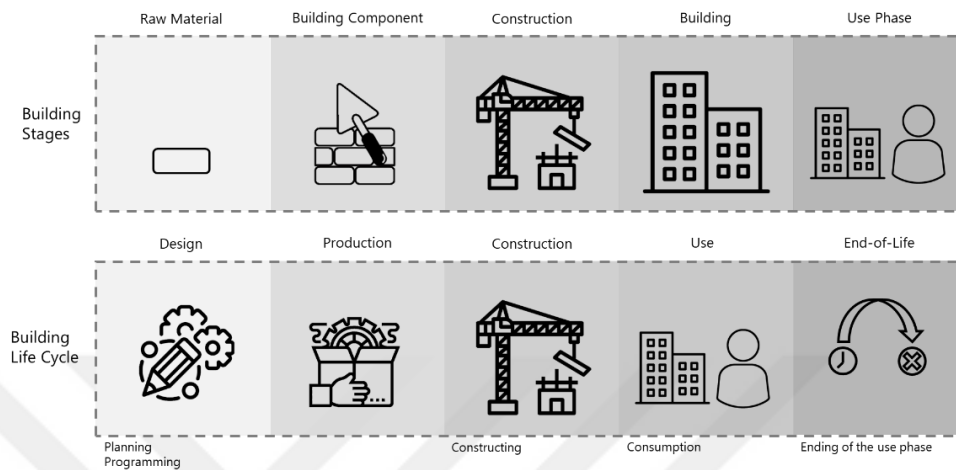


Figure 2.13 Building Life Cycle and Stages (Adapted from Bertino et al., 2021) (Developed by author)

Crawford (2011) states that there are six stages in the life cycle of the building; raw material extraction, manufacturing, construction, operation and maintenance, demolition and disposal, reuse, or recycling. He goes on to say that even when the buildings are no longer in use, the environmental impacts of these stages will continue.

The end-of-life phase shows that the building can have an afterlife with different scenarios. Bertino et al. divided the end-of-life scenarios into five: maintenance, refurbishment, demolition, and deconstruction (2021). Wilkinson et al. stated that buildings have been adapted throughout history, and this adaptation can occur in the use or end-of-life phases (2014).

According to Wilkinson et al., buildings feature a cyclical life cycle process with three types of lifespan, which can be seen in Table 2.2; and the lifespan of the building is affected by the “state of obsolescence of the building” (2014, p. 100). Table 2.2 shows the types of life span and their attributes. The research on structural vacant office buildings concluded that there are four scenarios; “consolidation,

adaptation or upgrading, demolition and new construction, and conversion” (Wilkinson et al., 2014, p. 121).

Table 2.2 Types of Building Lifespan /Adapted from Wilkinson et al., 2014)
(Developed by author)

Technical Lifespan	Functional Lifespan	Economic Lifespan
• Period of the fulfilled technical and physical conditions • Can be prolong with maintenance, as repairing or restoring the conditions	• Period of the user's demand about function • Ends with the conclusion of the use • Adapt with the same use • Convert the function	• Period of more income than costs • Ends when the income seems less than the costs

According to Crowther (2005), the built environment has alternatives other than demolition for its end-of-life phase, as seen in Figure 2.14. The paper explains that the disassembly and the principles of circular economy, such as reprocessing, recycling, and relocation, can be used in the design of buildings. He states that design for disassembly allows change over time and greatly benefits the environment and economics (2005).

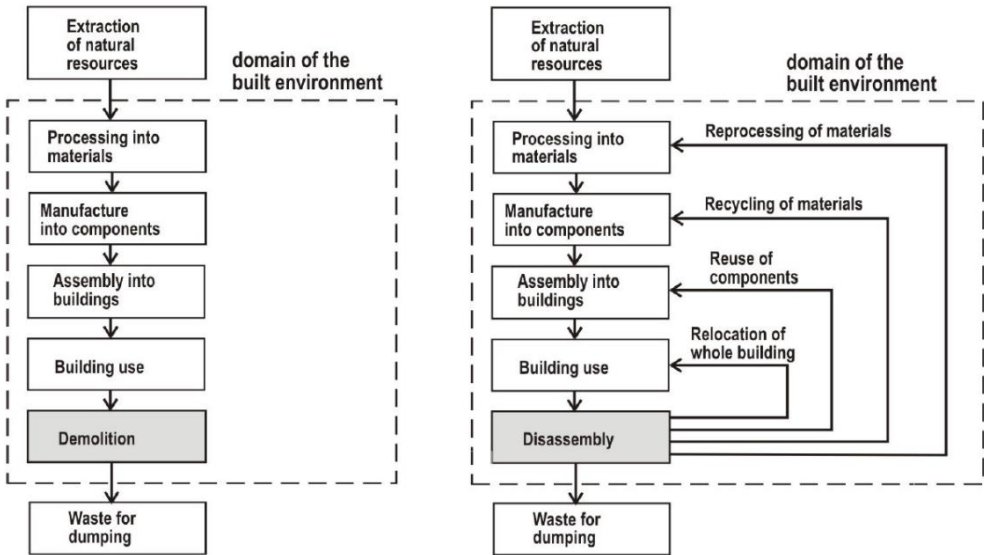


Figure 2.14 Building Life Cycle Scenarios (Crowther, 2005)

As mentioned in the articles by Condotta and Zatta (2021) and Crowther (2005), buildings do not have to go through an end-of-life phase but can instead have an after-life phase. Buildings informed by circular principles can have this after-life cycle and extend their lifespan. These changes can be seen as the result of applying circular principles to the building industry.

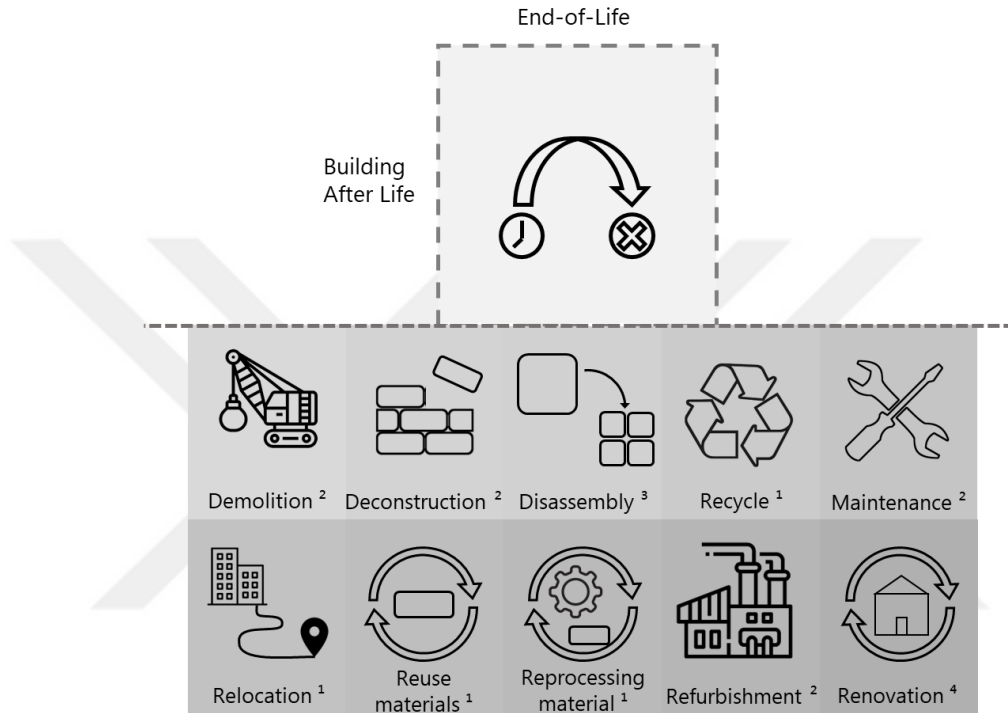


Figure 2.15 Afterlife Scenarios (Bertino et al., 2021; Çetin et al., 2021; Crowther, 2005; Hasik et al., 2019) (Developed by author)

Figure 2.15 demonstrates a summary of the existing afterlife scenarios collected from various papers. Terms collected from Crowther (2005) marked as ¹, Bertino (2021) marked as ², Çetin (2021) marked as ³, and Hasik (2019) marked as ⁴. These scenarios show that the lifespan of the buildings can be changed according to the selected action, and so does the effects on the environment. It should be mentioned that there can be combinations of these actions, and not every scenario is suitable for every building. The mentioned systems, circularity principles, shearing layers, MP, and life cycle of buildings are all intertwined. It can be seen in literature and practice that these topics need more studies to reduce the inconsistency and the lack of knowledge.

2.3 Green Building Rating Systems

The certification systems are developed with the increase in circular and green buildings and along with the need to evaluate and rate these buildings and increase the knowledge about them (Reed et al., 2009; Tang et al., 2020). Certification systems are developed to achieve a more sustainable and circular built environment and to distinguish the level of circularity. These certifications, known as Green Building Rating Systems (GBRS), are used to evaluate green buildings. USGBC explains green buildings as buildings that increase the positive effects and decrease the negative effects on the environment throughout all phases (Kriss, 2014). Illankoon et al. define green buildings as “an environmentally friendlier building with the efficient use of energy, water and other resources” (2017, p. 210).

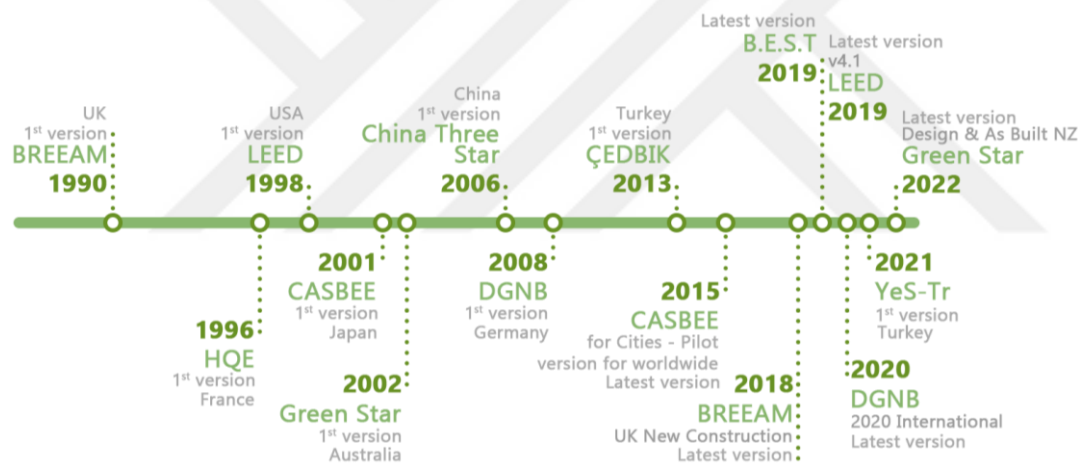


Figure 2.16 Timeline of the GBRS (Adapted from Guldager Jensen et al., 2018; Pedro et al., 2019) (Developed by author)

Many certification systems have been established in different countries and have different rating criteria according to the needs and environment, some of which can be seen in Figure 2.16. According to Hamedani and Huber (2012), at the beginning of the 1990s, sustainable development increased with various definitions and concepts. The paper continues that sustainable development has three main aspects, major, economic, and social; moreover, it can be seen in different levels such as neighborhoods, cities, countries, and the world. Certification systems are “a

quantitative standard to measure the concept of sustainable development in each area” (Hamedani & Huber, 2012, p. 123). Seyis et al. note that GBRS have been developed to assist in measuring building performance and to meet sustainable requirements; while there can be different systems, concerns about achieving efficiency and sustainability in the built environment are their common points (2021).

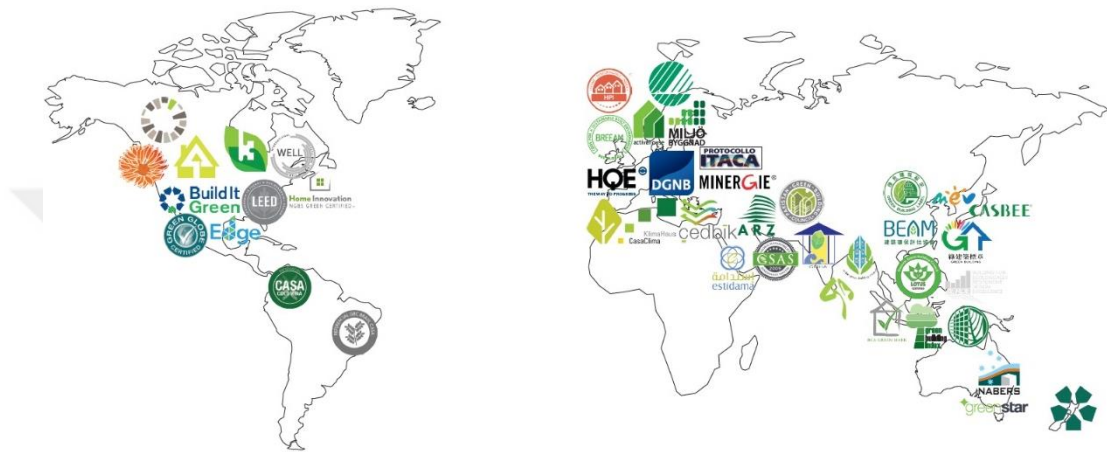


Figure 2.17 Sustainable Rating Systems Around World (Guldager Jensen et al., 2018)

Currently, there are hundreds of rating systems in various countries with different degrees of rating tools with different areas of focus, some of which can be seen in Figure 2.17 (Reed et al., 2009). Even though the certification systems created a field to measure the circularity of the buildings, comparing the certification systems requires unity in the framework of categories (Guldager Jensen et al., 2018). The study by Illankoon et al. shows that most of the GBRS focus on some of the projects' main aspects: " site, energy, water, IEQ, material, waste and pollution, and management” (2017, p. 218).

For the time being, there are 1088 buildings with LEED, 47 buildings with BREEAM, one building with DGNB, and two buildings with Passive House certifications in Turkey, which can be seen in Figure 2.18 (*BREEAM Projects*, n.d.; *DGNB Projects*, n.d.; *LEED Projects*, n.d.; *Passive House Projects*, n.d.). According

to ÇEDBİK (Turkish Green Building Council), there are 23 projects with B.E.S.T. certification, but no further information could be found about them (B.E.S.T., n.d.).

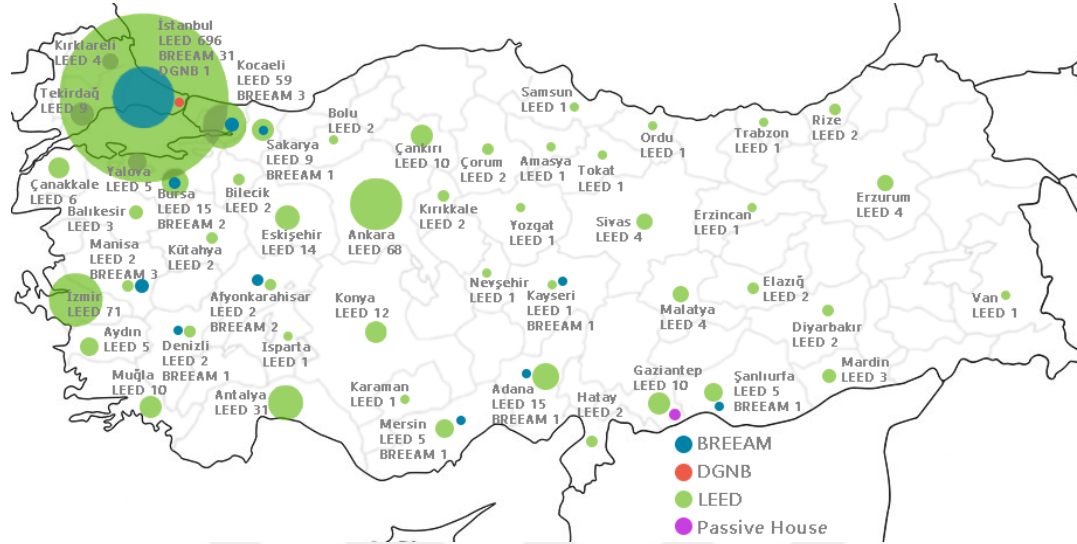


Figure 2.18 Certificated Buildings in Turkey (Adapted from (BREEAM Projects, n.d.; DGNB Projects, n.d.; LEED Projects, n.d.; Passive House Projects, n.d.) (Developed by author)

Table 2.3 shows six selected certification systems: BREEAM, LEED, DGNB, Green Star, B.E.S.T., and YeS-TR. Two of the selected systems were developed in Turkey; B.E.S.T. and YeS-TR. BREEAM, LEED, and DGNB were selected for their wide field of application and their presence in Turkey. Green Star is selected for worldwide application in places like Australia and Africa.

Table 2.3 demonstrates the overview of the selected GBRS; general and Turkey-specific information has been collected. It can be seen that LEED is the first place in the certified buildings in Turkey. Even though Turkey has developed its own certification systems, they are much newer compared to the others, which is why the information about the certified building was unavailable. It is visible that there is a big difference in the ratings and the categories. These differences and the comparison of these GBRS are discussed below.

Table 2.3 Selected Certification Systems. (Developed by author)

	 BREEAM	 LEED	 DGNB	 GREEN STAR	 B.E.S.T	 YeS-TR
Name	Building Research Establishment Environmental Assessment Method	Leadership in Energy and Environmental Design	Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council)	Green Star	Binalarda Ekolojik ve Sürdürülebilir Tasarım (Ecological and Sustainable Design in Buildings)	Ulusal Yeşil Sertifika Sistemi (National Green Certification System)
Launch Date	1990	1998	2007	2003	2013	2021
Latest Version	2018	2019	2020	2022	2019	2021
Origin	United Kingdom	United States of America	Germany	Australia	Turkey	Turkey
Countries	77	164	21	7	1	1
Initiator	BRE (Building Research Establishment)	USGBC (United States Green Buildings Council)	DGNB	GBCA (Green Building Council of Australia)	ÇEDBİK (Turkish Green Building Council)	Ministry of Environment, Urbanisation and Climate Change
Ratings	Pass/ Good/ Very Good/ Excellent/ Outstanding	Certified/ Silver/ Gold/ Platinum	Bronze/ Silver/ Gold/ Platinum	One Star/ Two Star/ Three Star/ Four Star/ Five Star/ Six Star	Certified/ Good / Very Good/ Excellent	Pass/ Good/ Very Good/ National Supremacy
Total Registered	2,217,000	n/a	n/a	1491	n/a	n/a
Total Certified	564,000	157,702	8700+	3645	23	n/a
In Turkey	47	1113	1	0	23	n/a
Levels in Turkey	3 Pass 12 Good 21 Very Good 4 Excellent 5 Outstanding	597 Unlabeled 36 Certified 69 Silver 340 Gold 71 Platinum	1 Gold	0	n/a	n/a
Criteria	12 • Management • Water • Energy • Transport • Health & wellbeing • Resources • Resilience • Land use & ecology • Pollution • Materials • Waste • Innovation	10 • Integrative • Process • Location and transportation • Sustainable sites • Water efficiency • Energy and atmosphere • Materials and resources • Indoor environmental quality • Innovation • Regional priority	6 • Environmental quality • Economic quality • Sociocultural and functional quality • Technical quality • Process quality • Site quality	9 • Management • Indoor environment quality • Energy • Transport • Water • Materials • Land use and ecology • Emissions • Innovation	9 • Integrated Green Project Management • Land Use • Water Use • Energy Use • Health and Comfort • Material and resource use • Residential life • Operation and maintenance • Innovation	6 • Integrated Building Design, Construction and Management • Indoor environment quality • Building material and life cycle • Energy use and efficiency • Water and waste management • Innovation

Note. Data collected from Guldager Jensen et al., 2018; Reed et al., 2009; Environment and Urban Ministry (Turkey), n.d.; <https://bregroup.com/>, <https://cedbik.org/>, <https://www.dgnb.de/en/>, <https://www.usgbc.org/leed>, and <https://new.gbca.org.au/> (Accessed on December 1, 2022)

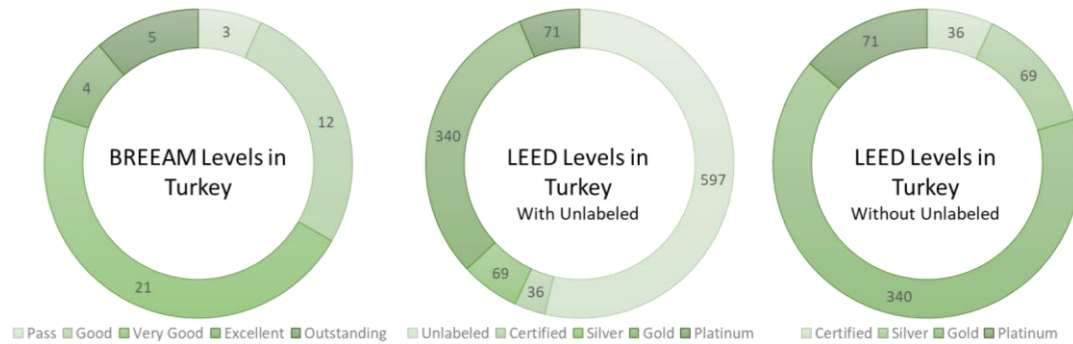


Figure 2.19 GBRS Levels in Turkey (Developed by author)

Figure 2.19 shows the LEED and BREEAM levels in Turkey. As seen, more than half of the LEED certificated projects are unlabeled; apart from that, the remaining part shows an unbalanced result. It seems that most of the projects get Gold certification, while BREEAM certificated buildings get Very Good certification. In order to compare these certifications and understand the differences, the categories, ratings, weighting, and inconsistencies in these systems needed to be identified.

2.3.1 Comparison of Certification Systems

As mentioned before, the existing GBRS are found in large numbers across the globe, focusing on different topics. For this reason, the six selected GBRS are used for this section. In order to compare these systems, Table 2.4 shows the categories of the described certification systems. According to Deligöz et al. (2020), it can be seen that LEED is stood out in the energy area; BREEAM is more improved in carbon; meanwhile, B.E.S.T has essential points such as renewable energy and wastewater. The paper continues that the certification systems, even though they are based in different countries and have distinct evaluation systems, have the same idea, a sustainable built environment.

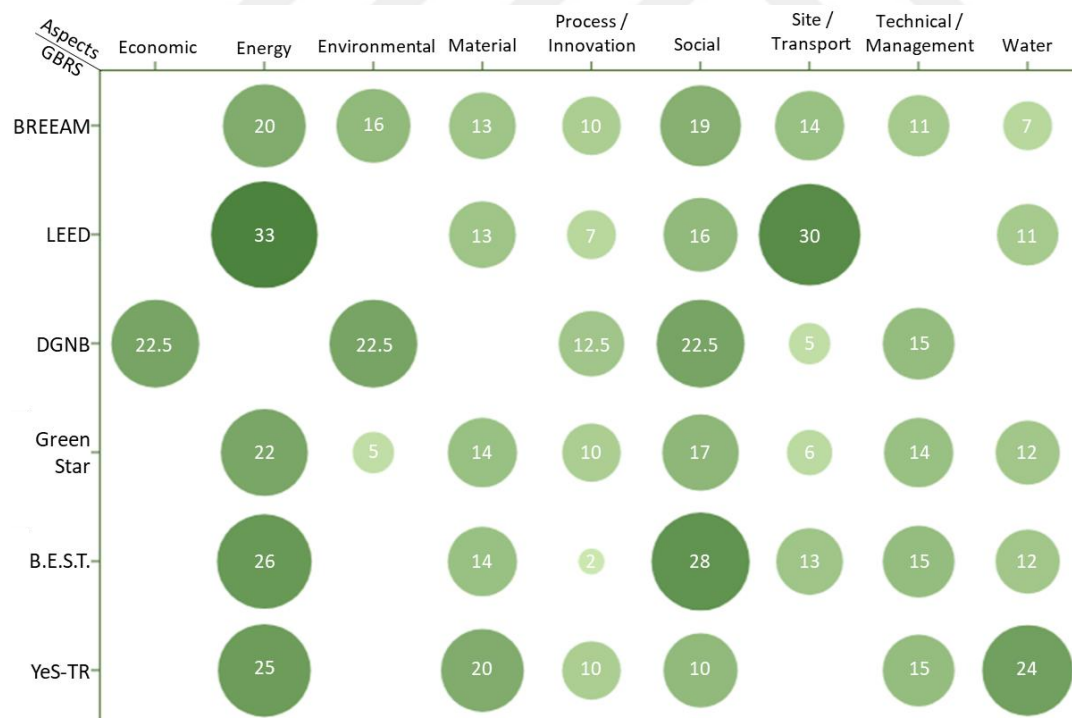
Table 2.4 Rating Criteria of the Circular Building Rating Systems (Developed by author)

Rating Criteria	BREEAM	LEED	DGNB	GREEN STAR	B.E.S.T.	YeS-TR
 Health & Wellbeing	•		•		•	
 Resources	•	•	•		•	
 Resilience	•					
 Land Use & Ecology	•		•	•	•	•
 Pollution / Emissions	•			•		
 Materials	•	•		•	•	•
 Waste	•					
 Innovation	•	•		•	•	•
 Integrative Process		•				
 Regional Priority		•				•
 Indoor Environmental Quality		•	•	•		•
 Sustainable Sites / Environment		•	•	•		•
 Location		•				
 Economic Prosperity			•			•
 Sociocultural and functional quality			•	•	•	
 Operation, Maintenance and Technical Quality			•		•	•
 Life Cycle Assessment			•			•

Note. Data collected from Environment and Urban Ministry (Turkey), n.d.; <https://bregroup.com/>, <https://cedbik.org/>, <https://www.dgnb.de/en/>, <https://www.usgbc.org/leed>, and <https://new.gbca.org.au/> (Accessed on October 30, 2022)

Reed et al. state that BREEAM scores higher in management and health and wellbeing, while Green Star scores lower in the energy and transport categories (2009). The paper also notes that Green Star gives more points in water related categories due to environmental factors, while BREEAM gives more points in land use and ecology due to population density. Reed et al. (2009) also show the difficulties in comparison of the GBRS as the differences in building standards, categories, and inadequate flexibility. Tang et al. (2020) note that the most common criteria in comparing GBRS are energy, water, indoor environmental quality, health, and wellbeing. Pedro et al. show that integrating computer-based models with rating systems can be considered a gap in this field (2019).

Table 2.5 Weightings and Credits of the GBRS (Developed by author)



Note. The credits are from the latest versions. Data collected from BRE Global, 2016; ÇEDBİK, 2019; DGNB System – New Buildings Criteria Set, n.d.; Green

Star - Design & As Built v1.3, n.d.; *LEED v4.1 Building Design +Construction - Scorecard*, n.d.; Environment and Urban Ministry (Turkey), n.d.

Table 2.5 shows the differences between the categories and their weightings of the selected GBRS. It can be seen that not one of the systems covers all of these categories, as they are all based on different local regulations and priorities in different aspects.

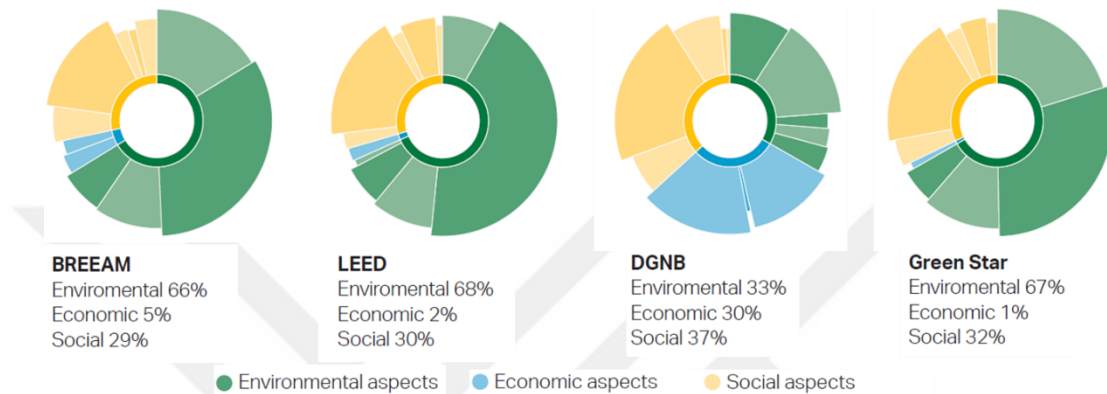


Figure 2.20 GBRS Aspects (Guldager Jensen et al., 2018) (Developed by author)

These categories are merged by Guldager Jensen et al. as environmental, economic, and social aspects, known as sustainability dimensions, in order to compare the GBRS, which can be seen in Figure 2.20 (Guldager Jensen et al., 2018). Figure 2.20 demonstrates that DGNB is more balanced compared to the other systems, as their economic aspects are overly low. What they lacked in the economic aspects, they made up for in the environmental aspects. Due to this situation, comparing these systems becomes more difficult.

2.4 Circular Design Assessments

In addition to the increase of circular buildings, computer-based technologies have also started to merge with circular design as part of the design process. These tools can be used for analyses, testing, and modeling in different stages of the design. Çetin et al. (2022) address the relationship between digital technologies and circular buildings. The paper shows that digital tools can be used in different phases of

circular design while corresponding to different circular strategies. The linkages between these tools can be seen in Figure 2.21. It can be seen that these technologies are described in different linkages in literature by different authors. Çetin et al. (2022) note that BIM and MP appear to be the most widely used technologies in the circular built environment in both academics and practice.

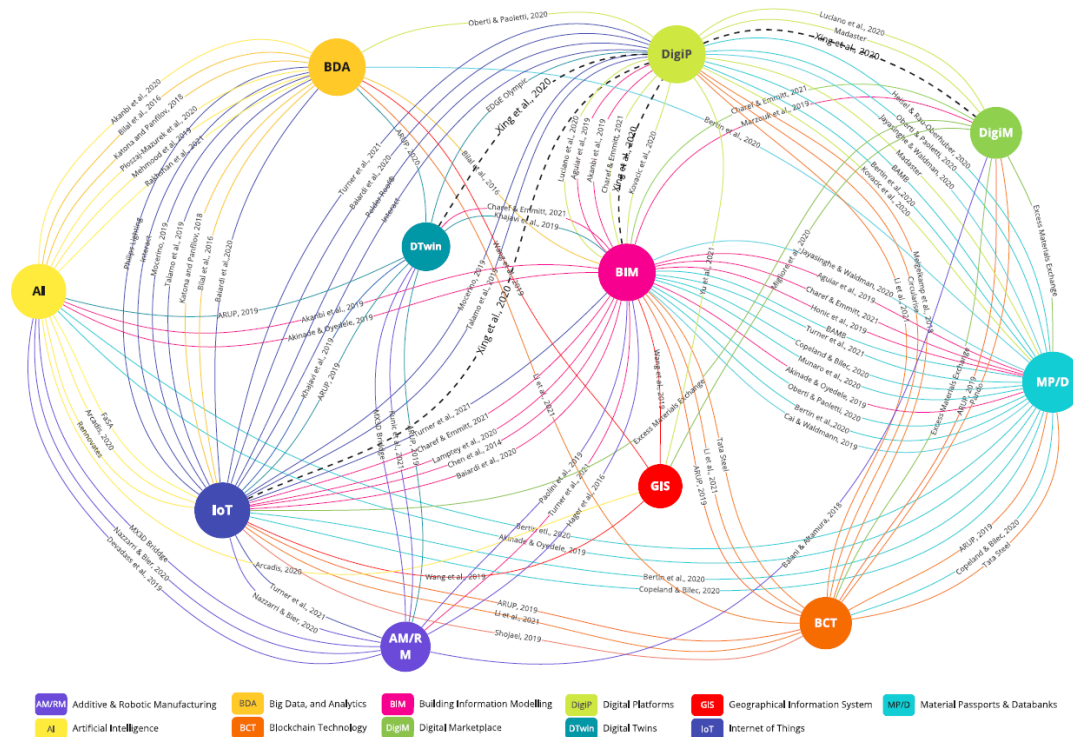


Figure 2.21 Connection between Digital Technologies (Çetin et al., 2021)

The existing design support tool for circular buildings is researched by Cambier et al. (2020). The paper examines the tools with the circular design stages and the needs of the users. The study states that the available tools do not entirely resolve the needs of designers, and some features are insufficient or unnecessary. The examined tools and their places in the design phase can be seen in Figure 2.22. The paper states that these tools and the study shows different meanings to practitioners, developers, and researchers (Cambier et al., 2020). For practitioners, it shows the existing tools and their area of usage; for developers, it reveals which phase of design is covered and the parts that need new tools; for researchers, it displays the framework that shows the supply and demand in this field (Cambier et al., 2020).

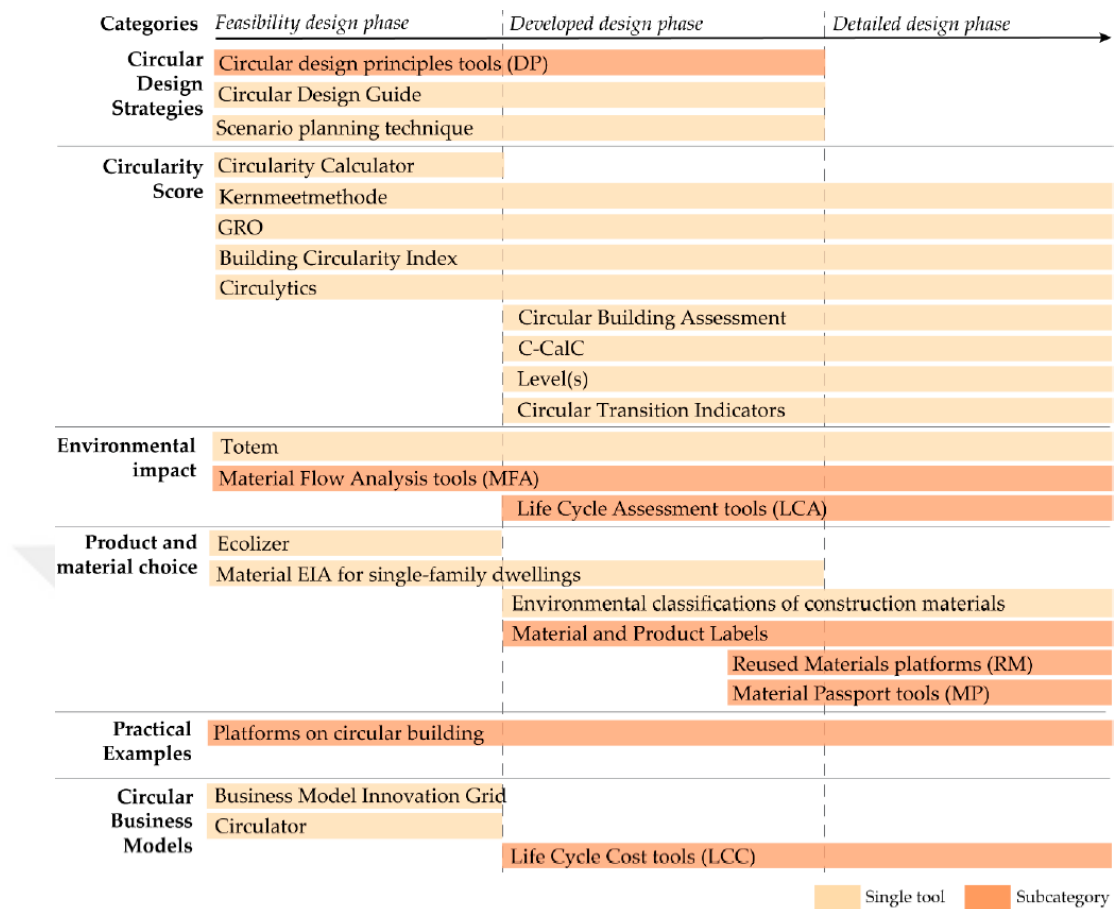


Figure 2.22 Circular Design Tools (Cambier et al., 2020)

As seen in Figure 2.22, these tools can be used in different parts of the design phases. These tools are used in circular design and buildings to increase accuracy, facilitate interdisciplinary connections, and reduce the time needed. This part will explain some of these tools; material passports, BIM, and LCA tools in the concept of circular buildings and connections with the GBRs.

2.4.1 BIM and LCA Tools

As mentioned, BIM and LCA tools are discussed in the context of circular design and its relationship with the GBRs. ARUP explains BIM as “an open-source digital 3D modelling tool that communicates information relating to all phases of an asset’s lifecycle” (2016, p. 89). The relationship between BIM and certification systems has

been studied by many sources (Jalaei & Jrade, 2014; Romano & Riediger, 2020; Seyis et al., 2021; Veselka et al., 2020). Romano and Riediger show the usage of BIM with the energy category of the certification systems and demonstrate that “BIM can assist 100% of DGNB's energy-related criteria, 60% in the case of BREEAM and dropping to 55% for LEED certification” (2020, p. 3). The paper shows that even with some disadvantages, such as time and cost, implementing BIM in the certification systems can create an automated process where the certifications' requirements are supported (Romano & Riediger, 2020).

Jalaei and Jrade (2014) proposed a flowchart that implements BIM to LEED, exploring energy and daylight, sustainability strategies, and green building rating strategies. It shows that the implementation of BIM to the certification systems created a process that is partly automated where some manual inputs and different analysis tools are required.

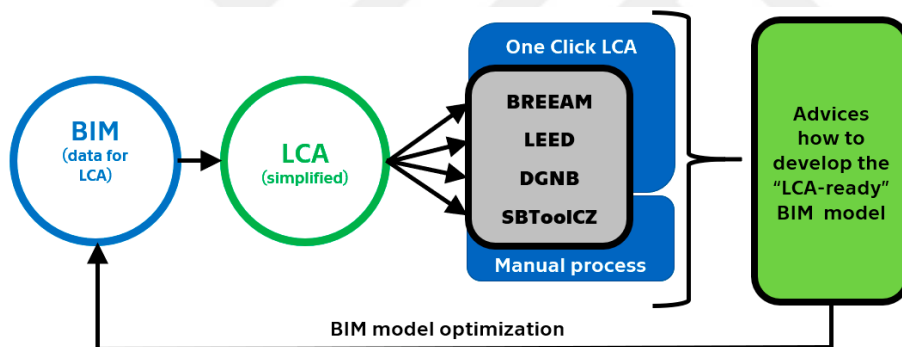


Figure 2.23 Workflow of implementing BIM with LCA to the Certification Systems (Veselka et al., 2020)

Honarvar et al. (2022) show the integration of the BIM, LCA, CE, and material selection into the building system, as seen in Figure 2.24. The paper shows that the system can be used for new and old houses, which demonstrates that combining these systems in the building model strengthens the construction and environment relationship.

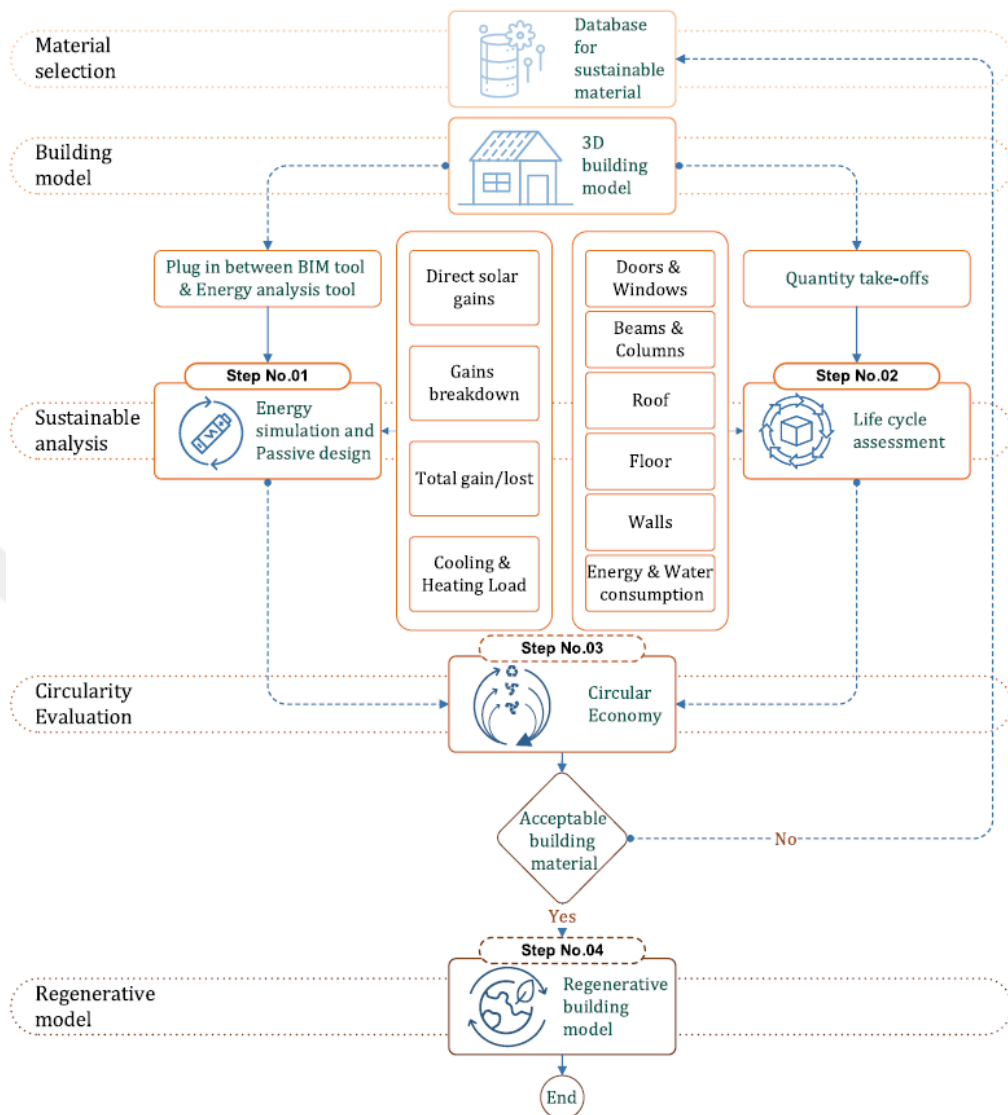


Figure 2.24 Integrating BIM and LCA into the Design Process (Honarvar et al., 2022)

Veselka et al. (2020) note that BIM can be used in the workflow, and with the LCA, a building model can be developed for the certification systems. The paper continues that One Click LCA, a software that can collect data from BIM, calculate environmental impacts, and guide various certification systems, is used to apply LCA to certification systems. It is noted that the material information should be used in BIM in detail to achieve an automated LCA workflow (Veselka et al., 2020). The proposed workflow can be seen in Figure 2.23.

Kovacik et al. (2019) stated that implementing BIM, LCA, and MP into an automated system has problems, such as the lack of information necessary for MP. Figure 2.25 shows the framework of these assessments combined in a project where the life cycles of the building can be seen.

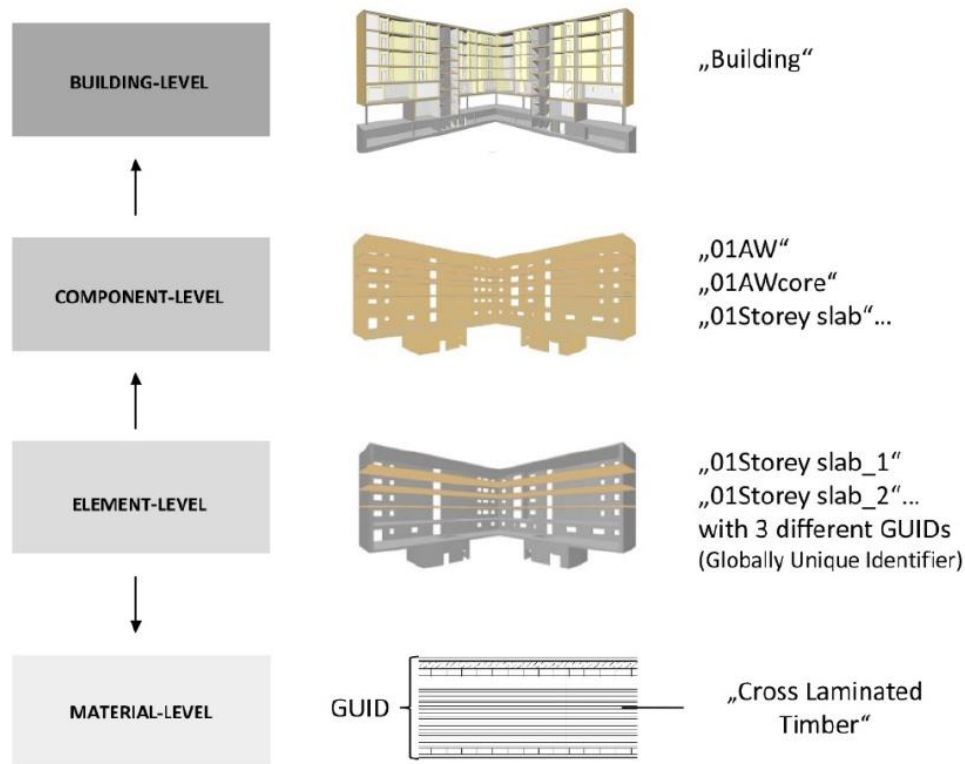


Figure 2.25 BIM, LCA, and MP combined (Kovacik et al., 2019)

Honic et al. show the relationship between BIM and MP on existing buildings with a case of end-of-life staged building (2021). The proposed workflow of the material passports used at the end-of-life phase with the information on the geometry, demolition, and materials. The paper shows that the BIM software allows the model to access the three dimensions, access information about the models, and transfer data between different applications. The article shows the different applications and how BIM and MP are integrated.

Honic et al. (2019) explained that due to the comparable BIM technique and data requirements for LCA and MP, LCA was incorporated into MP. Material passports and BIM help with the existing inefficient practices in the built environment. As

mentioned, a material passport collects the information and effects of materials used in the buildings in a digital format. These assessments can be used together to achieve a better workflow for the circular design.

2.5 Critical Review of Literature

Even though the concepts of circular design and building, GBRS, and circular design assessments are not new to the literature, it seems that there are still some gaps. It was observed that the terms and the frameworks of circularity used in the studies with different meanings. This causes confusion in the literature, as well as in practice. People who face these problems remain distant from approaching these issues, which leads to a lack of progress on circular buildings and design.

As mentioned, there are various GBRS developed in different countries, and for that, their categories and ratings differ from each other. These systems can be used internationally, and there can be buildings certified by different systems in one city. This leads to confusion due to a lack of understanding of their equivalence with respect to each other. For this reason, another problem faced in the literature is the lack of examples comparing GBRS with case studies. Although there are a few examples of multi-certified buildings, the comparison papers do not include these examples in their studies. These examples can give definite answers when comparing the GBRS as they show different results from different systems.

Even though the GBRS are evaluating the circularity and sustainability of a building, some studies have supported the hypothesis that not every building with green building certification is circular, and furthermore, there are a lot of circular buildings without any certifications. This shows a mismatch in the system, which should be studied further. The aim of making everything circular is seen as unrealistic since it would reduce the circularity of processes and results. Furthermore, it can be seen that in some cases, non-circular approaches can be more sustainable, which is discussed

further. ISO and SDG frameworks also show a linear process to a circular outcome, which creates mismatches.

The emerging view from this review shows that material is the key issue contributing to the gap between the GBRS and circularity. The weakest point in the GBRS is found in the materials issue, which is considered as the focus point of the thesis.



CHAPTER 3

MATERIALS AND METHODS

This chapter explains the methods and materials used in the thesis. Figure 3.1 shows the method of the research. Along with the literature review, two sets of keyword analysis was done. In order to find the results of practices, a website search was done. After these steps, the case studies were selected.

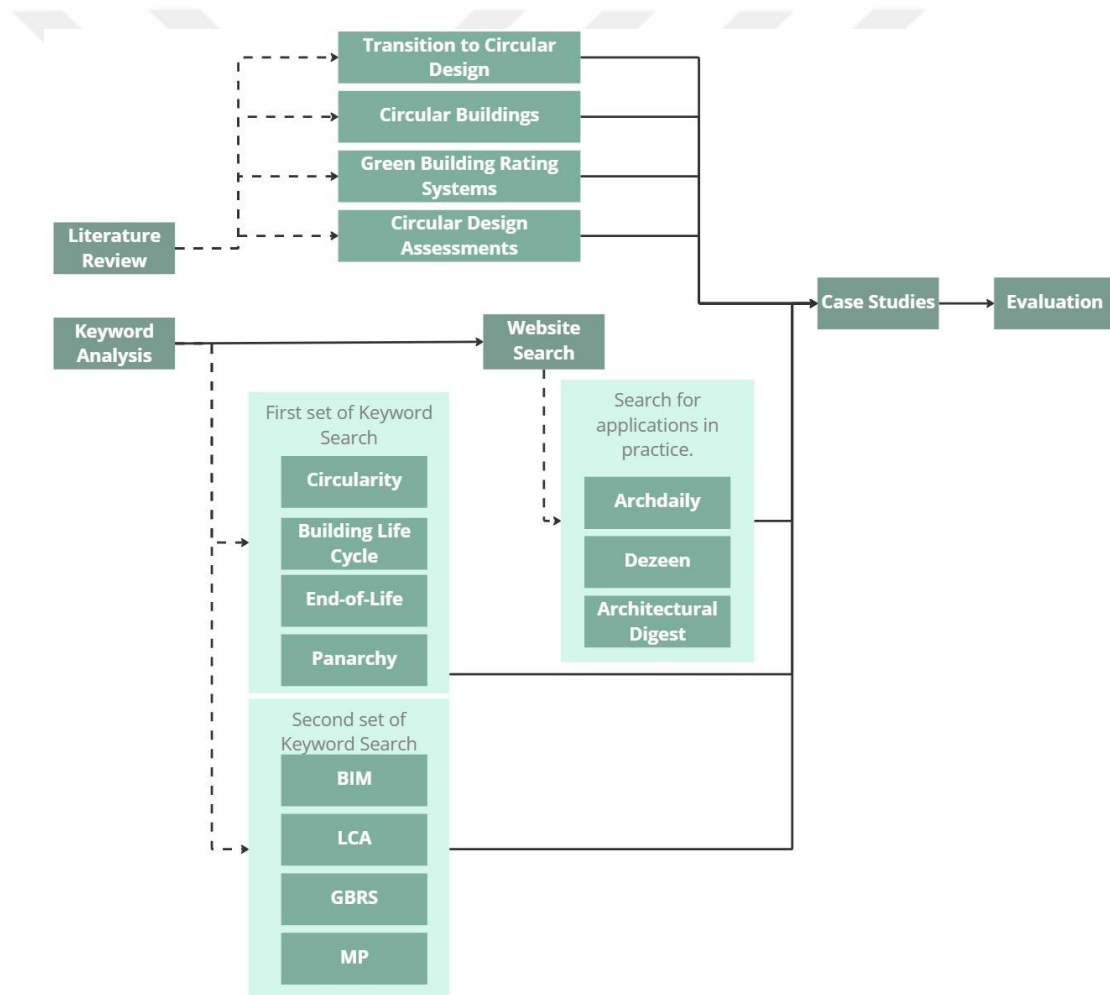


Figure 3.1 Method of the Research (Developed by author)

3.1 Keyword Analysis

Two sets of keyword analyses were made. The first set was related to the circular economy and the life stages of the building, and the second set was related to the circular design assessments and the GBRS. The keyword searches were done with Web of Science, and VosViewer was used for the visualizations.

- First Keyword Analysis

A keyword analysis is conducted with keywords related to the circular economy, life cycle assessments, and panarchy. The summary of the first keyword analysis can be seen in Figure 3.2

This analysis shows that the selected terms are increasing in academics. One of the problems faced is emerging of the out of topics. In order to prevent this, the most appeared terms are added as ‘not’. It can be seen that circular economy, LCA, sustainability, and BIM are the most frequently used keywords. It should be noted that terms related to the GBRS appeared in the results but did not occur enough to be visible in the visualization.

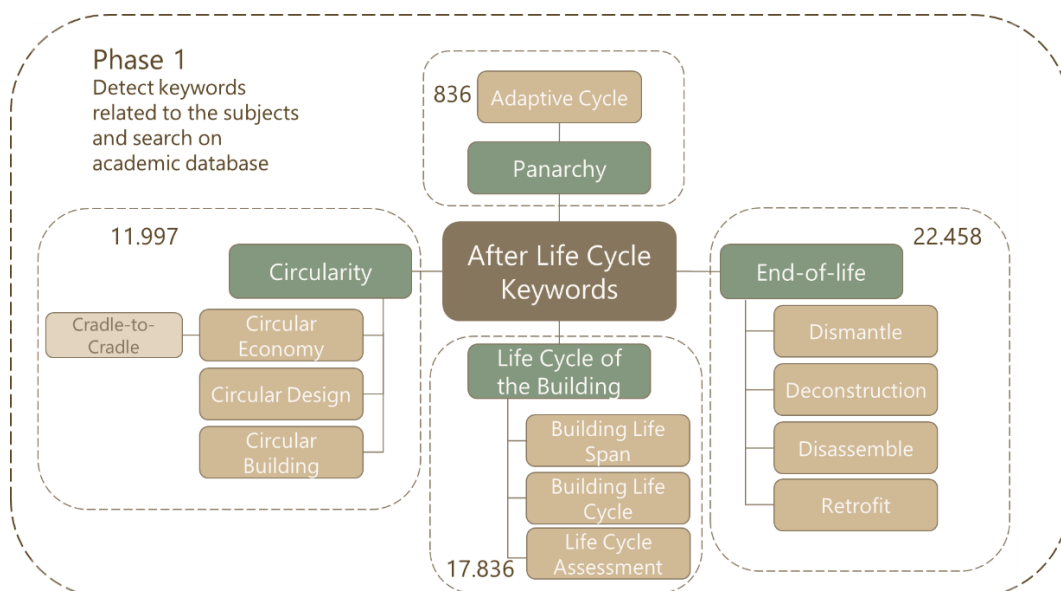


Figure 3.2 Summary of the First Keyword Analysis (Developed by author)

Since the intersection of these keywords does not give any results, the blue and orange boxes show the expanded intersection used in the analyses. In the general search, it can be seen that the papers have been published starting from 2003, while with the addition of ‘architecture’, the publishing years started from 2012.

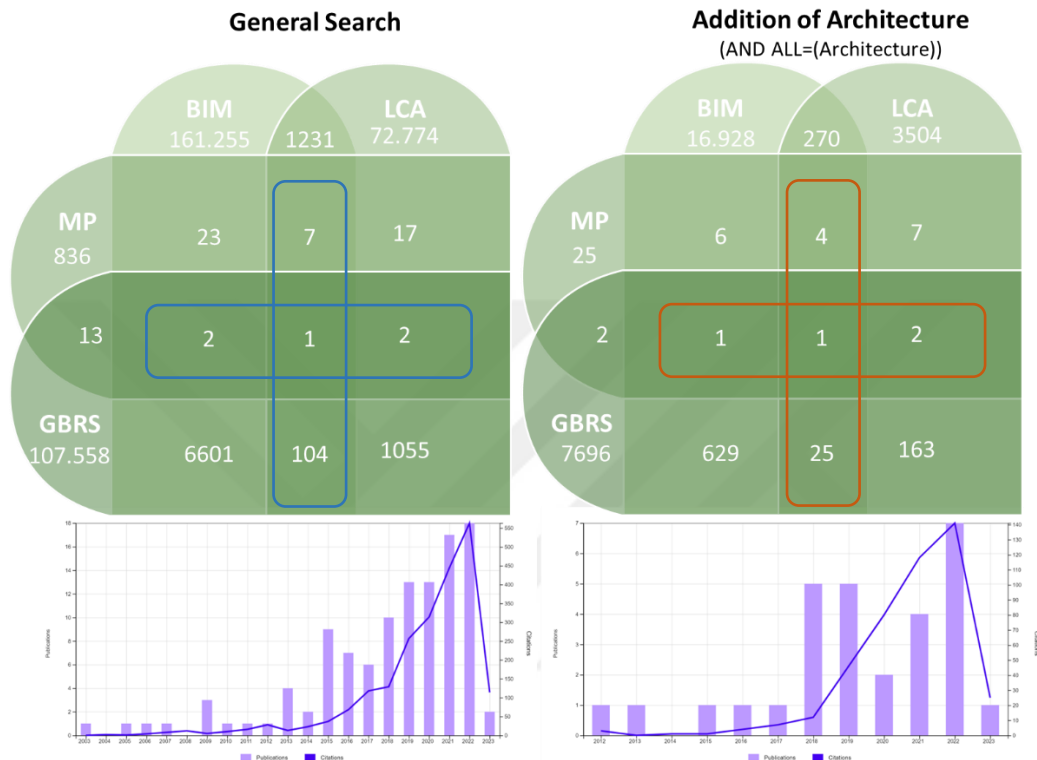


Figure 3.3 Keyword Analysis (Developed by author)

The intersected papers, as seen in the blue boxes in Figure 3.3, are used for the visualization of Figure 3.4. From the total of 111 papers, 416 keywords were gathered, 120 of them left unconnected. This visualization was done without the addition of ‘architecture’. It can be seen that BIM, LCA, sustainability, circular economy, and GBRS are the most frequently used terms. This search reveals that circular economy is not used as commonly as the first set of keyword searches.

Figure 3.4 shows the keyword analysis and their connections with each other. The selected papers can be seen in the orange boxes in Figure 3.3 and Table 3.1. From the selected 30 papers, 130 keywords were collected, and 48 of them were left unconnected.

It can be seen that BIM and LCA were used the most in those papers. The visualization of Figure 3.4 is the result of the addition of ‘architecture’, and the terms were searched as ‘all’. Figure 3.4 demonstrates that with these searches, terms such as circular economy, building circularity, and sustainability are among the results. As seen in Figure 3.4 a and b, it is visible that keywords related to carbon emission and footprint, sustainability, and specific types of certification systems appeared less with the addition of architecture.

Table 3.1 shows the bibliometric overview of the keyword search with the term ‘architecture’. It can be seen that most of the papers were released in recent years.

Table 3.1 Bibliometric Overview of the Selected Papers (Developed by author)

Ref	Authors	Article Title	Document Type	Author Keywords	Times Cited	Year
[1]	Chiu, CK; Chien, WY; Noguchi, T	Risk-based life-cycle maintenance strategies for corroded reinforced concrete buildings located in the region with high seismic hazard	Article	concrete structures; deterioration; seismic analysis; maintenance; risk	6	2012
[2]	Biswas, T; Wang, TH; Krishnamurti, R	From Design to Pre-Certification Using Building Information Modeling	Article	sustainable design rating system; building information model; sustainability assessment; certification	5	2013
[3]	Lee, S; Tae, S; Roh, S; Kim, T	Green Template for Life Cycle Assessment of Buildings Based on Building Information Modeling: Focus on Embodied Environmental Impact	Article	green template; building information modeling (BIM); life cycle assessment; embodied environmental impact; building	71	2015
[4]	Federico, F; Felice, SD	Integration between GBC Historic Building (R) and BIM: the methodological innovation for conservation project workflow	Article	BIM; GBC Historic BUILDING (R); Modeling; Preservation	0	2016
[5]	Maltese, S; Tagliabue, LC; Ceconi, FR; Pasini, D; Manfredi, M; Ciribini, ALC	Sustainability assessment through green BIM for environmental, social and economic efficiency	Proceedings Paper	BIM; Green BIM; sustainability; rating; BEM	29	2017
[6]	Seghier, TE; Ahmad, MH; Wah, LY; Samuel, WO	Integration Models of Building Information Modelling and Green Building Rating Systems: A Review	Proceedings Paper	Building Information Modelling (BIM); Green Rating System; Green Building Certification; Building Sustainability; Assessment	5	2018
[7]	Saldana-Marquez, H; Gomez-Soberon, JM; Arredondo-Rea, SP; Gamez-Garcia, DC; Corral-Higuera, R	Sustainable social housing: The comparison of the Mexican funding program for housing solutions and building sustainability rating systems	Article	Social housing; Building sustainability rating systems; Comparative approach; Housing program funding; Certification; Green building rating systems	28	2018
[8]	Charef, R; Alaka, H; Emmitt, S	Beyond the third dimension of BIM: A systematic review of literature and assessment of professional views	Review	Building Information Modelling (BIM); 4D; 5D; 6D; 7D; Dimension; Practitioners	85	2018

Table 3.1 (Continued)

Ref	Authors	Article Title	Document Type	Author Keywords	Times Cited	Year
[9]	Tagliabue, LC; Di Giuda, GM; Villa, V; De Angelis, E; Ciribini, ALC	Techno-economical Analysis based on a Parametric Computational Evaluation for decision process on envelope technologies and configurations	Article	Multicriteria evaluation; Building parametric performance; Cost optimality; Energy retrofit; Envelope technology optioneering	7	2018
[10]	Solis-Guzman, J; Rivero-Camacho, C; Alba-Rodriguez, D; Martinez-Rocamora, A	Carbon Footprint Estimation Tool for Residential Buildings for Non-Specialized Users: OERCO2 Project	Article	Life-cycle assessment; Carbon footprint; Construction materials; Non-specialized users; Estimation tool; Environmental impact assessment; Social awareness; Sustainability; Residential buildings	13	2018
[11]	Honic, M; Kovacic, I; Sibenik, G; Rechberger, H	Data- and stakeholder management framework for the implementation of BIM-based Material Passports	Article	Material Passport; Building Information Modelling; Data- and stakeholder management; Resources efficiency; Recycling	21	2019
[12]	Cao, Z; Liu, G; Duan, HB; Xi, FM; Liu, GW; Yang, W	Unravelling the mystery of Chinese building lifetime: A calibration and verification based on dynamic material flow analysis	Article	Building lifetime; Building stock; China; Dynamic material flow analysis; Calibration; Verification	31	2019
[13]	Lavagnaa, M; Bessi, A; Meneghelli, A; Moschini, P	The environmental dimension of detailed design. Experiences and future perspectives	Article	Integrated design; Building Information Modeling (BIM); Life Cycle Assessment (LCA); Green Building Rating Systems; Minimum Environmental Criteria (CAM) in Green Public Procurement (GPP)	1	2019
[14]	Moreno, LMV	Sustainable constructions, environmental impacts	Article	envelope in buildings; energy efficiency; durable materials; Life Cycle Assessment (LCA); certifications	0	2019
[15]	Edwards, RE.; Lou, E; Bataw, A; Kamaruzzaman, SN; Johnson, C	Sustainability-led design: Feasibility of incorporating whole-life cycle energy assessment into BIM for refurbishment projects	Article	Sustainability-Led Design; BIM; Refurbishment; Energy	43	2019
[16]	Pons-Valladares, O; Nikolic, J	Sustainable Design, Construction, Refurbishment and Restoration of Architecture: A Review	Review	building sustainability assessment systems (BSAS); green buildings; rating tools; life cycle assessment (LCA); multi-criteria decision making (MCDM); life cycle cost (LCC); building environment	17	2020
[17]	Cha, GW; Moon, HJ; Kim, YC; Hong, WH; Jeon, GY; Yoon, YR; Hwang, C; Hwang, JH	Evaluating recycling potential of demolition waste considering building structure types: A study in South Korea	Article	Demolition waste; Waste generation rate; Building structure; Recycling potential; Environmental effect; Economic value	15	2020
[18]	Zhang, N; Han, Q; de Vries, B	Building Circularity Assessment in the Architecture, Engineering, and Construction Industry: A New Framework	Article	building circularity assessment; material flow model; building circularity material passport; building circularity calculation method	7	2021
[19]	Tagliabue, LC; Cecconi, FR; Maltese, S; Rinaldi, S; Ciribini, ALC; Flammini, A	Leveraging Digital Twin for Sustainability Assessment of an Educational Building	Article	digital twin; dynamic checklist; sustainable BIM	31	2021
[20]	Wang, MZ	Ontology-based modelling of lifecycle underground utility information to support operation and maintenance	Article	Ontology; Semantic web; Information integration; Data interoperability; Underground utility; Operation and maintenance; Utility management; Decision support	2	2021

Table 3.1 (Continued)

Ref	Authors	Article Title	Document Type	Author Keywords	Times Cited	Year
[21]	Simhachalam, V; Wang, T; Liu, Y; Wamelink, H; Montenegro, L; van Gorp, G	Accelerating Building Energy Retrofitting with BIM-Enabled BREEAM-NL Assessment	Article	Building energy retrofitting; Building information modelling (BIM); Energy performance evaluation; BREEAM-NL; Energy transition; RACI matrix	1	2021
[22]	Caldas, LR; Silva, MV; Silva, VP; Carvalho, MTM; Toledo, RD	How Different Tools Contribute to Climate Change Mitigation in a Circular Building Environment?-A Systematic Literature Review	Review	Circular economy; Buildings; Life cycle assessment; Building information modeling; Materials passport; Virtual reality	1	2022
[23]	Jamoussi, B; Abu-Rizaiza, A; AL-Hajj, A	Sustainable Building Standards, Codes and Certification Systems: The Status Quo and Future Directions in Saudi Arabia	Review	buildings; sustainability; sustainable building; green building; assessment tools; construction; life cycle assessment	0	2022
[24]	Li, XJ; Xie, WJ; Xu, L; Li, LL; Jim, CY; Wei, TB	Holistic life-cycle accounting of carbon emissions of prefabricated buildings using LCA and BIM	Article	Prefabricated concrete building (PCB); Life cycle analysis (LCA); Building information modeling (BIM); Carbon footprint; Carbon emission strategy; Building energy conservation	8	2022
[25]	Gonzalez-Caceres, A; Karlshoj, J; Vik, TA; Hempel, E; Nielsen, TR	Evaluation of cost-effective measures for the renovation of existing dwellings in the framework of the energy certification system: A case study in Norway	Article	Energy Performance Certificate (EPC); Cost-effective; Renovation; Retrofitting; Model calibration; Holistic renovation; Life Cycle Cost (LCC)	3	2022
[26]	Schuetzenhofer, S; Kovacic, I; Rechberger, H	Assessment of Sustainable Use of Material Resources in the Architecture, Engineering and Construction Industry - a Conceptual Framework Proposal for Austria	Article	Circular economy; Sustainability evaluation; Waste management; Construction waste; Building demolition; Built environment	1	2022
[27]	Zhu, R; Wong, MS; Kwan, MP; Chen, M; Santi, P; Ratti, C	An economically feasible optimization of photovoltaic provision using real electricity demand: A case study in New York city	Article	Solar energy; Solar PV planning; Life cycle economic assessment; Techno-economic assessment; Building integrated photovoltaic; Geographical information science	6	2022
[28]	Hao, T; Sun, X; Ren, J	Construction and intelligent analysis of power grid physical data knowledge graph based on Internet of Things for power system	Article	Power system; Internet of things; Power grid physical data; Knowledge graph; Deep learning	0	2022
[29]	Jamoussi, B; Abu-Rizaiza, A; AL-Hajj, A	Sustainable Building Standards, Codes and Certification Systems: The Status Quo and Future Directions in Saudi Arabia	Review	Buildings; Sustainability; Sustainable building; Green building; Assessment tools; Construction; Life cycle assessment	0	2022
[30]	Marsh, E; Allen, S; Hattam, L	Tackling uncertainty in life cycle assessments for the built environment: A review	Review	LCA (Life cycle assessment); Embodied carbon; Environmental impact of buildings; Uncertainty analysis	0	2023

3.2 Research Materials

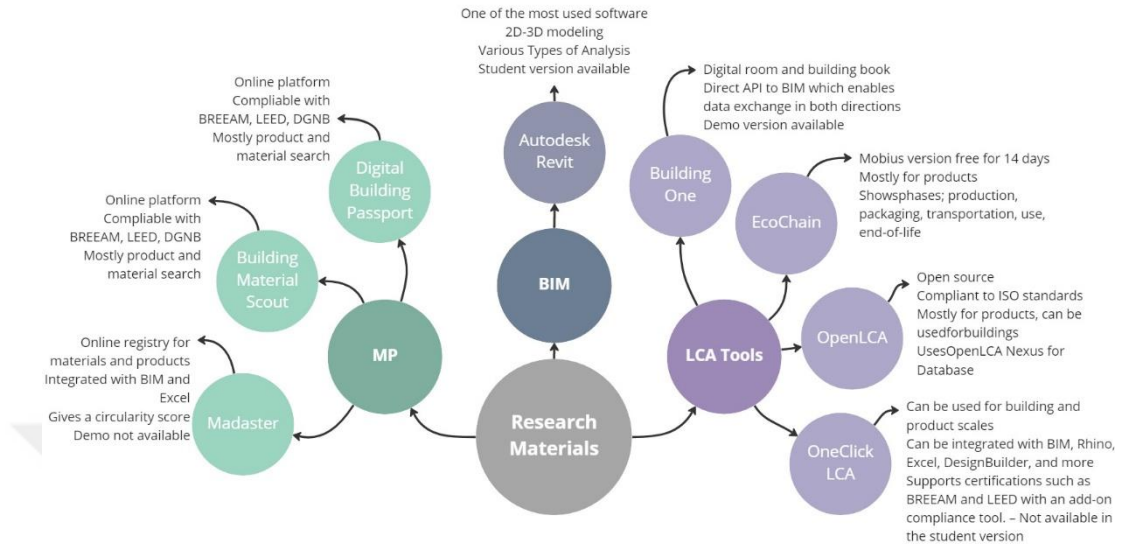


Figure 3.5 Research Materials (Developed by author)

Figure 3.5 shows the research materials. After the keyword analysis, case studies are used for the comparison of the GBRS. The categories and the ratings of the selected GBRS will be used to conduct the comparative studies, as well as the LCA tools to achieve a better result.

3.3 Critical View on the Circularity

Even though the main idea of circular economy and circularity is to have a non-linear approach to achieve a more sustainable environment, the existing frameworks and standards provide a linear approach to this process. As mentioned, there is a transition towards circularity in the built environment, which involves construction, materials, and waste. The materials are intended to have a closed-loop cycle, while there are examples of higher sustainable open-loop recycling options (Haupt et al., 2018). Haupt et al. state that circular economy concepts may result in creating more waste, and they need to be integrated with the LCA, which will result in an environmental increase in the cycles (2018).

General direction	Type of relationship	Short description Circularity/closed loop systems are seen as ...	Examples in literature	Graphical representation
Conditional	Conditional relation	One of the conditions for a sustainable system	Läpple, 2007 Rashid et al., 2013	$A \rightarrow B$
	Strong conditional relation	The main solution for a transformation to a sustainable system	Bakker et al., 2014 EMF, 2013b UNEP, 2006	$A \Rightarrow B$
	Necessary but not sufficient conditional relation	A necessary but not sufficient condition for a sustainable system	Nakajima, 2000	
Beneficial	Beneficial relationship	Beneficial in terms of sustainability, without referring to condition-ality or alternative approaches	European Commission, 2014	$+A \rightarrow +B$
	Subset relation (structured and unstructured)	One among several solutions for fostering a sustainable system	Allwood et al., 2012 Bocken et al., 2014 Evans et al., 2009 Garetti and Taisch, 2012 Seliger, 2007 Weissbrod and Bocken, 2017	
	Degree relation	Yielding a degree of sustainability with other concepts being more and/or less sustainable	OECD, 2009	
Trade-off	Cost-benefit/trade-off relation	Having costs and benefits in regard to sustainability, which can also lead to negative outcomes	Allwood, 2014 Andersen, 2007	
	Selective relation	Fostering certain aspects of sustainability but lacking others	Murray et al., 2015	

Figure 3.6 Type of Relationship Between Sustainability and Circular Economy (Geissdoerfer et al., 2017)

Geissdoerfer et al. (2017) note that there are some differences between sustainability and circular economy, with eight different relationship types, which can be seen in Figure 3.6. The paper continues that the most prominent is the idea of circularity seen as “a condition for sustainability, a beneficial relation, or a trade-off in literature” (Geissdoerfer et al., 2017, p. 767). Murray (2017) listed the limitations of the circular economy as; “confusion with semantics, and a lack of focus on social issues, followed by a critique of the Circular Economy’s potentially un-intended consequences and over-simplistic goals” (p. 375). The paper notes that sustainability has a social aspect, which is absent in the circular economy.

Another critical view can be done on the Circular Dutch economy by 2050, which intends to achieve a completely circular economy by 2050 (*Circular Dutch Economy 2050*, n.d.). The implementation of achieving to have a completely circular economy can result in reduced sustainability. Some of the barriers around a circular economy can be listed as neglected sustainability issues, such as social dimensions, relying on technology and innovation, which can result in increased consumption and waste, and economic issues (Corvellec et al., 2022; Ghisellini et al., 2016).



Figure 3.7 Timeline of Circular Dutch Economy 2050 (Retrieved from <https://www.government.nl/topics/circular-economy/circular-dutch-economy-by-2050> accessed on February 16, 2023)

These reviews showed that the mentioned limitations and mismatches are the results of the novelty of the circularity concept, varying and unclear principles, and the transition from the industry and economy to the built environment. As mentioned, the circular approaches have great potential in the context of sustainability and the environment, but they also have some negative effects. The concept of achieving a total circular economy, such as in the case of the Netherlands, can be seen as unreasonable. As stated in literature, some of the non-circular approaches have better sustainability; it is, therefore, unwise to advocate a purely circular economy. Furthermore, the available standards for circularity, such as ISO, are promoting a very linear approach to a nonlinear process. This results in a confusion in the process and the need for a better framework. It should be mentioned that the idea being expressed is not that circularity is not sustainable but rather that circularity is being imposed, other sustainable approaches are being disregarded, and a more precise framework is required.

3.4 Mismatch in the Certification Systems

Figure 3.8 shows the developments made in the fields of this research. It can be seen that interest in the research topic is increased over time. Even though developments started in the 1990s, the first GBRS in Turkey developed in 2013 with ÇEDBİK, which then changed into B.E.S.T. in 2019 (*B.E.S.T.*, n.d.). As seen in Figure 3.8, following their establishment, GBRS required new versions. This may be the result of shifting environmental factors, expansion of their intended use, and the addition of ISO and building codes.

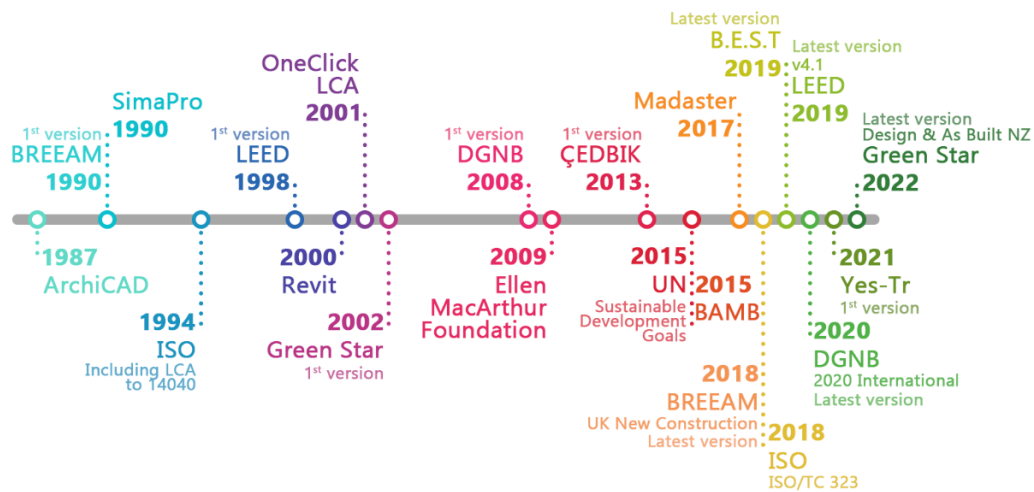


Figure 3.8 Timeline of the Development (Adapted from Pedro et al., 2019) (Developed by author)

As mentioned before, every GBRS have their own rating categories and scores, which complicates the process of comparing the certifications. Reed et al. (2009) state that there are three major problems when facing the GBRS: the need for a global comparison set to eliminate mismatch, to take into account the characteristics of countries, and the increasing variety of buildings handled. Figure 3.9 shows the research made by Pedro et al. (2019) about the gaps in academics in the field of urban sustainability; it can be seen that these gaps are also visible in the built environment. The paper also shows that integrating computer-based models with rating systems can be considered a gap in this field (Pedro et al., 2019).

Gaps identified	% of Papers
G1 Lack of consensus on sustainability definition and concepts	10%
G2 Overlapping and incoherent distribution of criteria and weighting	18%
G3 Need for widening the scope by including evaluation criteria on socioeconomic conditions, mobility and walkability, disaster resilience and climate change, cultural factors	26%
G4 Little flexibility for local adaptation, particularly for developing countries	28%
G5 Need to adapt the assessment systems for urban regeneration projects	11%
G6 Regulatory bodies involvement and participation	18%
G7 Need for widening the scale of assessment	9%
G8 Integration of the NSA with computer-based models	6%

*total number of papers analyzed: 124

Figure 3.9 Gaps in the GBRS (Pedro et al., 2019)

Hamedani and Huber (2011) state that the weight of the criteria, minimum scores, and rating levels are the major differences in the GBRS. The paper notes that between BREEAM, LEED, and DGNB; BREEAM uses the most labels, DGNB has stricter rules, while LEED seems simplest (2011). Pedro et al. note that getting a high score on a GBRS does not mean it can be obtained in another system (2019). This shows that depending on the certification, the same project could get different scores and ratings. The different scores in GBRS can be seen in Figure 3.10

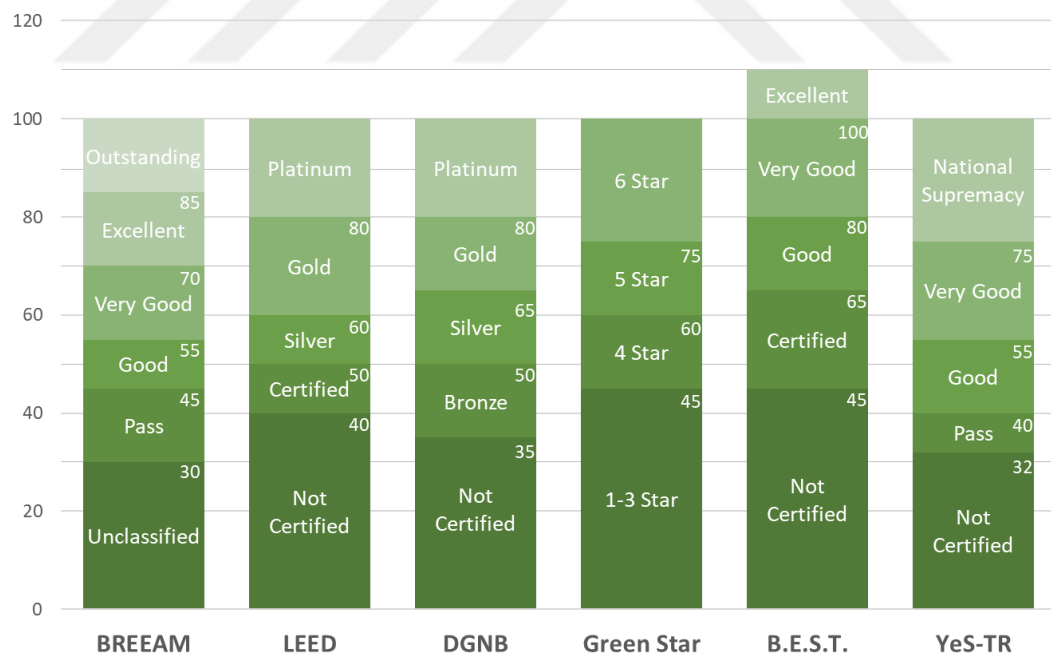


Figure 3.10 Selected GBRS Scores. Data collected from Environment and Urban Ministry (Turkey), n.d.; <https://bregroup.com/>, <https://cedbik.org/>, <https://www.dgnb.de/en/>, <https://www.usgbc.org/leed>, and <https://new.gbca.org.au/> (Developed by author)

These scores will be used along with their categories and weighting in the case studies to compare these systems. Figure 3.10 shows the different ranges of scores in these systems. The number of ratings and changes in the ranges leads to a problem, as the received point can be equal to different ratings in different systems. In order to analyze this issue, multi-certified buildings are selected as case studies.

- Merged System: GBRS, LCA, and Circularity Principles

As mentioned before, there is a proposed merged system of GBRS, LCA, and circularity principles. According to Braulio-Gonzalo et al. (2022), there are deficiencies in GBRS and LCA, and there is a need for confluence. The paper continues that GBRS and LCA focus on different scales in the built environment and that there is a lack of study about GBRS with sustainability and the life cycles of the building.

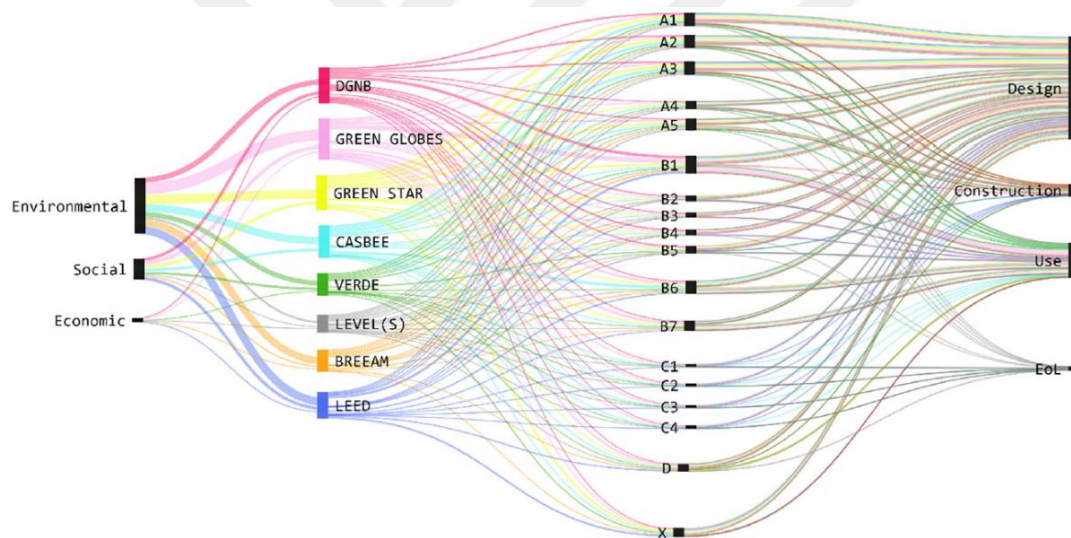


Figure 3.11 Indicators and sustainability dimensions of the GBRS (Braulio-Gonzalo et al., 2022)

Figure 3.11 shows the sustainability dimensions of GBRS within the EN 15978 boundary, which can be seen in Figure 3.12. As seen, the building life cycle is divided into product, construction, use, and end-of-life stages by the standards. Some of the 10R strategies can be seen in these stages.

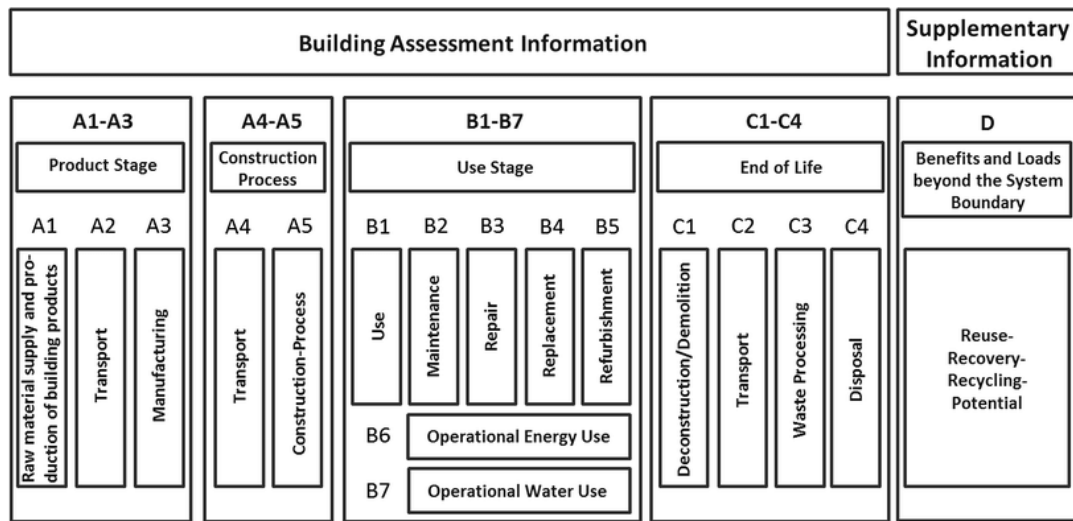


Figure 3.12 Life Cycle Stages of Buildings in EN 15978 (British Standards Institution, 2011)

Figure 3.13 shows the selected GBRS with their aspects and 9R circularity principles. It should be mentioned that ‘recover’ is used as ‘reclaim’ in many of the examples instead of incarnation for energy recovery. It can be seen that ‘reduce’ has the most input even though ‘refuse’ is the most recommended principle as it avoids waste instead of decreasing it. Similarly, ‘recycle’ is also used a lot in GBRS. One of the reasons for this is the popularity of the word, as it is one of the most known and repeated principles, yet it is the second least recommended one.

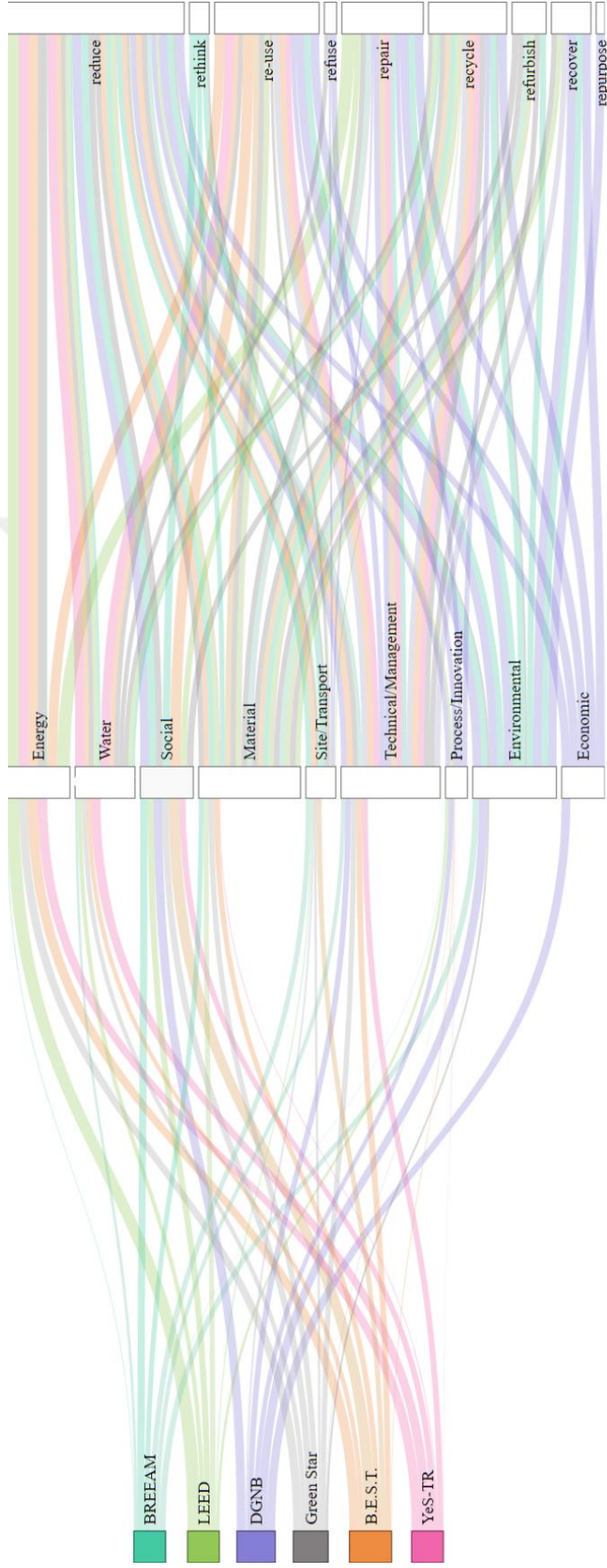


Figure 3.13 GBRS with Circularity Principles (Developed by author)

3.5 The Mention of Material in the Certification Systems

This study focuses on the material aspects of the certification system in order to achieve a better comparison between the systems. Three leading GBRS are used for the comparison: BREEAM, DGNB, and LEED. Table 3.3 shows the issues that focus on materials and their effects on the calculation process in different versions of the certification systems, while Table 3.2 shows the version that focuses on the new constructions and buildings in order to make a comparison.

Table 3.2 Mention of Material in the new building versions of GBRS (Adapted from BRE Global, 2021; DGNB System, 2020; U.S. Green Building Council, 2022) (Developed by author)

	BREEAM	DGNB	LEED
Version	International New Construction V6	New Construction, Buildings Version 2020 International	Building Design + Construction v4.1
Category	Materials	Environmental Quality Technical Quality Process Quality	Materials and Recycling
Issues	• Mat 01 Life cycle impacts • Mat 02 Hard landscaping and boundary protection • Mat 03 Responsible sourcing of construction products • Mat 04 Insulation • Mat 05 Designing for durability and resilience • Mat 06 Material efficiency	• ENV1.2 Local environmental impact • ENV1.3 Sustainable resource extraction • TEC1.6 Deconstruction and recycling • PRO1.4 Sustainability aspects in tender phase	• MR 1 Storage and Collection of Recyclables • MR 2 Construction and Demolition Waste Management Planning • MR 3 PBT Source Reduction – Mercury • MR 4 Building Life-Cycle Impact Reduction • MR 5 Building Product Disclosure and Optimization – EPD • MR 6 Building Product Disclosure and Optimization – Sourcing of Raw Materials • MR 7 Building Product Disclosure and Optimization – Material Ingredients • MR 8 PBT Source Reduction – Mercury • MR 9 PBT Source Reduction – Lead, Cadmium, and Copper • MR 10 Furniture and Medical Furnishings • MR 11 Design for Flexibility • MR 12 Construction and Demolition Waste Management
Total Issues	6	4	12
Category Weightings	• Non-residential • Fully fitted 13.00% • Shell only 18.41% • Shell and core 14.67% • Single residential dwellings • Partially fitted 13.98% • Fully fitted 13.29% • Multiple residential dwellings • Partially fitted 13.21% • Fully fitted 12.50%	• Environmental quality 22.5% • Technical Quality 15% • Process Quality 12.5% • ENV1.2 4.7% (Shopping Center 4.5% Assembly Buildings 5.0%) • ENV1.3 2.4% (Shopping Center 2.3% Assembly Buildings 2.5%) • TEC1.6 2.5% (Consumer Market 2.9% Shopping Centre 2.9% Department Store 2.9% Logistics 2.7% Production 2.7% Assembly Buildings 2.6%) • PRO1.4 1.6%	Credits (Total 110 Possible Points) • New Construction 13 • Core and Shell 14 • Schools 13 • Retail 13 • Data Centers 13 • Hospitality 13 • Healthcare 13

Note: The latest versions of the GBRS are selected in the context of new constructions and buildings.

The average weighting of BREEAM is 14.15, DGNB is 16.66, and LEED is 13.14; the calculation was made with the versions mentioned in Table 3.2. It should be mentioned that the calculation of LEED was made with points out of 110, as the system does not refer to any weighting. As mentioned, Table 3.3 shows the most recent versions of BREEAM, DGNB, and LEED. It can be seen that while BREEAM and LEED have categories that are specifically for materials, DGNB treats this subject in different categories. BREEAM includes a *Materials* category, while LEED has a *Materials and Recycling* category; in contrast, DGNB covers material-related issues within its *Environmental*, *Technical*, and *Process Quality* categories. Of these categories, LEED has 36, BREEAM has 14, and DGNB has 8 issues in total that focus on the materials. While the number is higher than the other certification systems, it can be seen that many of the issues are slightly different from each other as the version changes. Another reason for this is the LEED category: materials and recycling. This situation has led to recycling-related issues located in this category. An example of those mentioned can be shown;

- Construction and Demolition Waste Management Planning
- Construction and Demolition Waste Management
- Construction Waste Management
- Construction and Demolition Waste Management

It can be seen that LEED alters the issues according to the requirements of the version of the certification, resulting in a higher number of issues related to materials.

Table 3.3 Mention of Material in GBRS (Adapted from *BREEAM*, n.d.; *DGNB*, n.d.; *LEED*, n.d.) (Developed by author)

BREEAM			
International New Construction V6	Category	Materials	
	Issue	Mat 01 Life cycle impacts Mat 02 Hard landscaping and boundary protection Mat 03 Responsible sourcing of construction products Mat 04 Insulation Mat 05 Designing for durability and resilience Mat 06 Material efficiency	
	Credits	Mat 01 Up to 6 credits Mat 02 N/A Mat 03 4 Mat 04 N/A Mat 05 1 Mat 06 1	
	Category Weightings	Non-residential = Fully fitted 13.00% Shell only 18.41% Shell and core 14.67% Single residential dwellings = Partially fitted 13.98% Fully fitted 13.29% Multiple residential dwellings = Partially fitted 13.21% Fully fitted 12.50%	
International Refurbishment and Fit-out 2015	Category	Materials	
	Issue	Mat 01 Life cycle impacts Mat 02 Hard landscaping and boundary protection Mat 03 Responsible sourcing of materials (RSM) Mat 04 Insulation Mat 05 Designing for durability and resilience Mat 06 Material efficiency	
	Credits	Mat 01 Up to 6 credits Mat 02 0 Mat 03 4 Mat 04 1 Mat 05 1 Mat 06 1	
	Category Weightings	Core 12.50% Part 1 (Fabric and Structure) 15.60% Part 2 (Core Services) 5.40% Part 3 (Local Services) 5.30% Part 4 (Internal Design) 19.30% Part 1 and 2 13.40% Part 3 and 4 13.70%	
In-Use V6 International	Commercial	Category	Part 1 Asset Performance: Resources Resilience
		Issue	Rsc 03 Resources inventory Rsc 04 Future adaptation Rsl 04 Durable and resilient features
		Credits	Rsc 03 4 Rsc 04 4 credits +1 Exemplary Rsl 04 4
		Category Weightings	Part 1 Asset Performance: Resources 13% Resilience 13%
	Residential	Category	Part 1 Asset Performance: Resources Resilience
		Issue	Rsc 03 Resources inventory Rsl 04 Durable and resilient features
		Credits	Rsc 03 4 Rsl 04 4
		Category Weightings	Part 1 Asset Performance: Resources 10.5% Resilience 14.5%
Communities 2012	Category	Step 3: Resources and energy	
	Issue	RE 05 – Low impact materials: Sustainable materials Road construction materials	
	Credits	RE 05 – Low impact materials 6: Sustainable materials Up to 3 credits Road construction materials Up to 3 credits	
	Category Weightings	Resources and energy 21.6%	
Infrastructure: Projects International V6	Category	Resources	
	Issue	7.1 Strategy for resource efficiency 7.4 Circular use of construction products 7.5 Responsible sourcing of construction products	
	Credits	7.1 104 7.4 254 7.5 49 (Total credits 5000)	
	Category Weightings	Resources: Materials, including waste 16%	
DGNB			
New Construction, Buildings Version 2020 International	Category	Environmental Quality Technical Quality Process Quality	
	Issue	ENV1.2 Local environmental impact ENV1.3 Sustainable resource extraction TEC1.6 Deconstruction and recycling PRO1.4 Sustainability aspects in tender phase	
	Credits	ENV1.2 4 ENV1.3 2 TEC1.6 4 PRO1.4 3	
	Category Weightings	Environmental quality 22.5% Technical Quality 15% Process Quality 12.5% ENV1.2 4.7% (Shopping Center 4.5% Assembly Buildings 5.0%) ENV1.3 2.4% (Shopping Center 2.3% Assembly Buildings 2.5%) TEC1.6 2.5% (Consumer Market 2.9% Shopping Centre 2.9% Department Store 2.9% Logistics 2.7% Production 2.7% Assembly Buildings 2.6%) PRO1.4 1.6%	

Table 3.3 (Continued)

Renovation of Buildings Version 2022 International	Category	Environmental Quality Technical Quality Process Quality
	Issue	ENV1.2 Local environmental impact ENV1.3 Sustainable resource extraction TEC1.6 Ease of recovery and recycling PRO1.4 Sustainability aspects in tender phase
	Credits	ENV1.2 4 ENV1.3 2 TEC1.6 4 PRO1.4 3
	Category Weightings	Environmental Quality 22.5% Technical Quality 15% Process Quality 12.5% ENV1.2 4.7% (Shopping Center 4.5% Assembly Buildings 5.0%) ENV1.3 2.4% (Shopping Center 2.3% Assembly Buildings 2.3%) TEC1.6 2.5% (Consumer Market 2.9% Shopping Centre 2.9% Department Store 2.9% Logistics 2.7% Production 2.7% Assembly Buildings 2.6%) PRO1.4 1.6%
Buildings in Use Version 2020	Category	Environmental Quality
	Issue	ENV3-B Materials and Recycling
	Credits	Plan 15 Do 35 Check 15 Act 25 Evaluation of performance 10 Circular Economy Bonus - Closed material cycle 10 (Additional)
	Category Weightings	Environmental Quality 40% ENV3-B 5%
Districts Version 2020	Category	Environmental Quality Technical Quality
	Issue	ENV1.2 Pollutants and hazardous substances TEC2.2 Resource management
	Credits	ENV1.2 4 (Only for Industrial Sites) TEC2.2 2 (Commercial Areas 3 Industrial Sites 3)
	Category Weightings	Environmental Quality 20% Technical Quality 20% ENV1.2 2.6% (Only for Industrial Sites) TEC2.2 (Urban Districts, Business Districts 2.2% Event Areas 2.4% Commercial Areas 3.2% Industrial Sites 3.3%)
LEED v4.1		
Building Design + Construction	Category	Materials and Resources
	Issue	MR 1 Storage and Collection of Recyclables MR 2 Construction and Demolition Waste Management Planning MR 3 PBT Source Reduction – Mercury MR 4 Building Life-Cycle Impact Reduction MR 5 Building Product Disclosure and Optimization – EPD MR 6 Building Product Disclosure and Optimization – Sourcing of Raw Materials MR 7 Building Product Disclosure and Optimization – Material Ingredients MR 8 PBT Source Reduction – Mercury MR 9 PBT Source Reduction – Lead, Cadmium, and Copper MR 10 Furniture and Medical Furnishings MR 11 Design for Flexibility MR 12 Construction and Demolition Waste Management
	Credits	MR 1 Prerequisite MR 2 Prerequisite MR 3 Prerequisite (Only for Healthcare) MR 4 5 (Core and Shell 6) MR 5 2 MR 6 2 MR 7 2 MR 8 1 (Only for Healthcare) MR 9 2 (Only for Healthcare) MR 10 2 (Only for Healthcare) MR 11 1 (Only for Healthcare) MR 12 2
	Category Credits	New Construction 13 Core and Shell 14 Schools 13 Retail 13 Data Centers 13 Warehouses and Distribution Centers n/a Hospitality 13 Healthcare 13 Total 110 Possible Points
Interior Design + Construction	Category	Materials and Resources
	Issue	MR 1 Storage and Collection of Recyclables MR 2 Construction and Demolition Waste Management Planning MR 3 Long-Term Commitment MR 4 Interiors Life-Cycle Impact Reduction MR 5 Building Product Disclosure and Optimization – EPD MR 6 Building Product Disclosure and Optimization – Sourcing of Raw Materials MR 7 Building Product Disclosure and Optimization – Material Ingredients MR 8 Construction and Demolition Waste Management
	Credits	MR 1 Prerequisite MR 2 Prerequisite MR 3 1 MR 4 4 (Retail 5) MR 5 2 MR 6 2 MR 7 2 MR 8 2
	Category Credits	New Construction 13 Retail 14 Hospitality 13 Total 110 Possible Points

Table 3.3 (Continued)

Operations + Maintenance		Category	Materials and Resources
		Issue	MR 1 Purchasing Policy MR 2 Facility Maintenance and Renovations Policy MR 3 Waste Performance MR 4 Purchasing
		Credits	MR 1 Prerequisite MR 2 Prerequisite MR 3 8 (0 pts required) MR 4 1
		Category Credits	9 Total 100 Possible Points
Residential	Single family homes	Category	Materials and Resources
		Issue	MR 1 Certified Tropical Wood MR 2 Durability Management MR 3 Durability Management Verification MR 4 Environmentally Preferable Products MR 5 Construction Waste Management MR 6 Material Efficient Framing
		Credits	MR 1 Prerequisite MR 2 Prerequisite MR 3 3 MR 4 5 MR 5 2 MR 6 2
		Category Credits	12 Total 110 Possible Points
	Multifamily homes	Category	Materials and Resources
		Issue	MR 1 Storage and Collection of Recyclables MR 2 Construction and Demolition Waste Management Planning MR 3 Building Life-Cycle Impact Reduction MR 4 Environmentally Preferable Products MR 5 Construction and Demolition Waste Management
		Credits	MR 1 Prerequisite MR 2 Prerequisite MR 3 5 MR 4 6 MR 5 2
		Category Credits	13 Total 110 Possible Points
Cities and Communities	New and developing cities and communities	Category	Materials and Resources
		Issue	MR 1 Construction and Demolition Waste Management MR 2 Solid Waste Management MR 3 Organic Waste Treatment MR 4 Recycling Infrastructure MR 5 Responsible Sourcing for Infrastructure MR 6 Smart Waste Management Systems
		Credits	MR 1 Prerequisite MR 2 Prerequisite MR 3 2 MR 4 5 MR 5 2 MR 6 2
		Category Credits	Cities 11 Communities 11 Total 110 Possible Points
	Existing cities and communities	Category	Materials and Resources
		Issue	MR 1 Solid Waste Management MR 2 Waste Performance MR 3 Special Waste Streams Management MR 4 Responsible Sourcing for Infrastructure MR 5 Material Recovery MR 6 Smart Waste Management Systems
		Credits	MR 1 Prerequisite MR 2 Prerequisite (Cities 4 Community 5) MR 3 1 MR 4 2 MR 5 1 (Community n/a) MR 6 2
		Category Credits	Cities 10 Communities 10 Total 110 Possible Points

Table 3.3 includes five versions of BREEAM and LEED and four versions of DGNB. An overview of Table 3.3 is shown in Figure 3.14. Noticeably, the total weightings are the highest in BREEAM, as the category weightings divide the most. From this figure, the average weightings of the materials mentioned in the certifications are calculated as BREEAM 14.99, DGNB 19.99, and LEED 11.59. It can be seen that DGNB has the highest number of weightings and LEED has the least, which can imply that the level of material requirements included in the system appears to correspond to an increase in difficulty.

CHAPTER 4

CASE STUDIES

As mentioned before, various certification systems have different criteria and rating systems. The current system has various gaps when it comes to defining whether the certified building is circular or not. For this reason, the main aim of this study is to clearly show the gaps between the rating systems, together with the circularity principles. In order to find mismatches in these systems, buildings with multiple certifications and green buildings without a certification are searched. Figure 4.1 shows the methodology of the case studies and the selection process. First, multi-certified buildings, circular buildings without certifications, and AIA COTE Top Ten Award recipients without certifications will be listed; following, the filtered case studies will be elaborated. Lastly, the comparison and evaluation of the selected case studies will be shown.

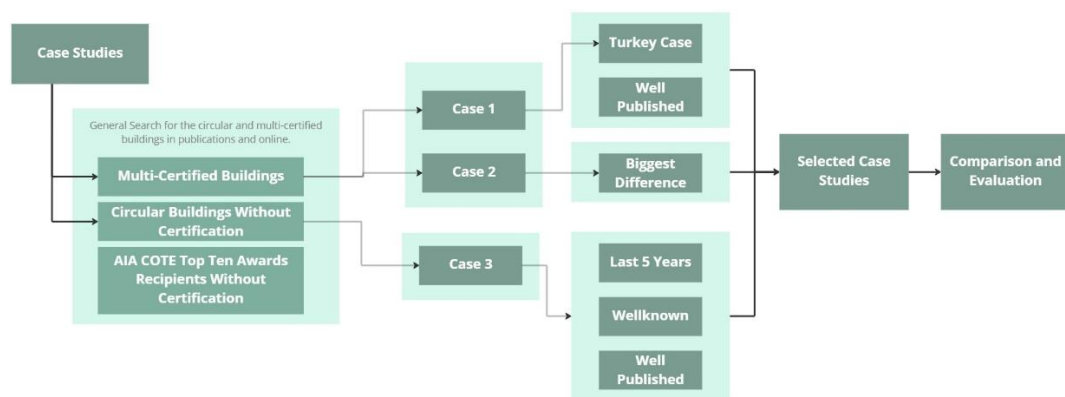


Figure 4.1 Methodology of the Case Studies (Developed by author)

- **Multi-Certified Buildings**

In order to find multi-certified buildings, literature, certification databases, and GBIG (Green Building Information Gateway) website searches were done. The general search was filtered with the buildings with greater differences. The selection

of these cases is made with literature and website research. For the literature research that mentioned buildings with multiple certifications, Assefa et al. (2022), Suzer (2019), and Penny (2012) are found. Further research was done on the websites of the GBRS and The Green Building Information Gateway, cross-referencing the projects to find the multi-certified projects (<https://bregroup.com/>, <https://cedbik.org/>, <https://www.dgnb.de/en/>, <https://new.gbca.org.au/>, <https://www.gbig.org/>, <https://www.usgbc.org/leed>, and <https://learn.kaiterra.com/en/resources/6-notable-projects-rated-platinum-by-the-well-standard>). It should be noted that the references that mention multi-certified buildings were observed to be insufficient.

Table 4.1 (Continued)

	6 BNP Paribas Luxembourg, Luxembourg 2016 https://www.sgigroupe.com/siege-de-la-bgl-bnp-paribas/				
	BREEAM	International 2009 Europe Commercial: Offices	2017	71.3%	Excellent
	DGNB	New Construction Offices, Version 2010	2018	76.4%	Gold
	HQE	n/a	2016	n/a	Exceptional
	7 Challenger Guyancourt, France 1988 (Renovation in 2008-2014) https://www.systemair.com/pe/about-us/references/bouygues-challenger/				
	BREEAM	International 2009 Europe Commercial: Offices	2014	88.5% Stage: Final	Outstanding
	LEED	LEED BD+C: New Construction v3 - LEED 2009	2012 2013 2014	89-Triangle Nord 90-Triangle Sud 91-Batiment principal	Platinum
	HQE	n/a	2014	n/a	Exceptional
	8 Concept Tower Warsaw, Poland 2012 https://cpipg.com/en/portfolio/concept-tower				
	BREEAM	International 2009 Europe Commercial: Offices	2014	33.4%	Pass
	LEED	LEED BD+C: Core and Shell v3 - LEED 2009	2016	73	Gold
	9 Discovery Building Madrid, Spain 2018 http://88designbox.com/architecture/discovery-building-by-estudio-lamela-2164.html				
	BREEAM	ES In-Use Part 1 ES In-Use Part 2	2020-2021 2021	70.02% 86.64%	Excellent Outstanding
	LEED	LEED 2009 Core and Shell	2018	81	Platinum
	10 ENOVOS Luxembourg, Luxembourg 2014 https://www.archdaily.com/561234/enovos-luxembourg-headquarter-jim-clenes-atelier-d-architecture-et-de-design				
	BREEAM	International 2009 Europe Commercial: Offices	2016	57.3%	Very good
	HQE	n/a	2016	n/a	Exceptional

Table 4.1 (Continued)

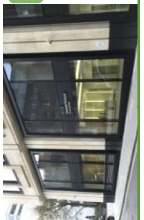
	11	ERKE Green Academy Istanbul, Turkey 1980s (Renovation in 2013) https://www.arkiv.com.tr/proje/erke-green-academy/297	BREEAM	International 2009 Europe Commercial: Offices	2015	67%	Very good
			LEED	LEED BD+C: New Construction v3 - LEED 2009	2013	82	Platinum
	12	Hewlett Packard Enterprise London Office London, United Kingdom https://www.abpm.com/hpe_london	BREEAM	Offices 2008	2014	70.6%	Excellent
			LEED	LEED ID+C: Commercial Interiors v3 - LEED 2009	2016	84	Platinum
	13	Höfe am Brühl Leipzig, Germany 2013 https://www.heinze.de/architekturobjekt/hoefe-am-bruehl/12574794	BREEAM	DE In-Use Part 1 BREEAM DE In-Use 2013 Part 1	Valid Until: 2023	85.4%	Outstanding
				DE In-Use Part 2 BREEAM DE In-Use 2013 Part 2	Valid Until: 2023	87.29%	Outstanding
			DGNB	New Construction Retail Buildings	2012	81,8%	Platinum
	14	International Commerce Centre Hong Kong, China 2010 https://www.archdaily.com/250681/international-commerce-centre-kpf	BREEAM	In-Use International 2015 Part 2 - Management Performance	Valid Until: 2023	85.4%	Outstanding
			LEED	LEED O+M: Existing Buildings v4.1 - LEED v4.1	2022	87/100	Platinum
	15	IZD Tower Wien, Austria 2001 https://www.mischek-zlat/buerogewerbe-data/izd-tower%2C-wagramer-stra%C3%9Fe-19%2C-1220-wien	DGNB	Existing Building Offices	2012	80,7%	Gold
			LEED	LEED O+M: Existing Buildings v3 - LEED 2009	2012	65	Gold
				LEED O+M: Existing Buildings v4 - LEED v4	2021	64	Gold

Table 4.1 (Continued)

	16 JLL Moscow Office Moscow, Russia 2012 (Closed) https://salimus.com/portfolio-items/ru-jll/	International 2009 Europe Commercial: Offices	2013	47.76%	Good
		LEED ID+C: Commercial Interiors v3 - LEED 2009	2013	62	Gold
	17 JLL Shanghai Office Shanghai, China 2017 https://officesnapshots.com/2017/07/04/jll-offices-shanghai/	LEED ID+C: Commercial Interiors v4 - LEED v4	2018	92	Platinum
		WELL v1	2017	n/a	Platinum
	18 Johnson Controls Shanghai, China 2017 https://www.gensler.com/projects/johnson-controls-headquarters-asia-pacific	LEED	2017	n/a	Platinum
		LEED O+M: Existing Buildings v4 - LEED v4	2017	n/a	EDGE ADVANCED
		EDGE	2017	n/a	Three Star Certification
		China Green Building Design Label	2017	n/a	
	19 Marquette Plaza Minnesota, United States 1972 (renovation in 2002) https://sah-archipedia.org/buildings/MN-01-053-0045	Energy Star Office	2011 2016 2018 - 2021	99 95 100 - 100	n/a
		LEED O+M: Existing Buildings v3 - LEED 2008	2011	68/91	Platinum
	20 Omega Center for Sustainable Living New York, United States 2009 https://www.bnrim.com/project/omega-center-sustainable-living	LEED BD+C: New Construction v2 - LEED 2.2	2010	59/69	Platinum
		Living Building Challenge	n/a	n/a	Living Certification

Table 4.1 (Continued)

	21 Ronesansbiz Kucukyali Office Park A-B Block Istanbul, Turkey 2014 https://ronesans.com/proje/ronesansbiz-kucukyali-ofis/					
	BREEAM	In-Use International 2015 Part 2 - Management Performance	Valid until: 2023	85.1%	Outstanding	
	LEED	LEED BD+C: Core and Shell v3 - LEED 2009	2015	80	Platinum	
	22 Sabanci University Nanotech. Research & App. Center Istanbul, Turkey 2011 https://www.altensis.com/proje/sabanci-universitesi-nanoteknoloji-binasi					
	BREEAM	International 2008 Bespoke	2015	56%	Very good	
	LEED	LEED BD+C: New Construction v3 - LEED 2009	2011	79	Gold	
	23 SkyTower Bukarest Bucharest, Romania 2012 https://www.skytower.ro/					
	DGNB	New Construction Offices	2021	74,50%	Silver (Pre-Certified) Gold	
	LEED	LEED O+M: Existing Buildings v4.1 - LEED v4.1	2021	81/100	Platinum	
	24 Phipps Center for Sustainable Landscapes Pennsylvania, United States 2013 https://www.archdaily.com/364575/center-for-sustainable-landscapes-the-design-alliance-architects					
	BREEAM	USA In-Use 2016 Part 2 - Management Performance	Valid Until: 2023	93.3%	Outstanding	
	Fitwel	n/a	2021	n/a	3 Star Rating	
	LEED	LEED BD+C: New Construction v2 - LEED 2.2	2013	63/69	Platinum	
	Living Building Challenge Sustainable Sites Initiative (SITES)	n/a	2015	n/a	Living Certification	
	WELL	2019 SITES v2	n/a	n/a	Platinum	
		n/a	n/a	n/a	Platinum	

Table 4.1 (Continued)

	25 Pixel Victoria, Australia 2010 https://www.archdaily.com/190779/pixel-studio505								
	LEED	LEED BD+C: New Construction v3 - LEED 2009	2012	105					Platinum
	Green Star	Office As Built v3 2012	2012	n/a					6 Stars
	26 Promenada Mall Bucharest, Romania 2013 https://nepirockcastle.com/portfolio/promenada-mall/								
	BREEAM	In-Use International 2015 Part 1-Asset Performance	Valid Until: 2023	72.0%					Excellent
	DGNB	In-Use International 2015 Part 2 - Management Performance	Valid Until: 2023	72.4%					Excellent
	27 University Place Pennsylvania, United States 2013 Not completed https://www.theshewardpartnership.com/2-0-university-place/								
	Energy Star	Energy Star	2015 -2018	84 (2018)					n/a
	LEED	LEED BD+C: Core and Shell v2 - LEED 2.0	2013	47/62					Platinum
	LEED	LEED ID+C: Commercial Interiors v3 - LEED 2009	2017	84					Platinum
	LEED	LEED BD+C: Core and Shell v4 - LEED v4	n/a	Pre-Certified					Platinum
	WELL	WELL v2	2022	Pre-Certified					Platinum
	28 Verwaltungsgebäude Max Frank Leibfing, Germany 2015 https://www.dgnb-system.de/en/projects/verwaltungsgebäude-max-frank								
	DGNB	New Construction Offices, Version 2012	2015	68,6% (calculated according to the weightings)					Gold
	LEED	LEED 2009 New Construction	2015	64					Gold

Note: Data collected from Assefa et al., 2022; Suzer, 2019; Penny, 2012; <https://bregroup.com/>, <https://cedbik.org/>, <https://www.dgnb.de/en/>, <https://new.gbca.org.au/>, <https://www.gbig.org/>, <https://www.usgbc.org/leed>, and <https://learn.kaiterra.com/en/resources/6-notable-projects-rated-platinum-by-the-well-standard>

The comparison made by Suzer (2019) shows that between BREEAM and LEED, BREEAM has higher expectations, and the buildings generally receive a lower score than the LEED certification. Figure 4.2 shows the scatter plot of the projects that receive certifications from BREEAM and LEED, and it is visible that projects get higher scores on LEED. The problem of the possible greenwashing of the GBRS is mentioned by Kurnaz (2021) as importing materials and employing non-sustainable strategies for receiving points, and using the certifications for marketing purposes. The paper continues that every GBRS has their criteria based on the country where they were developed, which creates a problem for the internationally certified buildings as their local requirements may not get enough points as they should. Kurnaz (2021) mentions that the cost of the GBRS is one of the reasons that not every sustainable building applies to be certified.

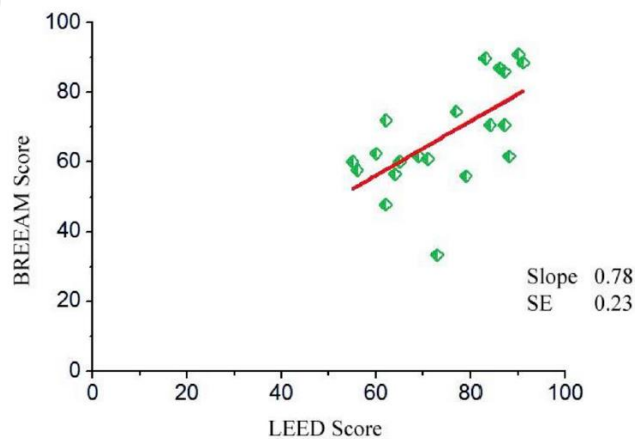


Figure 4.2 LEED and BREEAM Certified Buildings (Suzer, 2019)

In order to compare the scores of the case studies, a paired two-tailed t-test of LEED and BREEAM was done. To have a proper comparison, the scores were equalized to 100, and only the case studies that received both certifications were used. Figure 4.3 shows the calculations of these tests, and it can be seen that there is a significant

difference between the scores. The calculations show that the relationship between BREEAM and LEED is positively linear, as proven by Suzer (2019). The hypothesis for the two-tailed paired t-test can be seen below;

H_0 : LEED scores = BREEAM scores

H_1 : LEED scores $\neq$ BREEAM scores

Results of the paired t-test indicated that there is a significant medium difference between LEED (M = 76.1, SD = 11.5) and BREEAM (M = 67.9, SD = 17), $t(11) = 2.4$, $p = .032$. The P-value shows the probability value, whereas the significance level (α) means the maximum chance of an event can occur, which is set as .05. The lower p-value means H_1 is more accepted. The calculation shows that $p\text{-value} < \alpha$, which means H_0 is rejected, and there is an inequality between these systems.

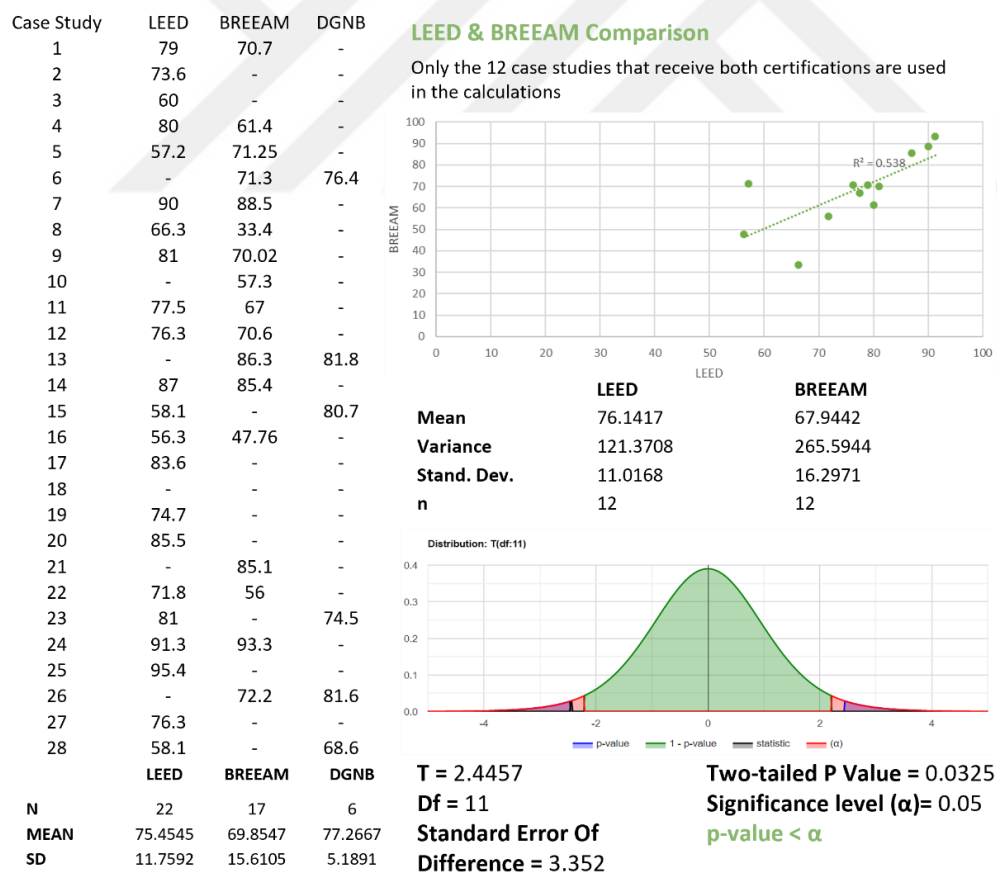


Figure 4.3 Calculations of the GBRs Comparison (Developed by author)

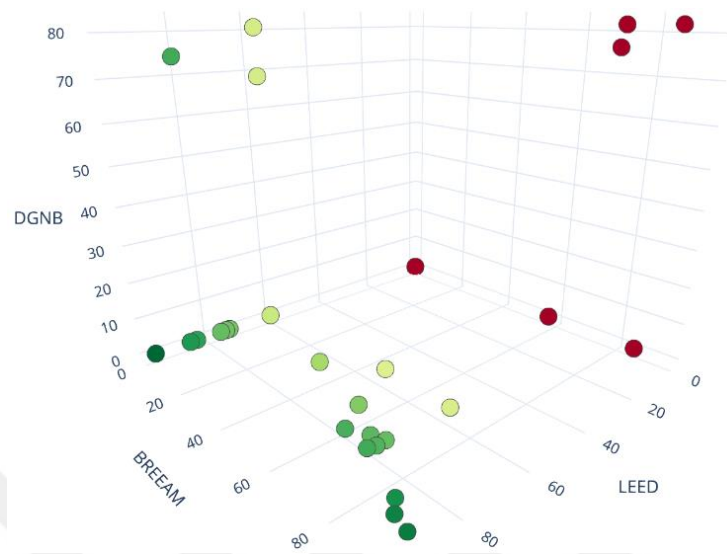


Figure 4.4 3D Scatter Plot of the Multi-Certified Buildings (Developed by author)

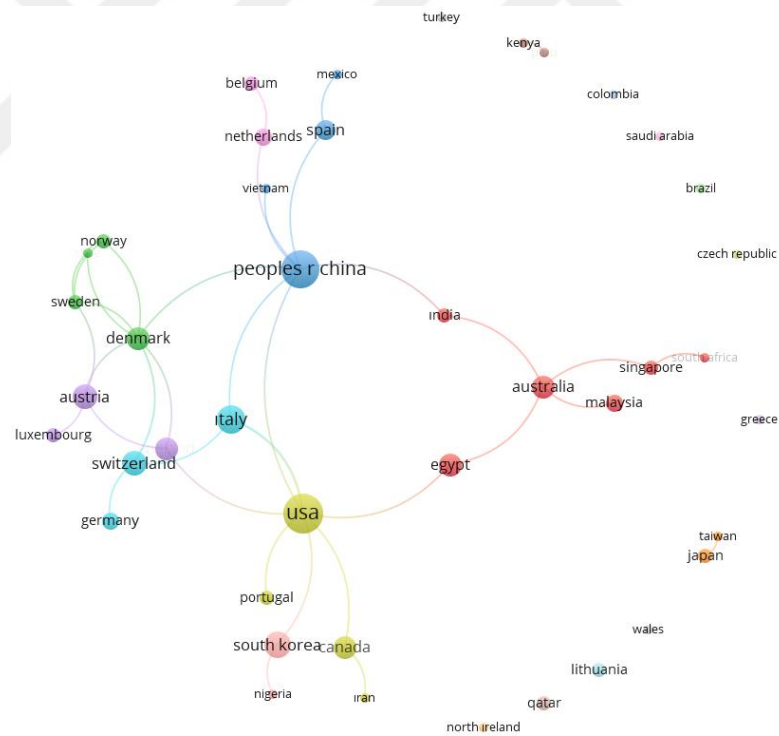


Figure 4.5 Countries of the Keyword Analysis (Last update: December 13, 2022)

Figure 4.4 shows the scatter plot of the GBRs scores. All of the case studies are used for this diagram, and as mentioned, the scores were equalized to 100. It can be seen

that LEED scores are slightly higher than the other scores, which were previously mentioned in the literature. One of the problems of the comparison is the lack of examples of the buildings certified by all of the GBRS. Figure 4.6 shows that many of the multi-certified buildings are located in the US and have received LEED and BREEAM certifications. Due to the wide prevalence of these certificates, they were used for the conducted comparisons. It can be seen that most of the examples are from the United States and China. Figure 4.5 shows the countries from the literature search made with the keywords BIM, LCA, GBRS, and MP, as seen in Figure 3.4. It is visible that most of the papers are again from the United States and China, which shows that practice and literature support each other.

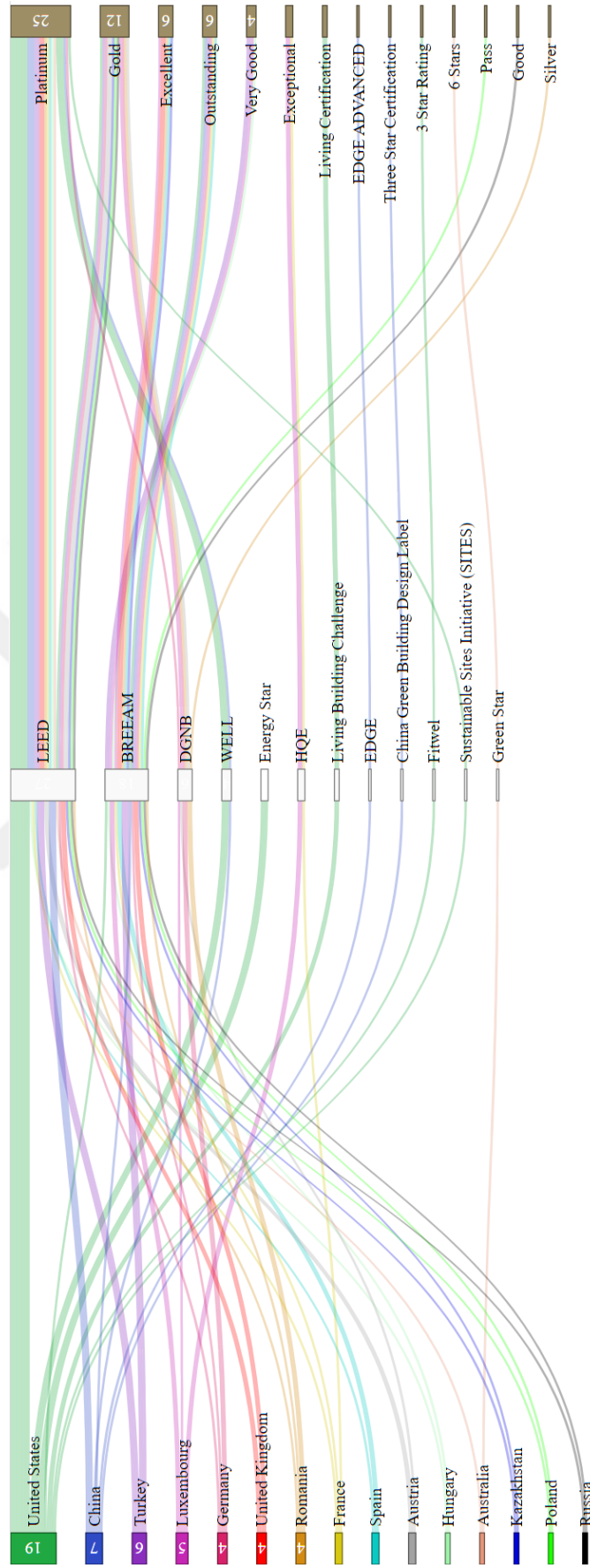


Figure 4.6 Diagram of Case Studies with Multiple Certification (Developed by author)

• Circular Buildings Without GBRS Certifications

Table 4.2 shows the buildings that are considered sustainable and circular but do not contain the GBRS certifications. The search was conducted by scanning architecture websites; AD, Archdaily, Dezeen, and Rethinking the Future. “Sustainable buildings” and “circular buildings” were selected as keywords, and the results that did not have any certifications were shown in the list (Jordan, 2022; Mafi, 2019; Rao A, n.d.).

Table 4.2 Circular Buildings Without GBRS Certifications (Developed by author)

	1 Amherst College Science Center Amherst, United States 2018 76% energy reduction • USGBC Green Building Showcase Market Leader, People's Choice, 2019 • USGBC Green Building Showcase Market Leader, Innovation, 2019 • AIA New England, Honor Award, 2019 • AIA COTE Top Ten Recipient, 2019 • American Architecture Award, 2020 • BSA Sustainable Design Awards Citation, 2020 • BSA Honor Awards for Design Excellence Award, 2020 • AIA Education Facility Design Award of Merit, 2020 • SCUP/AIA-CAE Excellence in Architecture Merit Award, 2020 • BSA Higher Education Design Award, 2021 • AIA Interior Architecture Award, 2022
	2 Bahrain World Trade Center Manama, Bahrain 2008 Building-Integrated Wind Turbines • LEAF Awards, Best use of Innovative Technology within a Large Scheme, 2006 • EDIE Award for Environmental Excellence, Building Award Winner, 2007 • Popular Science, Best of the Year Award, 2008 • Construction Week Awards, Tower Project of the Year Award Winner, 2008 • Cityscape Dubai, Shortlisted Best Commercial / Mixed Use Building, 2008 • Middle East Architectural Awards - Shortlisted Best Designed Building, 2008 • Building Design Awards - Architect of the Year Award Winner, 2008 • Building Exchange Awards - Sustainability Award Winner, 2008 • Council of Tall Buildings and Urban Habitats, Winner of 2008 'Best Tall Building Awards' MENA region, 2008 • Innovation Nova Award, Innovation Award Winner, 2009 • PALME Middle East Awards - Award Winner, 2010
	3 Bouwdeel D(emontabel) Delft, Netherlands 2019 Fully demountable building with the minimum materials that are easy to connect and detach. • Architectenweb Awards, Office Building of the Year, 2020
	4 Brummen Town Hall Brummen, Netherlands 2013 Designed for future reuse and reassembly. "Received the world's first materials passport that records information related to the building's materials, components, and products." ⁴ • Dutch Award for Sustainable Architecture, 2013

Table 4.2 (Continued)

	5 City Hall Venlo Venlo, Netherlands 2016 Inspired by C2C concepts and MP, has an air purifier façade and produces no waste. • Wood in architecture, nominated longlist, 2016 • Green Building Solutions Award, Honourable Mention, 2016 • Cradle to Cradle Products Innovation Institute Award, 2016 • Green Building Solutions Award, finalist, 2016 • 10th Annual International Color Awards, Honourable Mention, 2017 • Shaw Contract Design Awards, 2017 • WAN Sustainable Buildings Awards, nominated Shortlist, 2017 • Plan Award, winner category Office & Business, 2017 • Architizer A+ Awards, winner category overheidsgebouwen, 2017
	6 CopenHill Copenhagen, Denmark 2017 "Replacing an old plant, and the single largest environmental initiative in Denmark." ¹ • MIPIM AR Future Projects Awards, 2012 • P/A Progressive Architecture Awards, Citation, 2015 • Tekla Global BIM Awards, 2015 • European Steel Design Awards, 2015 • Architizer A+ Award, Architecture Photography, 2019 • Scandinavian Green Roof Award, 2019 • ArchDaily Building of the Year, Industrial Architecture, 2020 • Architizer A+ Awards Factories & Warehouses Popular Winner, 2020 • German Design Council Innovative Architecture, Best of the Best Award Winner, 2020 • Design Educates Award, 2020 • ICONIC Awards, Innovative Architecture, Best of the Best Award, 2020 • Popular Science Best of What's New Award, 2020 • IDEAT Future Award, Best Public Architecture, 2020 • Bundesverband GebäudeGrün Green Roof Award, 2020 • IOC, IPC and IAKS award international architecture prize, 2021 • World Architecture Festival Best Energy & Infrastructure Category Winner, 2021 • World Architecture Festival Best Building of the Year Winner, 2021 • Energy Globe National Award, 2022
	7 Ebury Edge London, United Kingdom 2020-2024 Temporary Work and Community Place, designed to be adapted and re-deploy after use and designed to be a 100% electric building while using reusable materials. • Structural Timber Awards: Ebury Edge, Retail and Leisure Project of the Year, 2021 • Architizer+ Awards, Architecture + Colour, Finalist, 2021 • Architizer+ Awards, Architecture + Community, Finalist, 2021 • New London Architecture Awards, 2021 • New London Architecture Awards, Shortlist, 2021 • Community Prize Civic Trust Award 2022
	8 Flat House Cambridgeshire, United Kingdom 2019 Pre-fabricated sustainable construction with natural materials and low carbon emissions. n/a
	9 Gallery of Furniture Brno, Czech Republic 2016 Transformation of an old building. Façade made from more than 900 black seats. Curtains were used for the interior, which created an adaptive area for the users' needs. • Architizer A+Awards, Commercial – Showrooms, Jury Winner, 2019

Table 4.2 (Continued)



<https://www.insitu.ch/projekte/196-k-118>

10 **K.118** | Winterthur, Switzerland | 2021

Using materials available on-site to achieve a circular closed loop material flow.

- Holcim Award for Sustainable Construction, European & Global Gold Winner, 2021
- Prix Acier, 2021



<https://www.archdaily.com/790591/bima-microlibrary-shau-bandung>

11 **Microlibrary Bima** | Cicendo, Indonesia | 2016

Used ice-cream tubs were used for the façade

- Architectural Review Emerging Award Finalist, 2016
- World Architecture Community Award 23rd cycle winner, 2016
- Architizer A+ Winner Architecture+Community category, Jury and Public Choice Awards, 2017
- Beazley Designs of the Year Nominee, 2018
- Aga Khan Award for Architecture, Shortlisted, 2019



https://vollark.no/portfolio_page/mjostarnet/

12 **Mjøstårnet** | Brumunddal, Norway | 2019

World's tallest wooden skyscraper

- 2018 New York Design Awards, Gold Winner, 2018
- Norwegian Tech Award, Building and Construction, 2018
- CTBUH, Tallest All-Timber Building in the World, 2019
- Guinness World Records, Tallest Wooden Building, 2019
- CTBUH Awards, Structural Engineering Award 2021 Award of Excellence, 2021
- CTBUH Awards, Life Safety Design Award 2022 Winner, 2022



<https://www.kraaijvanger.nl/en/projects/museum-voorlinden/>

13 **Museum Voorlinden** | Wassenaar, Netherlands | 2016

Using daylight with LED in the special light roof to maximize the use of daylight.

- Glass Award, winner, 2016
- RAP Rijnland Architecture Prize, nominated, 2017
- Plan Award, Culture, winner, 2017
- Leading Culture Destinations Awards, nominated, 2017
- BNA Best Building of the Year, nominated, 2017
- Roof Award, winner, 2017
- Herengracht Industry Prize, nominated, 2018
- Dutch Daylight Award, winner, 2018
- RIBA International Prize, nominated, 2018



<https://localworks.ug/project/mustardseed-junior-school>

14 **Mustardseed Junior School** | Wakiso, Uganda | 2021

Natural and local materials. Walls built from earthbags filled with soil and external walls finished with an unpainted lime-earth render. ³

- Dezeen Awards: Sustainable Building of the Year 2022



<https://www.archdaily.com/977403/bamboo-treehouses-at-playa-viva-atelier-nomadic>

15 **Playa Viva Treehouses** | Guerrero, Mexico | 2021

"Generates 100% of its energy from solar power" ²

- Green Good Design Award, Green Architecture, 2022
- Dezeen Awards, Sustainability longlist, 2022

Table 4.2 (Continued)

	16 Recyclinghaus am Kronsberg Hanover, Germany 2019 Majority of the building components are used and recycled materials, designed for disassembly. • Special Prize for Sustainability at the German Façade Award, 2020 • Lower Saxony State Prize for Architecture, 2020 • Federal Prize Ecodesign, Recognition, 2020 • Federal Award Environment and Building, "Special Award", 2020 • Prize for wood construction Niedersachsen, Recognition, 2020 • Innovationspreis2021 powered by BFW Landesverband Nord, Shortlist, 2021 • Nomination DAM Prize, Nomination, 2021 • Deutscher Nachhaltigkeitspreis, Finalist, 2021
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<https://www.cityfoerster.net/projects/recyclinghaus-218-2.html>

Note: The buildings were searched and selected from Business in the Community, 2020; <https://www.ukgbc.org/our-work/?work-type=case-studies&work-area=&work-topic=>, and https://ce-toolkit.dhub.arup.com/case_studies (The images were accessed on January 3, 2023)

Table 4.2 shows the results of the circular buildings in practice. The selected buildings did not receive any certifications even though they are sustainable and circular.

• AIA COTE Top Ten Awards Recipients Without GBRS Certification



Figure 4.7 AIA COTE Top Ten 2023 Criteria (The American Institute of Architects, 2023)

COTE (The Committee on the Environment) is a community in AIA (the American Institute of Architects) working on sustainability and the environment, presenting AIA COTE Top Ten Awards each year (AIA COTE Top Ten Awards, n.d.). Figure 4.7 shows the criteria to be considered for the awards. Table 4.3 shows the list of award recipients who do not have GBRS certification. All the projects that won the award in the last ten years without GBRS certifications are shown in the list.

**Table 4.3 AIA COTE Top Ten Awards Recipients Without GBRS Certifications
(Developed by author)**

	1 Roxbury Branch of the Boston Public Library Renovation Boston, Massachusetts, United States 2018 Perkins&Will • AIA COTE Top Ten Awards, 2022 • AIA New England Design Honor Award, 2021 • AIA/ALA Library Building Award, 2021 • Boston Preservation Alliance Preservation Achievement Award, 2021 • IIDA New England Award Community and Culture Award, 2021 • AN Best of Design Awards Honorable Mention in the Public category, 2021 • Boston Society of Architects (BSA) Sustainable Design Award – Award, 2021 • Boston Society of Architects (BSA) Honor Award for Design Excellence – Citation, 2021
	2 UPcycle Austin, Texas, United States 2018 Gensler • AIA COTE Top Ten Awards, 2022
	3 Amherst College Science Center Amherst, United States 2018 Payette • USGBC Green Building Showcase Market Leader, People's Choice, 2019 • USGBC Green Building Showcase Market Leader, Innovation, 2019 • AIA New England, Honor Award, 2019 • AIA COTE Top Ten Recipient, 2019 • American Architecture Award, 2020 • BSA Sustainable Design Awards Citation, 2020 • BSA Honor Awards for Design Excellence Award, 2020 • AIA Education Facility Design Award of Merit, 2020 • SCUP/AIA-CAE Excellence in Architecture Merit Award, 2020 • BSA Higher Education Design Award, 2021 • AIA Interior Architecture Award, 2022
	4 Asilong Christian High School Asilong, West Pokot, Kenya 2018 BNIM • Contact 2020 Inspirations Top Award, 2020 • AIA Central States Region, Honorable Mention, 2020 • AIA San Diego, Honor Award, 2020 • AIA COTE Top Ten Awards, 2019 • AIA Kansas City, Honor, Architecture Small, Design Excellence Awards, 2018
	5 St. Patrick's Cathedral New York, New York, United States 2017 Murphy Burnham & Buttrick Architects (MBB) • AIA COTE Top Ten Awards, 2019 • Glass Magazine, Glass Magazine Award, 2018 • Chicago Athenaeum Museum, American Architecture Award, 2018 • AIA National, Honor Award, 2016 • AIA NYC, Merit Award, 2016 • New York Landmarks Conservancy, Lucy G. Moses Award, 2016 • Municipal Arts Society Of New York, MAsterworks award for Best Restoration, 2016 • Architizer A+ Awards, Special Mention, 2016 • Faith & Form/IFRAA, Religious Art & Architecture Award, 2016 • Copper Development Association, North American Copper in Architecture Award, 2016

Table 4.3 (Continued)

	6 Tashjian Bee and Pollinator Discovery Center Chaska, Minnesota, United States 2016 MSR Design • AIA COTE Top Ten Awards, 2019
 https://www.aia.org/showcases/183506-albion-district-library	7 Albion District Library Toronto, Ontario, Canada 2015 Perkins+Will • ARIDO, Award of Merit, 2019 • AIA/ALA Library Building Awards, 2019 • Ontario Library Association, New Library Building Award, 2019 • Toronto Urban Design Awards, Award of Excellence, Public Buildings in Context, 2019 • AIA COTE Top Ten Awards, 2018 • Fast Company, Honorable Mention, Spaces, Places and Cities, Innovation by Design, 2018 • WoodWORKS!, Jury's Choice Award, 2018 • Interior Design Magazine, Best of Year Award, Honoree, 2017 • Canadian Architect Magazine, Award of Merit, Awards of Excellence, 2015
 https://www.aia.org/showcases/186146-ortliebs-bottling-house	8 Ortlieb's Bottling House Philadelphia, Pennsylvania, United States 2015 KieranTimberlake • AIA COTE Top Ten Plus Awards, 2018 • Preservation Alliance of Greater Philadelphia Grand Jury Award, 2017
 https://www.aia.org/showcases/181821-san-francisco-art-institute---fort-mason-ce	9 San Francisco Art Institute - Fort Mason Center Pier 2 San Francisco, California, United States 2017 Leddy Maytum Stacy Architects • California Preservation Foundation, Preservation Design Award: Rehabilitation (Phase 2), 2019 • AIA Education Facility Design Awards, 2019 • AIA COTE Top Ten Awards, 2018 • AIA San Francisco, Citation Award, 2018 • Architect's Newspaper, Best of Design: Adaptive Reuse, 2018 • ASHRAE Golden Gate Chapter Technology Award, 2018 • National Trust for Historic Preservation, Trustees' Emeritus Award for Excellence in the Stewardship of Historic Sites
 https://www.aia.org/showcases/185631-sawmill	10 Sawmill Tehachapi, California, United States 2014 Olson Kundig • AIA COTE Top Ten Awards, 2018 • AIA National Small Project Award, 2018 • AIA National Housing Awards, Honor Award, 2017 • AIA Northwest Pacific Region Citation Award, 2017 • Chicago Athenaeum, American Architecture Awards, American Architecture Award, 2017
 https://www.aia.org/showcases/76996-stanford-university-central-energy-facility	11 Stanford University Central Energy Facility Stanford, California, United States 2015 ZGF Architects LLP • AIA COTE Top Ten Awards, 2017 • Architecture Masterprize, Architectural Design / Industrial Buildings, Bronze • AIA Institute Honor Awards for Architecture, 2017 • AIA San Francisco Design Awards, 2016 • IDA Architecture, Sustainable Living/Green, Gold, 2015

Table 4.3 (Continued)

 https://www.aiaopten.org/node/517	12 Stanford University Central Energy Facility Galway, Ireland 2013 Payette • AIA New England, Merit Award, 2017 • Boston Society of Architects, Sustainable Design, Citation Award, 2016 • AIA COTE Top Ten Awards, 2016 • I2SL Go Beyond Award, Buildings Category, 2016 • SCUP/AIA-CAE Excellence in Architecture: New Building, Merit Award, 2015
 https://www.aiaopten.org/node/460	13 Hughes Warehouse Adaptive Reuse San Antonio, Texas, United States 2012 Overland Partners • Chicago Athenaeum Green Good Design, 2016 • SA Tomorrow Sustainability Award, 2015 • AIA COTE Top Ten Awards, 2015 • AIA COTE San Antonio Design Award, 2014 • Texas Society of Architects Design Award, 2014 • AIA San Antonio Design Merit Award, 2014 • Centro San Antonio Best of Downtown Awards, Best of Greater Downtown, 2014 • Power of Preservation Foundation Adaptive Reuse Award, 2013
 https://www.aiaopten.org/node/385	14 Sustainability Treehouse Glen Jean, West Virginia, United States 2013 Mithun, and BNIM • AIA Northwest and Pacific Region Design Awards, Citation Award, 2015 • Society for Experiential Graphic Design (SEGD) Exhibition Awards, Honor Award, 2014 • CORE77 Design Awards, Professional Award, Interiors and Exhibitions, 2014 • AIA COTE Top Ten Awards, 2014 • AIA Seattle Honor Awards, Award of Honor, 2013
 https://www.aiaopten.org/node/216	15 Clock Shadow Building Milwaukee, Wisconsin, United States 2012 Continuum Architects + Planners • AIA Wisconsin, Merit Award, 2013 • AIA COTE Top Ten Awards, 2013 • Office of Mayor Tom Barrett, Mayor's Design Award, 2013 • Daily Reporter, Top Projects, Nominee, 2013 • Business Journal of Greater Milwaukee, Best Environmentally Friendly Project, 2013 • LISC Wisconsin, State Farm Building Blocks Award, 2013 • Associated Builders + Contractors of Wisconsin, Project of Distinction, GOLD Award, 2013 • Engineering News – Record, Best Green Project in the Midwest, 2012 • Wisconsin Commercial Real Estate Women Association, Vision Award of Ingenuity, 2012
 https://www.aiaopten.org/node/29	16 Yin Yang House Venice, California, United States 2011 Brooks + Scarpa • AIA COTE Top Ten Awards, 2013

Note: The buildings were searched from <https://www.aia.org/awards/7301-cote-top-ten-awards> (The images were accessed on January 3, 2023)



Figure 4.8 Scatter Plot of the AIA COTE Top Ten Award Years and the Building Construction Years (Developed by author)

Figure 4.8 demonstrates the years of the AIA COTE Top Ten Award years and the construction years of the recipient projects. Although no uncertified project has received an award in the last three years, it is notable that each year except for 2012 has featured a project without a green building certification. Another point that can be seen from the projects is that the change in scale between the multi-certified buildings and AIA COTE Top Ten Award recipients. These projects are selected for their sustainability, and it can be seen that the scale is much smaller than the multi-certified buildings.

4.1 Case 1: Turkey Case



Figure 4.9 Turkey Case (Adapted from ERKE Green Academy, n.d.; *BREEAM - ERKE Green Academy*, n.d.; *LEED - ERKE Green Academy*, n.d.) (Developed by author)



Figure 4.10 Scores of Case 1 (Developed by author)

Figure 4.10 shows the differences in the scores and the levels of Case 1, ERKE Green Academy. It can be seen that the same building receives different scores and different levels of certifications. As mentioned before, the comparison of the scores demonstrated that LEED scores are higher than BREEAM, as it is here. This building shows a mismatch, as the same building receives LEED Platinum and BREEAM Very Good. Platinum is considered the highest level in LEED; in BREEAM, Very Good level is in the middle overall. As mentioned before with the hypothesis tests, there is a significant difference between LEED and BREEAM scores.

As shown in Figure 4.3, the average difference between LEED and BREEAM scores is 5.89, as found by $\text{Mean}_{\text{LEED}} - \text{Mean}_{\text{BREEAM}} = 75.74 - 69.85 = 5.89$ (The general Mean in the table is used for this calculation). The scores of Case 1 can be listed as, LEED score is 82/110, which is equivalent to 74.54, and BREEAM score is 67/100. The difference between these scores is 7.57 ($\text{LEED} - \text{BREEAM} = 74.54 - 67 = 7.57$). It is clear that the difference in the scores in Case 1 is higher than the average of the case studies. Figure 4.11 shows the material selection of Case 1 and the credits given to them. BREEAM scores are not available in a categorized form, whereas LEED shows the categories and the credits in each issue. It can be seen that Case 1 could not receive even half of the credits in the Material and Resources category of LEED, whereas it has been rewarded with the Platinum certification, the highest level in LEED. Which is the result of a less demanding material standard of LEED that allows higher points with less achievements.

FLOORING SYSTEM

CRI Green Label Plus certified carpet used in the seminar/meeting room has contributed to the building in terms of indoor air quality. Moreover, having **100% of recycled content** valued to the building in terms of using **sustainable materials**.

Cork material used on circulation, manager room and meeting room valued to the project in terms of its **environmentally friendly** features. Cork is extracted cyclically (9 to 12 year) from the cork oak trees without ever damaging them. Moreover, during the production there is **no toxin substances revealed**.

2tec2 carpet tiles has been preferred for circulation area, meeting room and social area located on the basement floor of the building. It can **easily install** and in any case of damage **easily can be replaced**. This innovative material made of a glass fibre core coated with vinyl and finished with a homogeneous backing. The material itself and the applied adhesive have **low VOC value** according to the green building standards. It also delivers all of the advantages of woven vinyl - **durability, hygiene and chemical, water and stain resistance** combined with the visual appeal of woven textiles.

ACOUSTIC PERFORMANCE

To obtain optimum reverberation time and speech intelligibility (STI) values; **fabric and perforated wooden panels** have been used for the meeting/seminar room. Moreover, **8mm Himerpa Isolgomma Grei Line PTB 8 roll** has been used under the screed applications.

SKYLIGHT

Velux skylight used for the seminar/meeting room provides 100% of natural daylight and ventilation so by increased indoor air quality.

COATINGS & WATERPROOFING

Using **low-emitting materials** is an important façade of sustainable buildings. In this scope;

- **KOSTER 2K FLEX**, cement based elastic water insulation

with two components has been applied on the wet areas.

VOC-Volatile Organic Compounds (g/L):

< 0,1

- **Low-emitting ceramic tile adhesive** has been used for flooring and wall tile ceramics. VOC (g/L): < 65

EPD certified low-emission porcelain tiles have been used for the wet areas of the building. **100% recyclable and moisture-resistant metal suspended ceiling system**

CIRCULATION AREA / RAILING SYSTEM

X-TEND stainless steel wire cable system has been used between the stainless steel posts placed on stairwell. **High efficiency LED luminaries** hidden inside the steel rails

INDOOR AIR QUALITY

Volatile organic compounds (VOCs) are carbon compounds that vaporize at normal room temperatures which cause negative impact on buildings occupants and environment. In this scope, materials below have been used in order to increase the indoor air quality;

WALL COATING

Greenguard certified white/green dry wall system and **low VOC Satentek plaster** have been

used for indoor partition walls and suspended ceilings.

Moreover, having **Environmental Product Declaration (EPD)** proves its **low carbon manufacturing process and products itself**.

Eco-friendly Ecocarot material used for the wall cladding **does not contain formaldehyde** that affects human health and indoor environment. It also absorbs humidity inside the room adversely gives off when the room humidity gets lower than 40%. This **nanotechnology material** located World Ecology Catalogue has been applied with **low emitting adhesive which contains 9g/L VOCs**.

FLOORING SYSTEM

FloorScore certified linoleum has been preferred for the open offices of the building. Moreover, having **60% of rapidly renewable content** valued to the building in terms of using **sustainable materials**.

LEED Score: 82/110 Level: Platinum

MATERIAL & RESOURCES Awarded: 5 / 14

BREEAM Score: 67/100 Level: Very Good

MRp1 Storage and collection of recyclables
REQUIRED

MRc1.1 Building reuse - maintain existing walls, floors and roof 2 / 3

MRc1.2 Building reuse - maintain interior nonstructural elements 0 / 1

MRc2 Construction waste Mgmt 0 / 2

MRc3 Materials reuse 0 / 2

MRc4 Recycled content 0 / 2

MRc5 Regional materials 2 / 2

MRc6 Rapidly renewable materials 1 / 1

MRc7 Certified wood 0 / 1

Flooring System

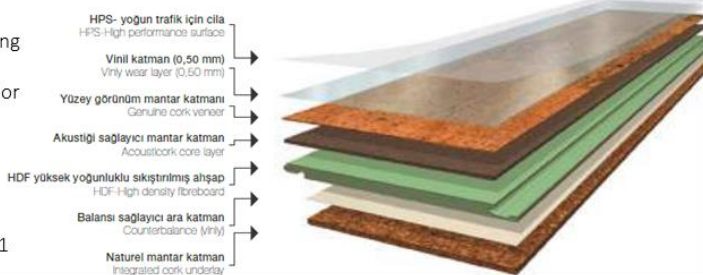


Figure 4.11 Case 1: Material Selection (Adapted from ERKE Green Academy, n.d.; BREEAM - ERKE Green Academy, n.d.; LEED - ERKE Green Academy, n.d.) (Developed by author)

4.2 Case 2: Dual-Certified Case



Figure 4.12 Dual-certified Case (Adapted from *BREEAM - Concept Tower*, n.d.; *CPIPG - Concept Tower*, n.d.; *FS&P Arcus Fajnaś Ścisło & Partnerzy - Concept Tower*, n.d.; *LEED - Concept Tower*, n.d.) (Developed by author)

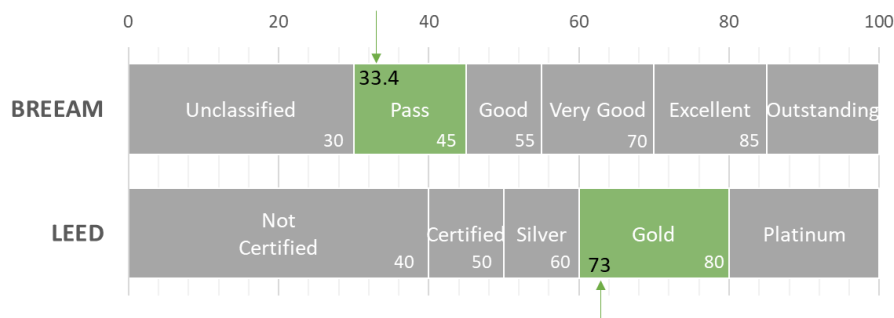


Figure 4.13 Scores of Case 2 (Developed by author)

Case 2 was selected for its extreme difference in scores. Figure 4.13 shows the differences in the scores and the levels of Case 2, Concept Tower. The building received 73/110 in LEED and 33.4/100 in BREEAM. As mentioned, LEED averages are higher than BREEAM's, the average difference between LEED and BREEAM scores is 5.89.

For this case, the scores of Case 2 can be listed as, LEED score is 73/110, which is equivalent to 66.36, and BREEAM score is 33.4/100. The difference between these scores is 32.96 ($LEED - BREEAM = 66.36 - 33.4 = 32.96$). This is the study with the most significant difference overall.

LEED	Score: 73/110 Level: Gold	BREEAM	Score: 33.4/100 Level: Pass
MATERIAL & RESOURCES		Awarded: 7 / 13	
MRp1 Storage and collection of recyclables 0 / 0			
MRc1 Building reuse - maintain existing walls, floors and roof 0 / 5			
MRc2 Construction waste Mgmt 2 / 2			
MRc3 Materials reuse 0 / 1			
MRc4 Recycled content 2 / 2			
MRc5 Regional materials 2 / 2			
MRc6 Certified wood 1 / 1			
		"Local and recycled materials Finishing materials with a low level of volatile organic compounds"	
		https://focusonbusiness.eu/en/real-estate/concept-tower-with-double-green-certification/800	

Figure 4.14 Case 2: Material Selection (Adapted from *BREEAM - Concept Tower*, n.d.; *Concept Tower with Double Green Certification*, 2016; *LEED - Concept Tower*, n.d.) (Developed by author)

Figure 4.14 shows that Case 2, similar to Case 1, did not achieve many of the credits for materials. Case 2 received the Gold certification, the second best level in LEED, achieving approximately half of the credits of the Material and Resources category. Similar to Case 1, BREEAM scores are not available in a categorized form.

4.3 Case 3: Circular Case



Figure 4.15 Circular Case Study (Adapted from Cepezed, 2020) (Developed by author)

Note: The old picture was captured from Google Maps Street View –Aug. 2014 on January 13, 2023.

Case 3, Boudwell D(emontabel), or known as Building D(emontable), is fully demountable, and it can be remountable in a different location with materials selected to be easily reused and recycled. Except for the ground, which is made from

poured concrete, the components are dry mounted and modular (Cepezed, n.d.). It can be seen that the building fulfills six of the 10R's.

4.4 Results of the Case Studies

One of the results from collecting the multi-certified, circular, and AIA COTE Top Ten Awards winner projects is the difference in scales. It can be seen that many of the multi-certified buildings are big-scaled offices and campuses, while the non-certified sustainable projects are found to be less in scale. These findings are in line with the mentioned gap and mismatch in the system. Between the case studies, it is visible that there are mismatches in the certification systems, as the same building could get different scores because of the focus of the certification system. This situation causes confusion about whether the building is indeed sustainable and circular. For this reason, the case studies are selected from multi-certified and circular non-certified buildings. It is visible that Case 1 and 2 receive certification in different levels, and Case Study 3 is considered as a circular building but did not receive any certification. Both case studies were a renovation and refurbishment of an existing building where the original building is aimed to be the guideline for the design.

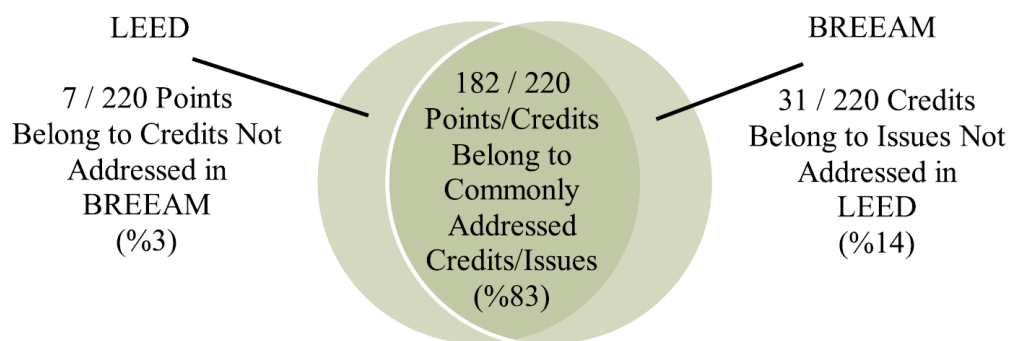


Figure 4.16 Differences between LEED and BREEAM (Suzer, 2019)

Figure 4.16 shows the differences and similarities between the issues and credits covered by LEED and BREEAM, where it is clear that the majority of the issues are commonly addressed by both systems (Suzer, 2019). The figure also shows that

BREEAM has more criteria than LEED, which can lead to higher expectations and lower scores (Suzer, 2019). The case studies show that the average of the BREEAM is indeed lower than the LEED scores. In order to evaluate the differences between multi-certified buildings and non-certified circular buildings, Table 4.4 has been developed.

Case 1 ERKE Green Academy	Case 2 Concept Tower
LEED	LEED
Last certified on: September 06, 2013 Rating system: LEED BD+C: New Construction v3 - LEED 2009 Score: 82/110 Level: Platinum	Last certified on: February 09, 2016 Rating system: LEED BD+C: Core and Shell v3 - LEED 2009 Score: 73/110 Level: Gold
 Sustainable Sites 21 / 26  Water Efficiency 8 / 10  Energy & Atmosphere 31 / 35  Material & Resources 5 / 14  Indoor Environmental Quality 9 / 15  Innovation 5 / 6  Regional Priority Credits 3 / 4	 Sustainable Sites 24 / 28  Water Efficiency 6 / 10  Energy & Atmosphere 24 / 37  Material & Resources 7 / 13  Indoor Environmental Quality 4 / 12  Innovation 4 / 6  Regional Priority Credits 4 / 4
MATERIAL & RESOURCES Awarded: 5 / 14	MATERIAL & RESOURCES Awarded: 7 / 13
MRp1 Storage and collection of recyclables REQUIRED MRc1.1 Building reuse - maintain existing walls, floors and roof 2 / 3 MRc1.2 Building reuse - maintain interior nonstructural elements 0 / 1 MRc2 Construction waste Mgmt 0 / 2 MRc3 Materials reuse 0 / 2 MRc4 Recycled content 0 / 2 MRc5 Regional materials 2 / 2 MRc6 Rapidly renewable materials 1 / 1 MRc7 Certified wood 0 / 1	MRp1 Storage and collection of recyclables 0 / 0 MRc1 Building reuse - maintain existing walls, floors and roof 0 / 5 MRc2 Construction waste Mgmt 2 / 2 MRc3 Materials reuse 0 / 1 MRc4 Recycled content 2 / 2 MRc5 Regional materials 2 / 2 MRc6 Certified wood 1 / 1

Figure 4.17 Material Selection Comparison Between Cases 1 and 2 (Adapted from *LEED - Concept Tower*, n.d.; *LEED - ERKE Green Academy*, n.d. (Developed by author)

Figure 4.17 shows the comparison of the material selection between Case 1 and 2 in the context of LEED. As seen, both of the cases are awarded with *LEED Building Design and Construction v3*, 2009, where Case 1 is under *New Constructions* and Case 2 is *Core and Shell*. Case 1 is awarded with 5/14 of the credits for the *Materials and Resources* category; meanwhile, Case 2 is awarded with 7/13. It is observable that Case 1 received a higher level of certification while obtaining fewer credits for the *Materials and Resources* category.

It can also be seen that there are differences between the issues of these rating systems. *The New Construction* system has 9 issues with 14 possible credits, whereas

Core and Shell system has 7 issues with 13 possible credits. The missing credits in Core and Shell regard nonstructural elements and rapidly renewable materials. Additionally, Case 2 demonstrates that the issue with the highest possible credits, *MRc1 Building Reuse – Maintain Existing Walls, Floors and Roof*, which intends to encourage building reuse, has not received any credits.



Table 4.4 Comparison of the Case Studies (Adapted from Cepezed, n.d.; ERKE Green Academy, n.d.; CIPPG - Concept Tower, n.d.)
(Developed by author)

Case 1 ERKE Green Academy		Case 2 Concept Tower	Case 3 Bouwdeel D(emontabel)
Year / Original Year	2013 / 1990's	2012	2019
Location	Istanbul, Turkey	Warsaw, Poland	Delft, Netherlands
Function / Old Function	Commercial / Residential	Commercial	Commercial
Floor Area / Floors	400 m² / 4 Floors	906 m² / 15 Floors	968 m² / 4 Floors
GBRS	LEED 82/110 BREEAM 67/100	LEED 73/110 BREEAM 33.4/100	n/a
Circularity Principles	Refuse Reduce Reuse Repair Recycle Renovation of an existing building Designed with the green building principles Produces energy from the solar panels Low energy technologies Water reuse system	Reduce Reuse Recycle Special design for daylight Recycled materials Water efficiency Optimized energy performance Easy to Access by transportation	Refuse Rethink Reduce Reuse Repair Repurpose Recycle Renovation of an existing building Fully demountable Minimum amount of materials Easy to reuse and recycle Can be remountable in a different location
Solutions	Reduce IEQ Site / Transport Recycle Reuse Water Repair Mater... Tech... Envl... Ener... Wat... Mat... Refuse Mater... Technical	Reduce IEQ Energy Material Recycle Material Site / Transport Environment Material	Reduce IEQ Energy Material Recycle Material Envir... Innov... Proce... Recycle Material Recycle Refuse IEQ Rethink Site / Trans... Reuse

Reuse

Material

Recycle

Material



CHAPTER 5

CONCLUSION

With the increase in waste, the construction industry, as one of the biggest contributors, started to shift towards a circular design to reduce environmental impacts. In this transition, principles, cycles, and levels of circularity are adapted to the built environment to increase the life span of the buildings and reduce building waste. This transition created circular and sustainable buildings, which started to be rated and evaluated at the beginning of the 1990s with green building rating systems (GBRS). Currently, there are hundreds of certification systems, each focusing on the buildings in a different manner and scale. The differences between the scores and the weightings result in mismatches in the system. Furthermore, there is a critical view of a forced circularity when there are other sustainable approaches.

As a result of the literature review, keyword analysis, and case studies, the hypothesis was found to be correct. A mismatch exists in the green building rating systems and the circularity principles that should be clarified. In order to find those issues, case studies were selected from the projects that received certification. These case studies are examined in the context of GBRS, circularity, and materials.

In order to find these mismatches, three sets of case studies were observed. The first set shows the multi-certified, the second shows the non-certified circular buildings, and the third set shows the AIA COTE Top Ten Awards recipients without any GBRS certifications. These studies are used for the comparison of the GBRS, and it can be seen that there is a significant difference between the systems, which shows that these certifications are not the indicator of circularity.

5.1 Discussion

As mentioned before, three sets of case studies were observed; 28 multi-certified buildings, 16 non-certified buildings, and 16 non-certified AIA COTE Top Ten Awards recipients. From these studies, a case that shows the situation in Turkey is selected, which is mentioned as Case 1; the case study with the biggest difference is mentioned as Case 2, and another one that shows the circularity in the built environment is mentioned as Case 3. A hypothesis test was conducted on the 28 multi-certified buildings, especially those that obtained LEED and BREEAM certifications. The result shows that there is a significant difference between the scores of these systems.

Cases 1 and 2 are used to compare the GBRS and the circularity principles used in these buildings. As proven before with the t-test, the scores of the case studies show significant differences between LEED and BREEAM. The second set of case studies shows that these certifications do not determine whether the structure is circular. This situation was also proven in Cases 1 and 2. An in-depth overview of Cases 1 and 2, and a comparison of the two buildings are shown. This comparison was made in order to demonstrate the differences between the GBRS scores and the impact of the materials in these scores. The results indicate that there are some mismatches in the cases. It can be seen that not every circular building has certification while fulfilling sustainability requirements.

The cases are discussed in the manner of materials and circularity principles, as from the literature review, these are observed to be the main gaps in the system. The cases are found to be received high levels of certifications without even fulfilling half of the material requirements, which shows the mismatches. Another finding of the case studies is the changes in the scale. It is observed that the multi-certified buildings are mostly bigger scaled than the circular and AIA COTE Top Ten Award recipients. This situation brings a question of whether the multi-certified buildings are usually big-scaled or if the small-scaled sustainable buildings do not require any certification.

5.2 Limitations and Projections

One of the biggest limitations was the inadequate resources of the multi-certified buildings. In order to find these buildings, the literature, and GBRS databases had to be searched thoroughly, resulting in very few sources being found. Along with the findings within the literature research, the GBRS databases are cross-referenced in order to find multi-certified buildings, which are mentioned in the Case Studies section. Another limitation is the number of multi-certified buildings, as the certifications require a registration fee, most of the owners do not keen to be certified by multiple systems. In addition to that, it is clear that there are mismatches in the systems, which can result in receiving a lower score from the new certifications.

In the case of circular buildings, the transition to circular design in the built environment has already started, but the examples in practice are very few. Most circular buildings are designed as pavilions and temporary places, whereas residential buildings are responsible for a significant amount of energy and emission, as mentioned in the literature. It should also be mentioned that the certifications have different schemes where their criteria and weightings change.

In this study, the scores are observed only with the certification system, not with the schemes, which can be future research about this subject. The main focus is selected as the handling materials in the GBRS, which is found to be the main gap in the system. In-depth research about all the issues located in the GBRS can be further studied, along with the changes in the scale of the built environment of the certified and non-certified projects. The reasons why small-scale sustainable projects are not certified or do not need to be certified can be a topic for future research. Studies can be focused on combining BIM into the GBRS and working with 3D models of the case studies while examining the certifications. The main examined certification systems are LEED and BREEAM in this study due to their widespread use worldwide; for future studies, other systems can also be observed. Currently, no information exists about the buildings certified with the mentioned Turkish

certification systems. Examining these certifications and their ratings in the built environment can be studied in the future.



REFERENCES

- AIA COTE Top Ten Awards. (n.d.). Retrieved March 4, 2023, from <https://www.aia.org/awards/7301-cote-top-ten-awards>
- ARUP. (2016). *The Circular Economy in the Built Environment*.
<https://www.arup.com/perspectives/publications/research/section/circular-economy-in-the-built-environment>
- Assefa, S., Lee, H. Y., & Shiue, F. J. (2022). Sustainability Performance of Green Building Rating Systems (GBRSs) in an Integration Model. *Buildings*, 12(2), 1–18. <https://doi.org/10.3390/buildings12020208>
- B.E.S.T. (n.d.). Retrieved October 3, 2022, from <https://cedbik.org/en/green-buildings-7-pg/b-e-s-t-residential-certification-system-12-pg>
- BAMB Material Passport. (n.d.). Retrieved October 3, 2022, from <https://www.bamb2020.eu/topics/materials-passports/>
- Bertino, G., Kisser, J., Zeilinger, J., Langergraber, G., Fischer, T., & Österreicher, D. (2021). Fundamentals of building deconstruction as a circular economy strategy for the reuse of construction materials. *Applied Sciences (Switzerland)*, 11(3), 1–31. <https://doi.org/10.3390/app11030939>
- Bouweconomie, D. C. (2018). *Transition Agenda - Circular Construction Economy*. <https://hollandcircularhotspot.nl/wp-content/uploads/2019/09/Circular-Construction-Economy.pdf>
- Brand, S. (1994). *How buildings learn : what happens after they're built*. Viking Press.
- Braulio-Gonzalo, M., Jorge-Ortiz, A., & Bovea, M. D. (2022). How are indicators in Green Building Rating Systems addressing sustainability dimensions and life cycle frameworks in residential buildings? *Environmental Impact Assessment Review*, 95(April), 106793.

<https://doi.org/10.1016/j.eiar.2022.106793>

BRE Global. (2016). *BREEAM International New Construction 2016*.

[https://files.bregroup.com/breeam/technicalmanuals/BREEAMInt2016Scheme Document/](https://files.bregroup.com/breeam/technicalmanuals/BREEAMInt2016SchemeDocument/)

BRE Global. (2021). *BREEAM International New Construction Version 6.0*.

<https://files.bregroup.com/breeam/technicalmanuals/sd/international-new-construction-version-6/>

BREEAM. (n.d.). Retrieved October 31, 2022, from

<https://bregroup.com/products/breeam/>

BREEAM - Concept Tower. (n.d.).

BREEAM - ERKE Green Academy. (n.d.). Retrieved January 6, 2023, from

<https://tools.breeam.com/projects/explore/buildings.jsp?sectionid=0&projectType=&rating=&certNo=&buildingName=erke&client=&developer=&certBody=&assessor=&location=&countryID=7&partid=10023&Submit=Search>

BREEAM Projects. (n.d.). Retrieved December 1, 2022, from

<https://tools.breeam.com/projects/explore/buildings.jsp>

British Standards Institution. (2011). *Sustainability of construction works*.

Assessment of environmental performance of buildings. Calculation method (BS EN 15978:2011).

Business in the Community. (2020). *Advancing Circular Construction: Case studies from the building and infrastructure sectors*.

https://www.bitc.org.uk/wp-content/uploads/2020/09/BITC_Casestudiesdoc_AdvancingCircularConstruction_September2020.pdf

Cambier, C., Galle, W., & De Temmerman, N. (2020). Research and Development Directions for Design Support Tools for Circular Building. *Buildings*, 1–20.

ÇEDBİK. (2019). *B.e.s.t - Konut: Sertifika Kılavuzu*.

[https://cedbik.org/static/media/content_images/files/B_E_S_T-KONUT
SERTİFİKA KILAVUZU -2019-Ağustos-V_2_0\(1\).pdf](https://cedbik.org/static/media/content_images/files/B_E_S_T-KONUT_SERTİFİKA_KILAVUZU_-2019-Ağustos-V_2_0(1).pdf)

Cepezed. (n.d.). *Building D(emountable) Press Kit*.

Çetin, S., De Wolf, C., & Bocken, N. (2021). Circular digital built environment: An emerging framework. *Sustainability (Switzerland)*, 13(11).

<https://doi.org/10.3390/su13116348>

Çetin, S., Rukanova, B. D., De Wolf, C., Gruis, V. H., & Tan, Y. (2022). A Conceptual Framework for a Digital Circular Built Environment The Data Pipeline, Passport Generator and Passport Pool. *The State of Circularity: The Content of "the 2nd International Conference on Circular Systems for the Built Environment*, 99–106.

Circular Dutch Economy 2050. (n.d.). Retrieved March 3, 2023, from

[https://www.government.nl/topics/circular-economy/circular-dutch-economy-
by-2050#:~:text=The Netherlands aims to have,and raw materials are reused.](https://www.government.nl/topics/circular-economy/circular-dutch-economy-by-2050#:~:text=The Netherlands aims to have,and raw materials are reused.)

Concept Tower with double green certification. (2016).

[https://focusonbusiness.eu/en/real-estate/concept-tower-with-double-green-
certification/800](https://focusonbusiness.eu/en/real-estate/concept-tower-with-double-green-certification/800)

Condotta, M., & Zatta, E. (2021). Reuse of building elements in the architectural practice and the European regulatory context: Inconsistencies and possible improvements. *Journal of Cleaner Production*, 318(January 2020), 128413.

<https://doi.org/10.1016/j.jclepro.2021.128413>

Corvellec, H., Stowell, A. F., & Johansson, N. (2022). Critiques of the circular economy. *Journal of Industrial Ecology*, 26(2), 421–432.

<https://doi.org/10.1111/jiec.13187>

CPIPG - Concept Tower. (n.d.).

Crawford, R. H. (2011). *Life Cycle Assessments in the Built Environment*.

- Routledge. <https://doi.org/https://doi.org/10.4324/9780203868171>
- Crowther, P. (2005). Design for disassembly - Themes and Principles. *RAIA/BDP Environment Design Guide*. <https://doi.org/10.1115/1.2991134>
- Debacker, W., & Manshoven, S. (2016). D1- Synthesis of the state-of- the-art. In *Bamb*. BAMB Horizon 2020. http://www.bamb2020.eu/wp-content/uploads/2016/03/D1_Synthesis-report-on-State-of-the-art_20161129_FINAL.pdf
- Deligöz, D., Kabak, S., & Sağlam, A. İ. (2020). Analysis of Green Building Certification Systems Used in Residential Buildings in Turkey, Context of the Resource Conservation. *GRID - Architecture, Planning and Design Journal*, 3(2), 0–1. <https://doi.org/10.37246/grid.743045>
- DGNB. (n.d.). Retrieved October 1, 2022, from [https://www.dgnb.de/en/council/DGNB Projects](https://www.dgnb.de/en/council/DGNB%20Projects).
- DGNB Projects. (n.d.). Retrieved December 1, 2022, from <https://www.dgnb-system.de/en/projects/>
- DGNB System. (2020). *New Construction, Buildings Criteria Set Version 2020 International*.
- DGNB System – New buildings criteria set. (n.d.). Retrieved December 6, 2022, from https://static.dgnb.de/fileadmin/dgnb-system/en/buildings/new-construction/criteria/Evaluation_and_structure_of_the_DGNB_system.pdf
- Dokter, G., Thuvander, L., & Rahe, U. (2021). How circular is current design practice? Investigating perspectives across industrial design and architecture in the transition towards a circular economy. *Sustainable Production and Consumption*, 26, 692–708. <https://doi.org/10.1016/j.spc.2020.12.032>
- Duffy, F. (1990). Measuring building performance. *Facilities*, 8(5), 17–20. <https://doi.org/10.1201/b19338-7>
- Ellen MacArthur Foundation. (n.d.-a). *Circular Economy Diagram*. Retrieved

February 3, 2022, from <https://archive.ellenmacarthurfoundation.org/circular-economy/what-is-the-circular-economy>

Ellen MacArthur Foundation. (n.d.-b). *The Butterfly Diagram: Visualising the Circular Economy*. Retrieved February 2, 2022, from <https://ellenmacarthurfoundation.org/circular-economy-diagram>

Ellen MacArthur Foundation. (2015). *Growth within: a circular economy vision for a competitive Europe* (p. 100).

Ellen MacArthur Foundation. (2021). *Completing the picture: How the circular economy tackles climate change*.

Environment and Urban Ministry (Turkey). (n.d.). *Green Certificate - Building [Yeşil Sertifika - Bina]*.
https://webdosya.csb.gov.tr/db/meslekihizmetler/menu/yesilbina-degerlendirme-kilavuzu_20210611120321.pdf

ERKE Green Academy. (n.d.). *ERKE Green Academy Booklet*. Retrieved December 5, 2022, from <https://www.erkegreenacademy.com/index.asp>

FS&P Arcus Fajnaś Ścisło & Partnerzy - Concept Tower. (n.d.).

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Jan, E. (2017). The Circular Economy e A new sustainability paradigm ? *Journal of Cleaner Production*, 143, 757–768. <https://doi.org/10.1016/j.jclepro.2016.12.048>

Gemeente Amsterdam. (2017). *Roadmap Circular Land Tendering: an introduction to circular building projects*.
<https://www.metabolic.nl/publications/city-of-amsterdam-roadmap-circular-land-tendering/>

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, 114, 11–32.
<https://doi.org/10.1016/j.jclepro.2015.09.007>

Green Star. (n.d.). Retrieved October 2, 2022, from <https://new.gbca.org.au/green-star/exploring-green-star/>

Green Star - Design & As Built v1.3. (n.d.). Retrieved December 6, 2022, from <https://gbca-web.s3.amazonaws.com/media/documents/dab-v1.3-credit-categories.pdf>

Guldager Jensen, K., Stokholm Poulsgaard, K., Lind, L., Østergaard Christensen, C., Skjelmose, O., Jayne Carruth, S., Knorr Jensen, K., Overgaard Canera, I., Manbodh, J., Birgisdottir, H., & Zimmermann, R. K. (2018). Guide to Sustainable Building Certifications. In K. Guldager Jensen & H. Birgisdottir (Eds.), *SBi and GXN*. <https://sbi.dk/Pages/Guide-to-sustainable-building-certifications.aspx>

Hamedani, A. Z., & Huber, F. (2012). A comparative study of DGNB, LEED and BREEAM certificate systems in urban sustainability. *WIT Transactions on Ecology and the Environment*, 155, 121–132. <https://doi.org/10.2495/SC120>

Hasik, V., Escott, E., Bates, R., Carlisle, S., Faircloth, B., & Bilec, M. M. (2019). Comparative whole-building life cycle assessment of renovation and new construction. *Building and Environment*, 161(May), 106218. <https://doi.org/10.1016/j.buildenv.2019.106218>

Haupt, M., Kägi, T., & Hellweg, S. (2018). Modular life cycle assessment of municipal solid waste management. *Waste Management*, 79, 815–827. <https://doi.org/10.1016/j.wasman.2018.03.035>

Heinrich, M., & Lang, W. (2019). *Materials Passports - Best Practice*. https://www.bamb2020.eu/wp-content/uploads/2019/02/BAMB_MaterialsPassports_BestPractice.pdf

Honarvar, S. M. H., Golabchi, M., & Ledari, M. B. (2022). Building circularity as a measure of sustainability in the old and modern architecture: A case study of architecture development in the hot and dry climate. *Energy and Buildings*, 275(112469). <https://doi.org/10.1016/j.enbuild.2022.112469>

- Honic, M., Kovacic, I., Aschenbrenner, P., & Ragossnig, A. (2021). Material Passports for the end-of-life stage of buildings: Challenges and potentials. *Journal of Cleaner Production*, 319(December 2020), 128702. <https://doi.org/10.1016/j.jclepro.2021.128702>
- Honic, M., Kovacic, I., Sibenik, G., & Rechberger, H. (2019). Data- and stakeholder management framework for the implementation of BIM-based Material Passports. *Journal of Building Engineering*, 23(January), 341–350. <https://doi.org/10.1016/j.jobbe.2019.01.017>
- Illankoon, I. M. C. S., Tam, V. W. Y., Le, K. N., & Shen, L. (2017). Key credit criteria among international green building rating tools. *Journal of Cleaner Production*, 164, 209–220. <https://doi.org/10.1016/j.jclepro.2017.06.206>
- International Organization for Standardization. (n.d.). Retrieved November 20, 2022, from <https://www.iso.org/home.html>
- International Organization for Standardization. (2006). *Environmental assessment - Life cycle assessment - Principles and framework (ISO Standard No: 14040:2006)*. <https://www.iso.org/standard/37456.html>
- International Organization for Standardization. (2010). *Sustainability in building construction — Framework for methods of assessment of the environmental performance of construction works — Part 1: Buildings (ISO Standard No. 21931-1:2010)*. <https://www.iso.org/standard/45559.html>
- Jalaei, F., & Jade, A. (2014). Integrating BIM with green building certification system, energy analysis, and cost estimating tools to conceptually design sustainable buildings. *Construction Research Congress 2014*, 140–149. <https://doi.org/10.1061/9780784413517.015>
- Jordan, C. P. (2022). *Dezeen Sustainability Awards*. <https://www.dezeen.com/2022/08/11/dezeen-awards-2022-sustainability-longlist/>

- Kanters, J. (2020). Circular building design: An analysis of barriers and drivers for a circular building sector. *Buildings*, 10(4), 1–16.
<https://doi.org/10.3390/BUILDINGS10040077>
- Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, 127(September), 221–232.
<https://doi.org/10.1016/j.resconrec.2017.09.005>
- Kovacic, I., Honic, M., & Rechberger, H. (2019). Proof of Concept for a BIM-Based Material Passport. *Advances in Informatics and Computing in Civil and Construction Engineering*, 741–747. https://doi.org/10.1007/978-3-030-00220-6_89
- Kriss, J. (2014). *What is green building?* USGBC.
<https://www.usgbc.org/articles/what-green-building>
- Kubbinga, B., Bamberger, M., Noort, E. van, Reek, D. van den, Blok, M., Roemers, G., Hoek, J., & Faes, K. (2018). *a Framework for Circular Buildings - indicators for possible inclusion in BREEAM*. Circle Economy; Metabolic; Dutch Green Building Council; SGS Search; Redevco Foundation.
- Kurnaz, A. (2021). Green Building Certificate Systems As a Greenwashing Strategy in Architecture. *Research Article Araştırma Makalesi Bartın University International Journal of Natural and Applied Sciences JONAS*, 4(1), 4.
- LEED. (n.d.). Retrieved October 2, 2022, from <https://www.usgbc.org/leed/why-leed>
- LEED - Concept Tower. (n.d.). <https://www.usgbc.org/projects/concept-tower>
- LEED - ERKE Green Academy. (n.d.). Retrieved January 6, 2023, from <https://www.usgbc.org/projects/erke-green-academy?view=overview>
- LEED Projects. (n.d.). Retrieved December 1, 2022, from

<https://www.usgbc.org/projects>

LEED v4.1 Building Design +Construction - Scorecard. (n.d.). Retrieved December 6, 2022, from <https://www.usgbc.org/leed/v41>

Madaster. (n.d.). Retrieved November 22, 2022, from <https://madaster.com/>

Madaster Foundation. (2021). *Madaster Circularity Indicator*.
<https://docs.madaster.com/nl/en/>

Mafi, N. (2019). *AD Sustainable Buildings*.
<https://www.architecturaldigest.com/gallery/buildings-prove-sustainable-architecture-high-design-perfect-pair>

McDonough, W., & Braungart, M. (2002). *Cradle to cradle : remaking the way we make things*. North Point Press.

Mulhall, D., Hansen, K., Luscuere, L., Zanatta, R., & Raymond, W. (2017). Framework For Material Passports. In *Internal BAMB Report* (Issue 642384, p. 125).

Munaro, M. R., & Tavares, S. F. (2021). Materials passport's review: challenges and opportunities toward a circular economy building sector. *Built Environment Project and Asset Management*, 11(4), 767–782.
<https://doi.org/10.1108/BEPAM-02-2020-0027>

Murray, A., Skene, K., & Haynes, K. (2017). The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. *Journal of Business Ethics*, 140(3), 369–380.
<https://doi.org/10.1007/s10551-015-2693-2>

Passive House Projects. (n.d.). Retrieved December 1, 2022, from <https://passivehouse-database.org/>

Pedro, J., Reis, A., Duarte Pinheiro, M., & Silva, C. (2019). A systematic review of the international assessment systems for urban sustainability. *IOP Conference*

- Series: *Earth and Environmental Science*, 323(012076).
<https://doi.org/10.1088/1755-1315/323/1/012076>
- Penny, J. (2012). *10 Tips for Green Building Certification*.
<https://www.buildings.com/sustainability-resilience/article/10189622/10-tips-for-green-building-certification>
- Pomponi, F., & Moncaster, A. (2017). Circular economy for the built environment: A research framework. *Journal of Cleaner Production*, 143, 710–718.
<https://doi.org/10.1016/j.jclepro.2016.12.055>
- Potting, J., Hekkert, M., Worrell, E., & Hanemaaijer, A. (2017). *Circular Economy : Measuring innovation in the product chain*. PBL Publishers.
- Rahla, K. M., Mateus, R., & Bragança, L. (2021). Implementing circular economy strategies in buildings—from theory to practice. *Applied System Innovation*, 4(2), 1–14. <https://doi.org/10.3390/asi4020026>
- Rao A, P. (n.d.). *Re-thinking The Future Green Buildings*. Retrieved December 23, 2022, from <https://www.re-thinkingthefuture.com/rtf-fresh-perspectives/a1057-20-highest-rated-green-buildings-in-the-world/>
- Reed, R., Bilos, A., Wilkinson, S., & Karl-Werner, S. (2009). International comparison of sustainable rating tools. *The Journal of Sustainable Real Estate*, 1(1), 1–22. <https://doi.org/10.1515/9781400827688.1>
- Rees, W. E. (1999). The built environment and the ecosphere: A global perspective. *Building Research and Information*, 27(4–5), 206–220.
<https://doi.org/10.1080/096132199369336>
- Reike, D., Vermeulen, W. J. V., & Witjes, S. (2018). The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. *Resources, Conservation and Recycling*, 135(February 2017), 246–264.

<https://doi.org/10.1016/j.resconrec.2017.08.027>

Romano, S., & Riediger, N. (2020). BIM as a tool for Green Building Certifications: An evaluation of the energy category of LEED, BREEAM and DGNB. *Journal of Physics: Conference Series*, 1425(1).
<https://doi.org/10.1088/1742-6596/1425/1/012162>

Seyis, S., Güven Işın, G., & Bayar, B. (2021). Bim-Based Energy Analysis and Design Tools for Leed Certification. *Uludağ University Journal of The Faculty of Engineering*, 26(3), 987–1002.
<https://doi.org/10.17482/uumfd.915932>

Sustainable Development Goals. (n.d.). Retrieved October 1, 2022, from
<https://sdgs.un.org/goals>

Suzer, O. (2019). Analyzing the compliance and correlation of LEED and BREEAM by conducting a criteria-based comparative analysis and evaluating dual-certified projects. *Building and Environment*, 147(August 2018), 158–170. <https://doi.org/10.1016/j.buildenv.2018.09.001>

Tang, K. H. D., Foo, C. Y. H., & Tan, I. S. (2020). A review of the green building rating systems. *IOP Conference Series: Materials Science and Engineering*, 943(1). <https://doi.org/10.1088/1757-899X/943/1/012060>

The American Institute of Architects. (2023). *AIA COTE Top Ten 2023 Call for Entries*.

Thomsen, A., Schultmann, F., & Kohler, N. (2011). Deconstruction, demolition and destruction. *Building Research and Information*, 39(4), 327–332.
<https://doi.org/10.1080/09613218.2011.585785>

U.S. Green Building Council. (2022). *LEED v4.1 Building Design and Construction* (Issue July). [https://www.usgbc.org/credits/new-construction-schools-new-construction-retail-new-construction-data-centers-new-2?view=language&return=/credits/New Construction/v4.1](https://www.usgbc.org/credits/new-construction-schools-new-construction-retail-new-construction-data-centers-new-2?view=language&return=/credits/New%20Construction/v4.1)

United Nations Environment Programme. (2020). *2020 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector*.

<https://wedocs.unep.org/handle/20.500.11822/34572;jsessionid=21FFFD8A515B44D28ED1FD1BE4DF7B8>

United Nations Environment Programme. (2021). *2021 Global Status report for Buildings and Construction: Towards a Zero -emission, Efficient and Resilient Buildings and Construction Sector*.

<https://www.unep.org/resources/report/2021-global-status-report-buildings-and-construction>

United Nations Environment Programme. (2022). *2022 Global Status Report for Buildings and Construction: Towards a Zero -emission, Efficient and Resilient Buildings and Construction Sector*.

<https://www.unep.org/resources/publication/2022-global-status-report-buildings-and-construction>

Veselka, J., Nehasilová, M., Dvořáková, K., Ryklová, P., Volf, M., Růžička, J., & Lupíšek, A. (2020). Recommendations for developing a BIM for the purpose of LCA in green building certifications. *Sustainability*, 12(15).

<https://doi.org/10.3390/su12156151>

WEF. (2016). *Shaping the Future of Construction: A Breakthrough in Mindset and Technology*. World Economic Forum - prepared in collaboration with The Boston Consulting Group.

Widmer, S. (2021). *Ellen Macarthur Foundation - Circular Design*.

<https://ellenmacarthurfoundation.org/articles/design-and-the-circular-economy>

Wilkinson, S. J., Remøy, H., & Langston, C. (2014). Sustainable Building Adaptation: Innovations in Decision-Making. In *John Wiley & Sons, Inc.*

<https://doi.org/10.1002/9781118477151>

Zeinal Hamedani, A., & Huber, F. (2011). A comparative study of DGNB, LEED and BREEAM certificate systems in urban sustainability. *WIT Transactions on Ecology and the Environment*, 155, 121–132.
<https://doi.org/10.2495/SC120111>

